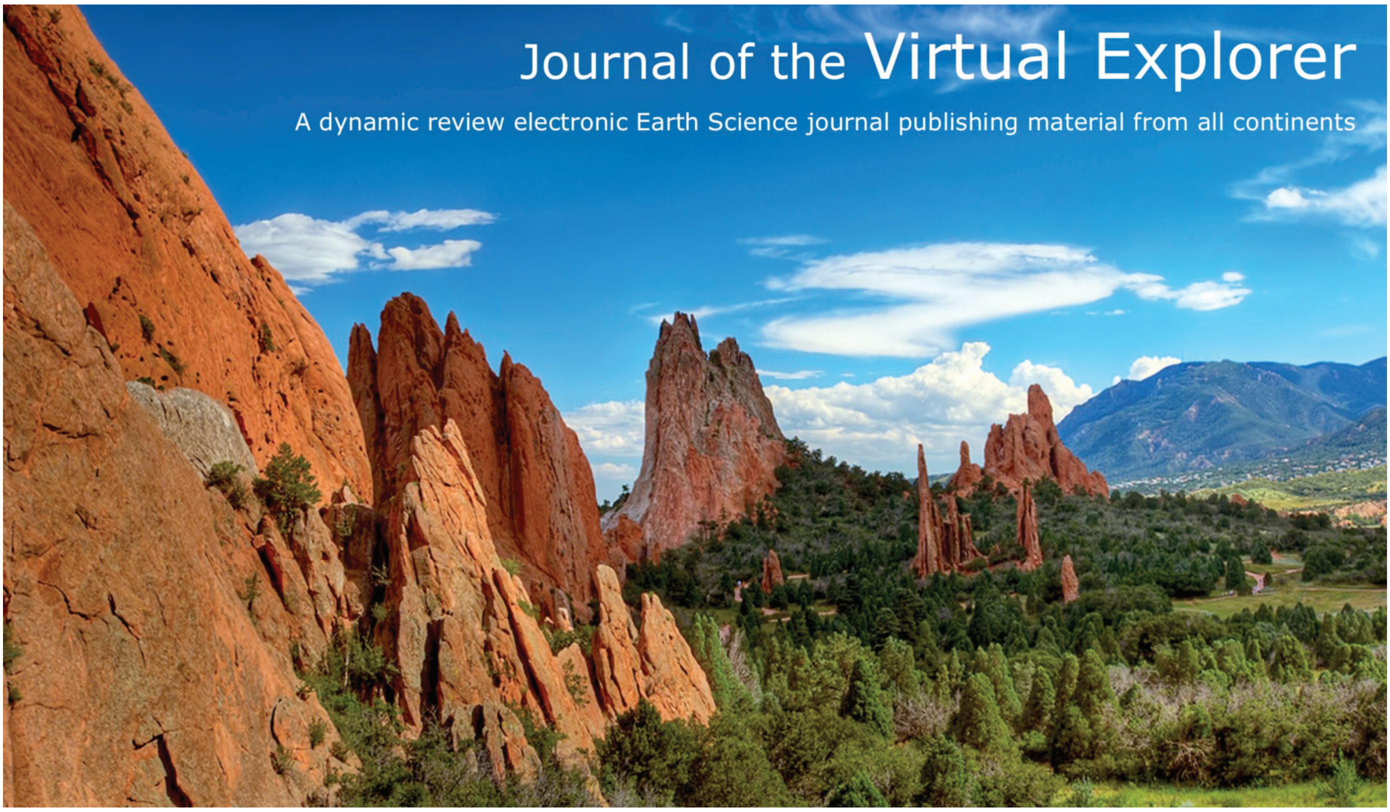

A methodological proposal for the assessment of cliffs equipped for climbing as a component of geoheritage and tools for Earth Science education: the case of the Verbano-Cusio-Ossola (Western Italian Alps)

Bollati I., Fossati M., Zanoletti E., Zucali M., Magagna A., Pelfini M.

Journal of the VIRTUAL EXPLORER, Electonic Edition, volume 49, Paper 1, In: (Eds) Emmanuel Skourtsos and Gordon Lister. General Contributions, 2016. boll

Journal of the VIRTUAL EXPLORER

A dynamic review electronic Earth Science journal publishing material from all continents

A methodological proposal for the assessment of cliffs equipped for climbing as a component of geoheritage and tools for Earth Science education: the case of the Verbano-Cusio-Ossola (Western Italian Alps)

Bollati I.[1], Fossati M.[1], Zanoletti E.[2], Zucali M. [1], Magagna A. [3], Pelfini M.[1]

[1]Department of Earth Sciences "Ardito Desio", Università degli Studi di Milano, via Mangiagalli, 34-20133, Milan, Italy

[2] Geoexplora - Geologia & Outdoor, Via Mussi, 5-28831, Baveno, Italy

[3] Department of Earth Sciences, Università degli Studi di Torino, via Tommaso Valperga Caluso, 35-10125, Turin, Italy

ARTICLE INFO

Citation
Bollati I., Fossati M., Zanoletti E. , Zucali M. , Magagna A. , Pelfini M. 2016. A methodological proposal for the assessment of cliffs equipped for climbing as a component of geoheritage and tools for Earth Science education: the case of the Verbano-Cusio-Ossola (Western Italian Alps). In: (Eds.) Emmanuel Skourtsos and Gordon Lister, General Contributions, Journal of the Virtual Explorer, Electronic Edition, volume 49, paper 1.

Correspondence to:
irene.bollati@unimi.it

Keywords
Geodiversity;
Geoheritage;
Climbing crags;
Verbano-Cusio-Ossola Province (Western Italian Alps);
Earth Science education

IN THIS ARTICLE

Subduction-collision mountain chains are regions where complex geological and geomorphological features due to several Earth-forming processes are exposed. They are characterized by high geodiversity with respect to other geological regions. The sites representing the best examples of these features are referred to as "geodiversity sites", and, if assessed as valuable for geoconservation and/or popularization, are called "geosites" and form the "geoheritage" of a region. In particular cases, as cliffs equipped for climbing, the observations of geological and geomorphological elements are highly favored by the cleanliness of the outcrops and site accessibility. At these sites, the popularization of Earth Science may be mediated by a sport activity that is strictly dependent on their physical features. The Verbano-Cusio-Ossola Province (VCO; Western Italian Alps) is a region characterized by a long mountaineering tradition and occurrence of several cliffs equipped for climbing located in a relatively narrow area. In the present paper, the most suitable climbing sites to be considered part of the geoheritage of the VCO have been detected through a quantitative assessment. The 14 identified geodiversity sites were evaluated using a methodology already tested on other geosites and slightly modified to fit the aim of the present analysis. In order to test the efficacy of the assessment procedure, a pilot educational project aimed at lower secondary school students was developed at three specific climbing sites, based on the ranking results. The test of the applied methodology has been inserted in a wider educational application that considers the use of rock samples and virtual strategies that introduce students to the three major families of rocks (igneous, metamorphic, and sedimentary) and landscape modeling. The educational project results confirm the efficacy of the assessment methodology proposed here for selecting the most valuable climbing geosites suitable for Earth Science education.

INTRODUCTION

Sites of geological interests (geosites sensu Wimbledon, 1996) are increasing in importance as an object of scientific research, as reported by Ruban (2015). The key point consists in the quantitative evaluation of the attributes of geosites from the perspective of geoconservation and/or popularization (Grandgirard, 1999). A common methodology for assessing their value, accepted by the scientific community, has not yet been defined (Reynard and Coratza, 2013), even though this is fundamental when the selection of geosites is related to specific targets or projects. Moreover, no specific studies have addressed potential sites of geological interest equipped for climbing.

The assessment of the value of sites of geological interest constitutes a subject within the wider research field of geodiversity. Several definitions of the term "geodiversity" have been proposed in the literature since the 1990s (see a review in Brock and Semeniuk, 2007). According to the one most frequently used, by Gray (2004, p. 8), and even previously by Dixon (1996), geodiversity may be considered as "the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems". Usually, geodiversity analysis is applied to a given area at a regional scale (Semeniuk, 1997), but considerations at the level of single sites are common (i.e., Pereira and Pereira, 2010). The scale-of-analysis issue requires a clarification of the terms adopted in the geodiversity framework. For this reason, we will propose and use the following terminology:

i. geodiversity of a region in comparison with other regions (*extrinsic geodiversity, EG*) (sensu Panizza, 2009);

ii. geodiversity within a region (*regional intrinsic geodiversity, RIG*) (e.g., Benito-Calvo et al., 2009);

iii. geodiversity at the level of a single site (e.g., a rock cliff; *site intrinsic geodiversity, SIG*) (e.g., Pereira and Pereira, 2010) (Fig. 1).

At regional scale (RIG), the "geodiversity sites", as defined by Brilha (2015), are exemplary locations for this kind of geodiversity. Among them, those that are "sites, locations, areas and territories in which it is possible to identify a geological or geomorphological interest for conservation" are referred to as "geosites" (Wimbledon, 1996) and constitute the "geoheritage" of a region. Geoheritage, in fact, "consists of all the significant Earth features and continuing processes that we wish to keep sustain, conserve, manage and interpret for their natural heritage value" (Osborne, 2000) and that are "important to our understanding of Earth history" (Bradbury, 1993). In addition, the geoheritage of a region may be intended as constituted by "those components of natural geodiversity which are of significant value to humans for purposes" that "may include scientific research, education, aesthetics and inspiration, cultural development and contribution to the sense of place experienced by human communities" (Dixon, 1996).

Among the richest areas in terms of EG and RIG, the subduction-collision mountain chains represent one of the best examples because of the complexity of geological situations exposed, in terms of the number of lithologies alternating in relatively narrow areas and of landforms and superficial processes that are triggered by relief energy (e.g., Brock and Semeniuk, 2007; Benito-Calvo et al., 2009). According to Grandgirard (1999) and Reynard et al. (2007), in such areas, the detection of geosites may be carried out with two aims (Fig. 1, A and B):

A. *Geosite conservation*, when the site is scientifically important but not suitable for popularization due to the difficulty of the topic and when the site is rare and subject to degradation due to both natural processes and human pressure. In these cases, the scientific criteria should be considered more important than the other features used in evaluation procedures;

B. *Earth Science dissemination*, when the site is ideal for educational purposes or popularization in terms of topic and accessibility and its usage will not compromise scientific integrity. In this case, additional values are considered in the evaluation procedures.

In both cases, a quantitative procedure to define the most valuable sites is mandatory. Since the 1990s, several methodologies for the ranking and selection of sites according to specific criteria have been proposed by researchers all over the world (e.g., Brilha, 2015, and references therein) and, as already mentioned, a univocal methodology has not been yet defined (Reynard and Coratza, 2013). Considering and analyzing all the proposals, in 2012 we developed a specific method (Bollati et al., 2012) that addresses geomorphosites (i.e., sites of geomorphological interest sensu Panizza, 2001) and is suitable for detecting sites for both aims, A and B. The method was modified by Bollati et al. (2014) due to problems faced when dealing with the quantitative assessment of the value of geosites in general (i.e., not only those in which the primary interest is geomorphological) and in the specific case of geodiversity sites equipped for climbing. Recently, only marginal interest has been directed towards the assessment of cliffs equipped for climbing as a component of geoheritage and tools for Earth Science education (e.g., Garlick, 2009; Motta & Motta, 2005; Panizza and Mennella, 2007). We decided to focus on this special category of geodiversity sites for several reasons:

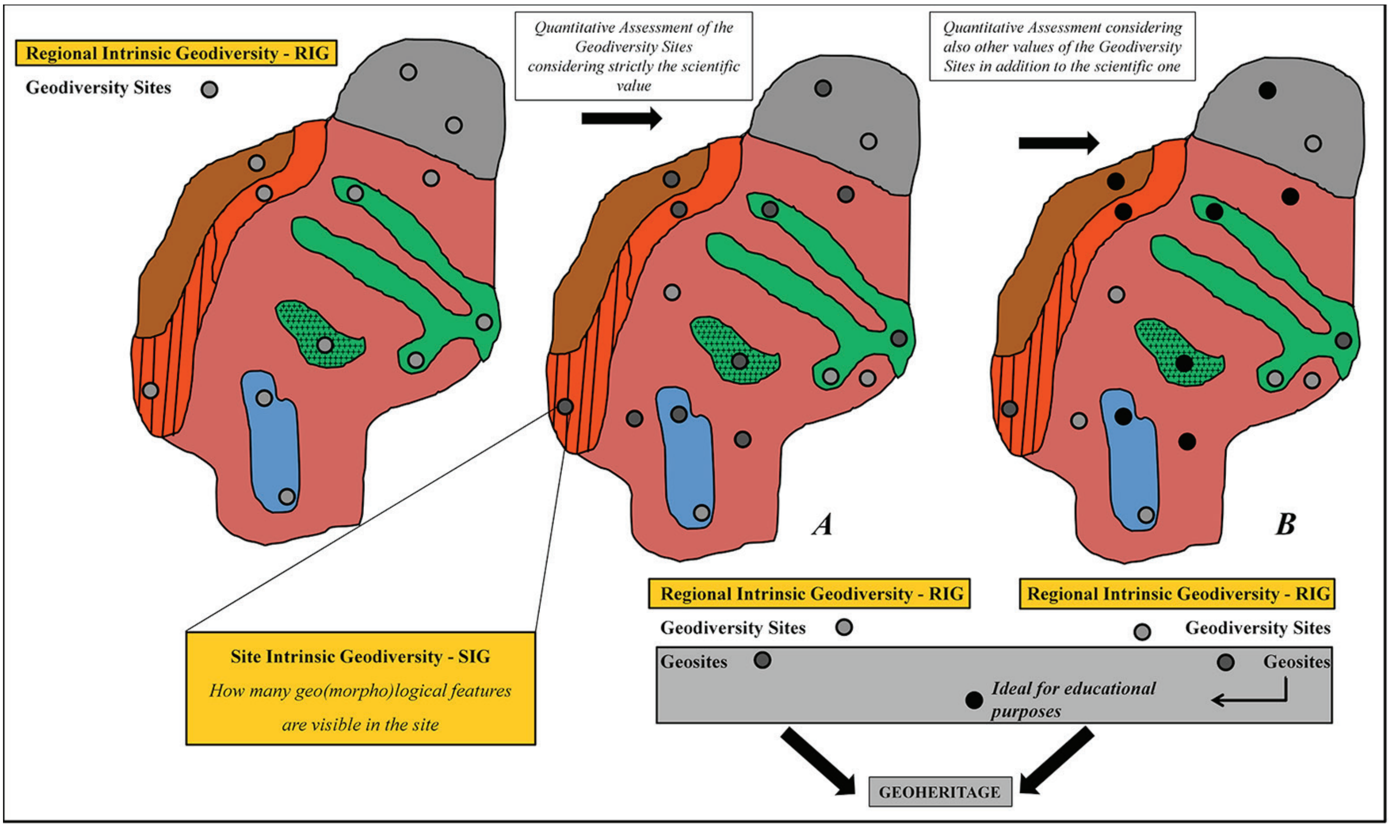

Figure 1
Sequence of steps in detecting geosites in the framework of geoheritage and final aims of assessment (A and B). The analysis of geodiversity at regional level (RIG) and at local scale (SIG) is reported.

i) they are sites where rocks, structures, and landforms developed by different geological and geomorphological processes, are usually well exposed and the outcrops are kept clean by the local communities of climbers, who feel a strong sense of place (sensu Dixon, 1996);

ii) due to this favorable rock exposure, scientific research at rock walls often provides a vast amount of geological and geomorphological information testifying to their importance in the understanding of Earth history (sensu Bradbury, 1993);

iii) the most relevant climbing cliffs are usually wide and their spatial extent attracts people;

iv) in such places, sports activities represent a strong link between lay people and the world of geological research, acting as a vehicle for transmitting Earth Science concepts to the general public. Climbing is a sports activity that elicits deep involvement of the emotional sphere (e.g., astonishment, fear; Trend, 2001) for both practitioners and spectators of this sport.

The assessment methodology used herein has already been applied for evaluating a test site. This site was one of the most famous climbing sites in the Western Italian Alps: the Montestrutto cliff located in the Eclogitic Micaschist Complex (Sesia-Lanzo Zone, Austroalpine Domain). It is a wide rocky outcrop in the Piemonte Region and is scientifically relevant as the outcropping of lithotypes shows the high-pressure–low-temperature metamorphism that is typical of subduction (see Bollati et al., 2014, and references therein). The site is easily accessible and characterized by rocks where structures and minerals are well visible and the geomorphological modeling due mainly to glacial action is evident.

This research has the main goal of exporting to a regional scale the methodology of quantitative assessment tested at Montestrutto, with a few further modifications. Within this scope, for our research we considered the Verbano-Cusio-Ossola province (VCO), in the Western Italian Alps, a district that has a strong mountaineering tradition and features about one hundred rock walls equipped for climbing and characterized by diverse styles of progression (Fig. 2). The area is located in the Alpine chain region and is easily ac-

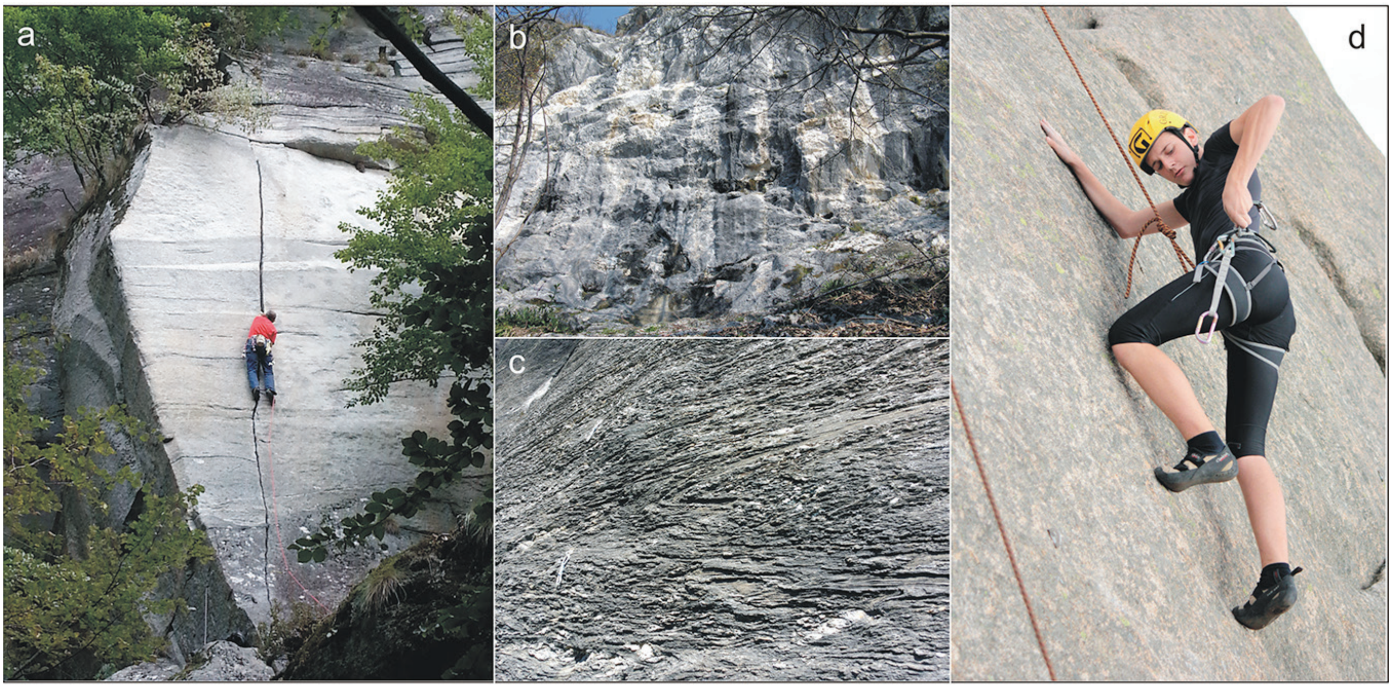

Figure 2
Example of different styles of progression within the VCO region. a) Sharp vertical cracks in orthogneisses; b) cannelures and hanging cliffs in limestones; c) technical climbing on rock notches in calcschists; d) grip and rounded crack climbing on granite.

cessible and characterized by geological complexity and hence by a high RIG, which has been object of abundant scientific research for a long time.

In order to test the efficacy of the method proposed to evaluate the most suitable climbing crags for Earth Science education, a pilot project addressed at a lower secondary school was developed. The whole educational project had the main educational aim of reinforcing some concepts related to different families of rocks (i.e., sedimentary, magmatic, and metamorphic) and the connections between progression and (micro) morphology deriving from the lithology, structures, and landforms related to both exogenous and endogenous processes. The proposed initial "remote" approach includes both traditional and innovative tools, since the combination of laboratorial activities (e.g. with rock samples) with multimedia (e.g. visualization and analysis of virtual tours, videos, photos, Web-based source of information) within classrooms has been recently discussed as a potential tool to improve knowledge through innovation and curiosity (e.g., Harris and Rea, 2009; Sherer and Shea, 2011; Magagna, 2013; 2016).

Summarizing, the main aim of the research was to assess the value of the potential geodiversity sites equipped for climbing in the VCO area and to test the efficacy of the procedure for ranking and selection of the sites through a pilot educational project for future applications.

STUDY AREA

The study area is located in the Italian Alps and covers the entire Province of VCO. It is an easily accessed area not far from Milan, connecting Italy and Switzerland via the Simplon National Road. The construction of the Simplon Tunnel during the early twentieth century contributed to the comprehension of the deep structure of the Alps. The VCO Province has been the object of scientific researches (Bigioggero et al., 2006, and references therein) since its south–north development makes it possible to cross, in a relatively narrow area, a great part of the structural domains of the Italian Alps (the Southern Alps, Austroalpine, and Lower to Upper Pennine units), as far as the deepest ones (the "Zero Element" by Argand, 1911). Moreover, the VCO Province may be split into two main portions: i) the area located south of the Insubric Line, here called Canavese Line (CL), which belongs to the Southern Alps and is characterized by a low dominant alpine deformation; ii) the area located north of the CL and pervasively characterized by an Alpine tectonic imprint that restructured the whole rocks. The region is also known as one of the most important quarrying areas of the Italian Alps (Cavallo et al., 2004; Zucali et al., 2014).

In order to include rocks of a sedimentary origin in the study area, the analyzed region was widened to the eastern coast of the Maggiore Lake,

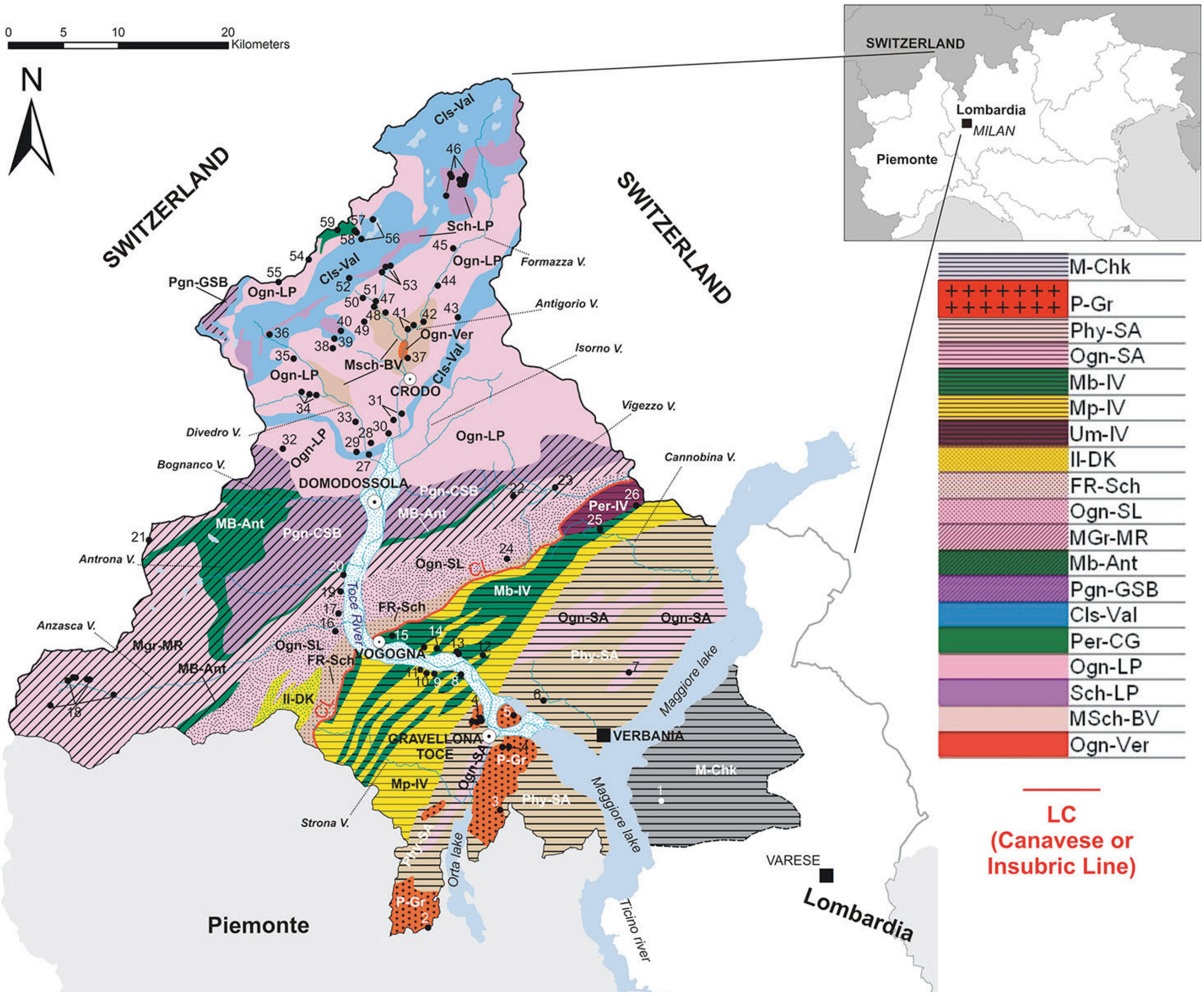

Figure 3

Simplified structural model of the Verbano-Cusio-Ossola Province including a part of the Varese Province. The model was obtained by combining the information from the Structural Model of Italy (1:500000; CNR) and the Geological Map of Switzerland (1:500000; Service géologique national). The limit of the M-Chk unit is dashed in the area of interest. Black dots indicate the positions of the 59 analyzed climbing sites, indicating the presence of more than one sector. Their numbers correspond to the list in Table 2.

where a representative sedimentary coverage of the Southern Alps outcrops.

In Figure 3, a simplified structural model summarizes the main geological units, herein described from south to north.

The Southern Alps, representing a portion of the African passive continental margin, which include:

- the sedimentary coverage of the Lombardy Basin: Mesozoic basinal and pelagic deposits (M-Chk);
- the Southern Alpine crystalline basement, representing the upper to intermediate continental crust: phyllites, micaschists, and minor paragneisses (Phy-SA) of the pre-Upper Carboniferous and the Hercynian orthogneisses (Ogn-SA);
- the Ivrea Verbano zone, which is related to the lower continental crust and upper mantle: metabasites (Mb-IV) and metapelites (Mp-IV) in granulite to amphibolite facies and mantle-peridotite slices (Per-IV);
- the late and post Hercynian igneous rocks: Permian granitoids: (P-Gr).

The Canavese Line (CL), separates the Southern Alps from the axial part of the Alpine chain and specifically from the Austroalpine system of the Sesia-Lanzo, here including the II- Dioritic–Kinzigitica zone (II-DK; granulite to amphibolite facies micaschists, gneisses, and metabasites) and the Sesia-Lanzo zone (Ogn-SL, orthogneiss). The product of the deformation along the CL is locally represented by the unit of the Fobello-Rimella mylonitic schists (FR-Sch).

The Piemont-Ligurian ophiolite nappe system, which is derived from the closure of the Piemont–Ligurian basin, is represented by the metabasalts of the Antrona oceanic unit (AMb-Ant).

The Pennine Units consist of an Upper Unit, the Monte Rosa nappe, mainly constituted by metagranitoids (Mgr-MR) and the intermediate Gran San Bernardo nappe, constituted by paragneisses (Pgn-GSB). The Valais Calcschists Units (Cls-Val) are metamorphic sedimentary sequences intervening within the Lepontine nappes of the basement, derived from the closure of the Valais trough. Lepontine basement nappes include ultramafics of the Cervandone–Geisspfad unit (Per-CG). The lower Pennine nappes are constituted by orthogneisses (Monte Leone, Pioda di Crana, and Antigorio nappes) (Ogn-LP) and by schists of the Lebendun nappe (Sch-LP). The Infrapennine basement nappes of the micaschists (MSch-BV) and the Verampio orthogneisses (Ogn-Ver; the "Zero Element" of Argand, 1911), are exposed within the two tectonic windows of Baceno and Varzo,.

The VCO province reveals important signs of glaciation; several rock slopes along the main Ossola Valley and in the tributary valleys show clear evidences of glacial modeling since the region was characterized by a pulsating glacial history. Hankte (1988) reconstructed the evolution of the Toce Glacier and Toce River flows since the Miocene. According to the author, in fact, during that period the northern watershed was located between Domodossola and the Anza River and the Toce paleodrainage was towards the north. Only after intense tectonic movements and the uplift of the Aar massif in Switzerland, during the lower Miocene, this drainage setting changed, with the watershed moving towards the north and leading to the present day flows of the Toce towards the south-southeast. The history of the Toce Glacier was characterized by several episodes of transfluence and interaction with the Ticino Glacier, located to the east. The contact between these glacial bodies was identified along the Vigezzo and the Cannobina valleys (Fig. 3).

The VCO province has a particular climatic regime and is known for the intense rainfall events that repeatedly characterize the area, as recently happened in 1978, 1987, 1993, and 2000 (Cat Berro et al., 2014). In addition, the geological features (lithologies and regional setting) locally favor intense slope processes (Hankte, 1988) and debris flow events such as the severe one that happened during 1978. Among the most important hazardous events, the Antrona landslide happened in 1642 in the valley of the same name (see Fig. 3); it involved 12 million cubic meters of rocks and was responsible for the creation of the Antrona Lake by damming. A more recent landslide occurred in 2005 and dammed the Val Fredda stream with 500,000 milion cubic meters of rocks, near one of the evaluated climbing sites (no. 13 in Fig. 3).

From geological and geomorphological points of view, the VCO area is characterized by sites of interest and a sites listing project has recently been concluded (i.e., Interreg Italy–Switzerland 2007–2013 "SITINET –Progetto per il censimento, la messa in rete e la valorizzazione turistica di siti geologici e archeologici nella Regione Insubrica" ["Project for the census, networking and touristic valorization of the geological and archeological sites of the Insubric Region"]). In the framework of this project, a website (http://www.sitinet.org/glist) including all the information on geosites was built, a geolab was created in Crodo municipality (see Fig. 3), and different publications are freely available to people for visiting glaciological and geological trails in the area (e.g., Pirocchi, 2012; Zanoletti, 2012). Moreover, the interest in the quarrying activities in terms of valorization led to the development of projects like: "Pietre del VCO" (http://www.pietredelvco.it/) and "Pietre del Cusio, del Mottarone e della Valle Strona" (http://pietredelcusio.weebly.com/).

The great naturalistic value of the VCO district is testified by the presence of two main protected areas, the "Aree Protette dell'Ossola" and the "Val Grande National Park", and by the numerous faunistic regions and wetlands present in the territory. Moreover, in 2013 the Sesia-Val Grande Geopark was officially recognized by the UNESCO Committee and the geological value of the southern part of the Ossola Valley was recognized. A geolab was created in the Vogogna municipality (see Fig. 3) and thematic paths focusing on geological and geomorphological features of the area were developed.

METHODS

Cliffs equipped for climbing represent ideal situations for analyzing lithology because of the wide and well-exposed surfaces and, in some exemplary cases, their immediate accessibility. Nevertheless, since not all the cliffs may be considered ideal for educational purposes, a quantitative assessment was necessary. A methodology addressed specifically to this category of geodiversity sites has not yet been proposed. The whole workflow adopted during the research is reported in Fig. 4 and described in the following paragraphs.

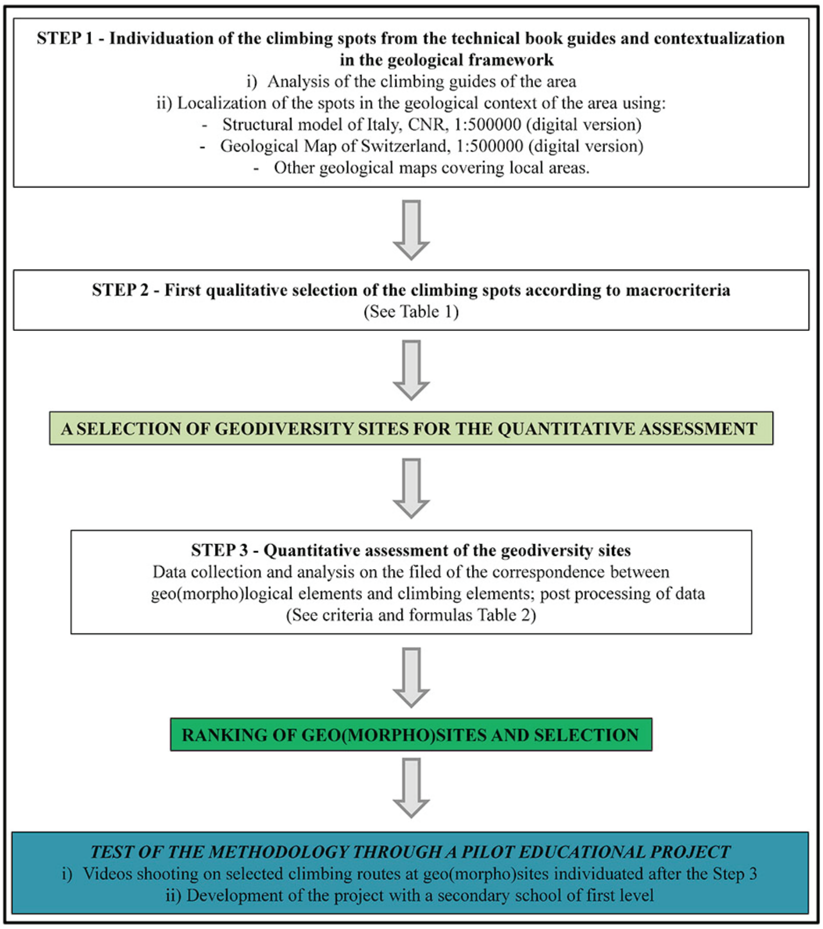

Figure 4
The analysis workflow. The main outputs of each step are shown in dark gray; the step of testing the methodology for quantitative assessment is shown in light gray

Identification of the climbing sites from the technical book guides and contextualization in the geological framework (Step 1, Fig. 4)

The first phase of the work consisted in the collection of technical reports on climbing cliffs located in the VCO area as potential geodiversity sites. In this step the published climber guide for the area (Manoni et al., 2014, and previous editions) was analyzed, and the information was completed by adding personal reports of local people and nailers.

The geological context of each site was detailed according to the simplified structural model reported in the map in Figure 3. Since no outcrops of sedimentary rocks occur in the VCO area the climbing guide of Varese Province, on the opposite side of the Maggiore lake (Mazzucchelli, 2011), was also analysed, to add a climbing site on sedimentary rocks and broaden the educational field,.

The locations of the identified cliffs for the following analyses are reported in Figure 3. The numbering of the sites on the map corresponds to the list in Table 3.

First qualitative selection of the climbing sites according to macrocriteria (Step 2, Fig. 4)

The geodiversity sites equipped for climbing were then qualitatively selected according to the macrocriteria indicated in Table 1. A first phase of pre-selection of potential geosites is common but often no clear and defined criteria are adopted (Reynard et al., 2016). In fact, some of the sites considered, on first analysis, are not characterized by suitable features at all from the perspective of future educational projects. Examples of the applied macrocriteria are reported in Figure 5. This first phase of evaluation of the climbing walls was based on personal experience of the authors and on the knowledge previously gained on the area. Some specifications may be set out:

- Criterion E (Table 1): none of the analyzed sites can be considered absolutely safe from natural hazards and consequent risk scenarios. Therefore the ones where the hazard was defined and clearly indicated by signals were not taken into consideration;
- Criterion F (Table 1): this is strictly linked with the definition of "geodiversity site" and the corresponding "climbing diversity site" (Bollati et al., 2014), which refers to the difference in the style of progression required by the climbers. Considering relatively close sites characterized by the same rocks and the same styles of progression, the most accessible and representative

Table 1. Macrocriteria adopted during the first qualitative selection of the climbing sites.

FIRST EVALUATION MACROCRITERIA	
A	PRIMARY ACCESSIBILITY (difficulty and safety of the path)
A1	PRESENCE OF CHAIRLIFT OR CABLELIFT TO REACH THE SITE
B	SECONDARY ACCESSIBILITY (difficulty of the climbing routes)
C	ROCK CLIFF QUALITY (e.g., fracturing, cleanliness)
D	ADEQUATE SPACE AT THE BASE OF THE CLIFF FOR GROUPS OF PEOPLE (about 20-25)
E	PRESENCE OF EVIDENT AND ACTIVE HAZARDS
F	SIMILARITY OF GEOLOGY AND CLIMBING WITH OTHER BETTER SITES
G	HUMAN INTERVENTION ON THE CLIFF

ones were considered;

• Criterion G (Table 1): as a rule, but not in general, human intervention on the cliff (i.e., excavation of holds) was not considered positively, as it led to confusion in the identification of human versus naturally derived micro- and meso-landforms. The pervasiveness of the intervention with respect to the width of the cliff and the number of routes involved with respect to the total was considered during the evaluation of this feature.

The output of this qualitative selection is a certain number of geodiversity sites that can undergo the quantitative assessment phase.

Quantitative assessment of the geodiversity sites equipped for climbing (Step 3, Fig. 4)

After the first qualitative selection, a restricted number of sites emerged for the quantitative assessment. As mentioned before, Bollati et al. (2012) proposed a methodology originally addressed to sites of geomorphological interest and later extended to the specific category of geodiversity sites equipped for climbing, which brought some modifications (Bollati et al., 2014). This methodology was applied herein, with slight modifications (details are given in Table 2). Macrocriteria (Scientific Value, Additional Values, Potential for Use, Global Value, Educational Index, Scientific Index, Total Score; Table 2) are calculated considering single attributes according to the

Figure 5

Examples of cliff features of the region that were considered during the first qualitative selection using the macrocriteria reported in Table 1. a) Low rock quality in terms of cliff cleanliness and old equipment (see yellow ellipse) at La Pineta cliff (no. 22, Fig. 3); b) adequate space at the base of the cliff for groups of people at San Giano (no. 1, Fig. 3); c) low difficulty of the climbing routes and adequate space at the base of the cliff for groups of people in the “Baby” sector of the Valletta cliff (no. 28, Fig. 3); d) the hazards made manifest in the Nibbio main sector (no. 13a, Fig. 3).

formulas reported in Table 2 and some specifications of the attributes are reported as follows.

Among the Additional Values (AV), the Aesthetic Value (Ae) was evaluated considering not only the site itself but also the landscape view from the site. Potential for Use (PU) increases since Sport Activities (SA) are linked directly with the rocks features. The PU was analyzed by considering the Spatial Accessibility (SAc) and evaluating the access to the site for the on-foot itinerary (Calculated Accessibility, CA). When the trail was characterized by a section of different difficulty, the "worst case" approach was adopted. The presence of Tourist Information (TI), that is, indications regarding the climbing site or, at least, the trail, such as signposting in loco, was considered positively, especially for on-foot itineraries. Moreover, the Presence of Geosites in the Surroundings (SGs) attribute was evaluated by considering the official geosites database of Regione Piemonte (http://www.geoportale.piemonte.it/geocatalogorp/) and other official initiatives (i.e., Sesia Val Grande Geopark; SITINET project) that have defined other sites of geological interest.

Some specific indexes were created that may be useful according to the scope of the final selection (e.g., educational or strictly scientific): i) Educational Exemplarity (EE); Ae and SAc contribute to the calculation of the Educational Index (EIn) (see formulas in Table 2); ii) Representativeness of Geomorphological Processes (RGmP), Representativeness of Geological Processes (RGP), and Geohistorical Importance (GI) concur with the calculation of the Scientific Index (Sin) (see formulas in Table 2).

Some examples of uses of attributes are reported in Figures 6, 7, and 8.

Fieldwork was performed at the selected sites to detail all the required geological and geomorphological information regarding the cliffs using dedicated field forms. The correspondence between geo(morpho)logical and climbing elements was analyzed in detail. For example, the different resistances to erosion/dissolution of lithotypes and minerals (e.g., quartz lenses, garnets, chert nodules) or the different typologies of fractures and the products of exfoliation (e.g., deriving from the unloading and exhumation of granitic plutons) were described and associated with the climber progression. An image analysis of pictures taken along the routes was then performed in the laboratory. The information helped in evaluating specific parameters (mainly SA, RGmP, and RGP; see abbreviations in Table 2).

The output of the quantitative assessment was the ranking of the sites according to the different calculated parameters. Then these parameters could be analyzed to choose the best sites according to different purposes.

In order to test the efficacy of the assessment methodology from the perspective of educational projects, the most valued geosites for each category of rocks (metamorphic, magmatic, and sedimentary) were selected for a pilot educational project

RESULTS

Analysis and qualitative selection of the geodiversity sites equipped for climbing (Steps 1 and 2)

Cliffs equipped for climbing are abundant in the VCO (more than 80 walls over about 2261 km2). In Table 3, a complete list of the 59 analyzed crags, subdivided into sub-sites (i.e., single walls), is reported.

In Figure 9, the cliffs are grouped according to the rock genesis process (Fig. 9a) and, in more detail, according to the lithology (Fig. 9b). The sedimentary site (1) is included in the calculation. The greatest part of the cliffs is constituted by metamorphic rocks derived from an acid magmatic protolith (43%), mainly orthogneisses. The second category in order of abundance is constituted by metamorphic sedimentary rocks (33%) including micaschists, calcschists, coarse metaclastic schists and paragneisses.

Five per cent of the total number of cliffs (Fig. 9b) are located in correspondence with the contact between two units that may be intercalated more or less rhythmically at regional scale (e.g., metapelites/metabasites of the Ivrea-Verbano Unit).

The output of the first qualitative selection according to the criteria listed in Table 1 was a list of 14 geodiversity sites out of 59 (23.72%) (light blue in Table 3) that were suitable for the quantitative assessment.

As can be seen in Figure 9c, among the 14 cliffs the percentages of lithotypes are more homogeneously distributed, the largest fraction of cliffs (22%) is characterized by the contact of two units, 15% are constituted by metagranites, 14% are constituted by the micaschists of the Veram-

Table 2. List of parameters and formulas adopted according to the methodology of Bollati et al. (2014) with adaptations.

SCIENTIFIC VALUE (SV)		
RGmP Representativeness of (paleo)Geomorphological Process	0 0.33 0.67 1	Poor/None representativeness of a morphogenetic system Discrete representativeness of a morphogenetic system Good representativeness of a morphogenetic system Exemplar representativeness of a morphogenetic system
RGP Representativeness of geological process	0 0.33 0.67 1	Poor/None representativeness of a geological process Discrete representativeness of a geological process Good representativeness of a geological process Exemplar representativeness of a geological process
EE Educational Exemplarity	0 0.33 0.67 1	Representativeness without any educational value Representativeness with poor educational value Representativeness difficult for non experts Representativeness with excellent educational value
SE Spatial Extension	0.25 0.50 0.75 1	1 -100 m² > 100 m² Landscape Landscape and punctual sites
Gd Site Intrinsic Geodiversity	0 0.50 1	1 lithology, 1 main landform 1 lithology, n-landforms > 1 lithologies, n-landforms
GI Geo-historical importance	0 0.33 0.67 1	Without production or scientific divulgation Low frequent topic for scientific research (communications, papers…) Relevant topic for scientific research Fundamental for the development of Earth Sciences in general
ESR Ecologic support role	0 0.33 0.67 1	Without any connection with the biologic element Presence of interesting flora and fauna The geo(morpho)logical features condition the ecosystems The geo(morpho)logical features determine the ecosystems
In Integrity	0 0.50 1	Essential geo(morphological elements are not preserved Essential geo(morpho)logical elements are just preserved Essential geo(morpho)logical elements are intact
Ra Rareness	0 0.50 1	Frequent also at level of the study area Rare at level of the study area. abundant at national level Rare at national level
**CALCULATED ACCESSIBILITY (CA) (only for on foot itineraries)*		
Ti Tipology	0 0.2 0.4 0.6 0.8 1	Any traces Traces Path Mule tracks Dirt road Paved road
St Steepness	0 0.5 1	High Medium Low-null
Sl Sloping	0 1	Yes No
GM Ground Material	0 0.2 0.4 0.6 0.8 1	Ice Snow Coarse debris coverage Medium debris coverage Fine or soil debris coverage Bed rock or dirt/paved road
SI Slope Inclination	0 0.25 0.5 0.75 1	> 61° 51°-60° 41°-50° 31°-40° <30°
SM Slope Material	0 1	Fractured rock. soils. snow and ice Rocks and coherent deposits
TI Tourist Information	0 1	No Yes
Wi Width	0 0.25 0.5 0.75 1	<30 cm 30-50 cm 50-100 cm 100 cm >100 cm
WSP Water/Snow Along The Path	0 1	Yes No
DC Degree Of Conservation Of The Path	0 0.33 0.67 1	Very bad Fairly good Good Excellent
HI Human Interventions	0 0.33 0.67 1	Present and increasing vulnerability Absent Present not influencing Present and reducing vulnerability

ADDITIONAL VALUES (AV)		
Cu Cultural value s.s.	0 0.50 1	Any cultural feature in the surroundings Presence of cultural features not correlated with geo(morpho)logical features Presence of cultural features correlated with geo(morpho)logical features
Ae Aesthetic value	0 0.50 1	Not relevant Strong contrasts in landforms. lithologies and colours, spatial limited Strong contrasts in landforms, lithologies and colours
SEc Socio-Economic value	0 0.33 0.67 1	Element without exploitation or insertion in an economic area (Not touristic) Element with exploitation or insertion in an economic area (Not touristic) Element inserted in an economic-touristic area Element inserted in an economic-touristic circuit
POTENTIAL FOR USE (PU)		
TA Temporal Accessibility	0.25 0.5 0.75 1	Only in summer Except in winter Except in rainy days All over the year
SAc Spatial Accessibility	0.2 0.4 0.6 0.8 1	On foot,Experts* On foot, Touristic* On foot for numerous group, because difficult access for bus Allowed to means of transportation Allowed to means of transportation. access also to disables
Vi Visibility	0 0.2 0.4 0.6 0.8 1	Not observable or great difficulties in observing it Just visible or with special tools (artificial lights. ropes..) Reasonable visibility but limited by vegetation Good visibility but with need of moving to improve it Good visibility for all geo(morpho)logical elements Excellent visibility for all geo(morpho)logical elements
Se Services	0 0.33 0.67 1	Hotels and services far from 25 Km Hotels and services far from 10 - 25 Km Hotels and services far from 5 - 10 Km Hotels and services far from 5 Km
NT Number of Tourists	0 0.50 1	Few Medium Abundant
SA Sport Activities	0 0.50 1	None Yes. not correlated with geo(morpho)logical features Yes. correlated with geo(morpho)logical features
LC Legal Constraints	0 0.33 0.67 1	Total protection, prevented use Protection, limited use Under protection but with few or any prevention for use No protection or limitation in use
UGI Use of geo(morpho)logical interest	0 0.50 1	No divulgation or use Use in academic ambit With divulgation and use as geo(morpho)site
UAI Use of the Additional Interests	0 0.50 1	Any divulgation or use Use of additional interests Naturalistic or cultural paths already started
SGs Presence Of Geo(morpho)sites In The Surroundings	0 0.50 1	Any sites in the study area Sites in the neighbourhood but not genetically correlated Sites in the neighbourhood and genetically correlated

FORMULAS		
***SV**-SCIENTIFIC VALUE*	*SV = (GM+PgM+EE+SE+Gd+GI+EI+OI+In+Ra)*	*0-9*
***AV**-ADDITIONAL VALUES*	*AV = (Cu+Ae+SEc)*	*0-3*
***GV**-GLOBAL VALUE*	*GV = (SV+AV)*	*0-12*
***IU**-Index of Use* *Potential for Use s.s.* ***PPU**-Partial potential for Use* ***CA**-Calculated Accessibility** ***AFc**-Accessibility Factor (on foot)* ***AFs**-Accessibility Factor (other)* ***PU**-POTENTIAL FOR USE (on foot)* ***PU**-POTENTIAL FOR USE (other)*	*IU = EE+SE+Ae* *PUss = (TA+Vi+Se+NT+SA+LC+UGI+UAI+SGs)* *PPU = (PUss+IU)* *CA = (Ti+St+Sl+Wi+GM+WSP+SI+SM+DC+ HI+TI)* *if SAc≤0.4; AFc = (CA/11)*0.5* *if SAc≥0.6; AFs = SAc* *PUc = PPU +AFc* *PUs = PPU+AFs*	*0-3* *0.25-9* *0.25-12* *0-11* *0-0.5* *0.6-1* *0.25-13* *0.25-13*
***SIn**-Scientific Index* ***EIn**-Educational Index*	*SIn= (GM+PgM+GI)/3* *EIn= [EE+Ae+(A_Fc/s)]/3*	*0-1* *0-1*
***TS**-TOTAL SCORE*	*TS = GV+PUc/s*	*0.25-25*

Figure 6

Examples of some of highest valued situations concerning the attributes used in the assessment of the scientific value. The abbreviations of attributes are reported in parentheses in Table 2. a) Representativeness of the differential erosion process in micaschists (RGmP; EE) (no. 41a, Fig. 3); b) chert nodules within calcilutites and differential erosion (RGmP; RGP; In) (no. 1, Fig. 3); c) folding of a quartz vein in orthogneiss (RGP) (no. 28, Fig. 3); d) representativeness of both geological and geomorphological processes (RGmP; RGP; EE) of the flux structures and unloading fractures in granite (no.3a, Fig. 3); e) contact between portions of different lithological compositions and differential modeling (RGmP; Gd) (no. 8, Fig. 3).

pio Infrapennine basement nappes and of Lower Pennine orthogneisses, and 7% are constituted by very fine grained massive limestones (calcilutites), Permian granites, metapelites and metabasites of the Ivrea-Verbano Unit, and calcschists.

Quantitative assessment of the geodiversity sites equipped for climbing (Step 3)

After the qualitative assessment, 14 sites emerged (24% of the total).

The quantitative assessment allows a score to be assigned to each of the 14 cliffs according to the different attributes listed with the corresponding abbreviations in Table 2. In Table 4, the results of the site ranking are reported. The average Scientific Value (SV) of the climbing sites is higher than the average value between 0 and 9 (5.18) and in particular the average value of the RGP is high (0.91 out of 1), as are the EE and Integrity (In) of the sites (0.84 and 0.93 out of 1). The total SV is penalized by the low Ecological Support Role (ESR) and the low Rarity (Ra) of these kinds of landforms in the area. In fact, the area is characterized by several outcrops shaped by glaciers that

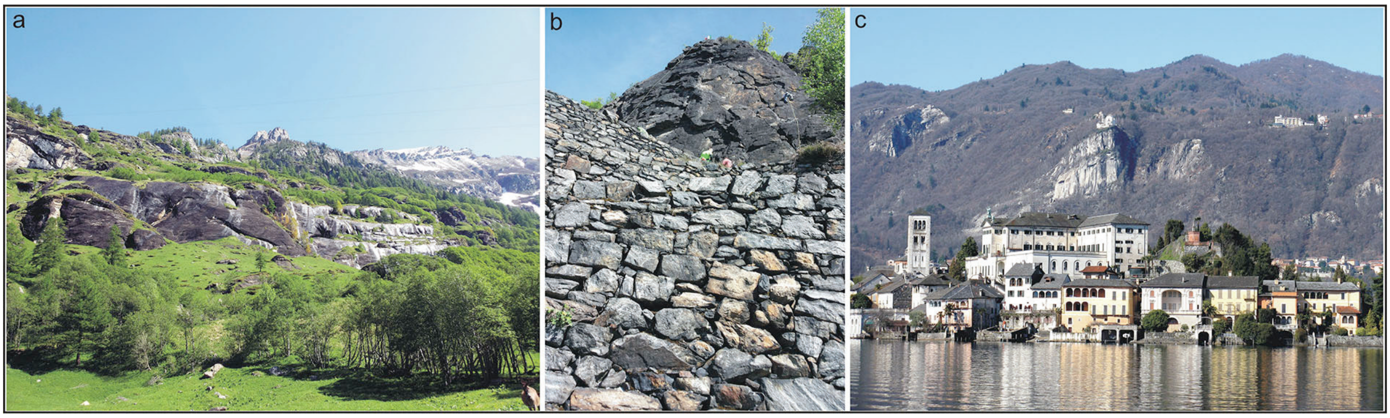

Figure 7

Examples of some of the highest valued situations concerning the attributes used in the assessment of the additional values. The abbreviations of attributes are reported in parentheses in Table 2. a) Strong contrast of color and width characterized the cliff of Ponte Campo (no. 36, Fig. 3) in calcschists (Ae); b) the “Strada Cadorna”, one of the vestiges of the First World War defense lines of the Alps, which confers a high cultural value to the cliff Nibbio (no. 13b, Fig. 3) located along it; c) the Madonna del Sasso Santuary is a cultural asset (Cu) located on a granitic spur equipped for climbing (no. 2, Fig. 3) and is located in an area that is highly developed from a touristic and economic point of view (SEc), namely the Orta lake district.

are not all nailed due to the low geotechnical quality of rock. The average SIn, which takes into account RGmP, RGP, and GI, is relatively high (0.63 out of 1).

The AV reaches an average of 1.23 out of 3, which is quite low due to the very low value of Cu (Cultural Asset) that stands out only at two sites located along the “Strada Cadorna” cultural trail (sites no. 8, 12b; Table 3 and Fig. 3). The Socio-Economic (Sec) value of the Ossola region is relatively high (0.62 out of 1) due to both tourism and the extraction of construction and ornamental materials.

The Global Value (GV) of the cliffs is clearly affected by the low AV (6.41 out of 12).

The Index of Use (IU) concurs with the calculation of the PU and has a mean value of 1.64 out of 3. The PU average is quite high (8.45 out of 13), especially due to the following attributes: i) Visibility (Vi) (0.87 out of 1), which is linked with the intrinsic definition of the cliff; ii) Services (Se) (1 out of 1), because all the sites selected after step 2 are located near to restoration points or accommodation (approximately 5 km away); ii) SA (1 out of 1), which is strictly dependent on the geological and geomorphological features of the sites; and iv) SGs (0.79 out of 1), due to the SITINET project for valorization of geosites in this region.

The EIn average is 0.60 out of 1 and the SIn average is 0.63 out of 1.

Finally the average Total Score (TS) of the sites, depending on all the considerations made so far, is 14.89 out of 25.

In Table 5 and Figure 10 some geo-climbing sites stand out with respect to others, especially for some parameters. According to SV, GV, and PU, for example, no site obtains the same score as another one, because the number of parameters involved in their definition is greater than that of the AV, allowing a clearer distinction among the sites. In particular, in Figure 10 the relation between SIn and EIn of the 14 evaluated sites is reported.

Some specific observations will be made regarding some relevant sites.

The maximum values of TS (19.47 out of 25), SV (0.89 out of 1), EI (0.93 out of 1), and PU (11.05 out of 13) were obtained by the Premia-Balmafregia (no. 41a, Tables 3 and 5 and Figs. 3, 6a, and 11), a cliff consisting of metasedimentary rock. It is a very accessible site, with climbing routes for both beginners and experts.

The micaschists of the Verampio Infrapennine basement nappes (Msch-BV) display an intense foliation, with outstanding garnets (Fig. 11a), that are also present in the debris at the base of the cliff; interlayered quartz levels, are boudinaged (Fig. 11b). Moreover, amphibolitic boudins are interlayered (Fig. 11b). The glacial and fluvial history of the gorge of Balmafregia is clearly visible from the shape of the cliff. The proximity of the Uriezzo potholes glaciological trail (i.e., SGs) allows development of wider educational activities (Fig. 11c). The climbing style is largely dependent on differential erosion, that acted on the mineralogical layers taking advantage of conjugate frac-

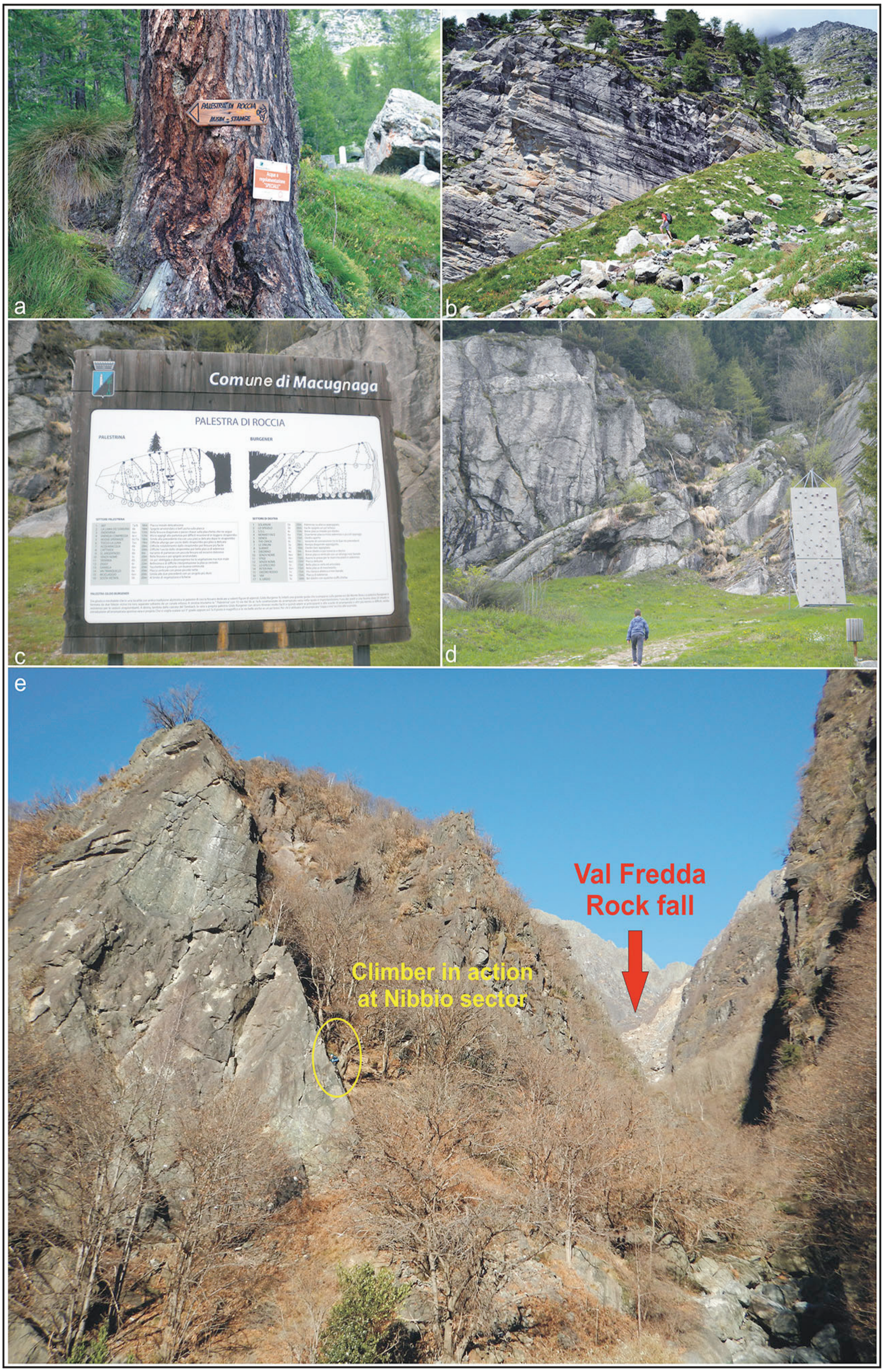

Figure 8
Examples of some of the highest valued situations concerning the attributes used in the assessment of the potential for use. The abbreviations of attributes are reported in parentheses in Table 2. a) and, b) Examples of information addressed to tourists and climbers (TI) and excellent visibility from the path (Vi) of the cliff of Codelago (no. 56a, Figure 3); c) and d) examples of information addressed to tourists and climbers (TI) and easy accessibility on foot to the rock wall of Macugnaga (no. 18a, Fig. 3); e) the rock fall in the Val Fredda represents a site of geomorphological interest located in the surroundings (SGs) of the rock climbing area of Nibbio (no. 13, Fig. 3).

Table 3. The list of the 59 analyzed climbing cliffs within the VCO Province including, in italics, the site identified in Varese Province (1). The numbering used in the lithology column corresponds to the numbers indicated in the legend of lithotypes in Figure 2, while the letters in the column of criteria for exclusion are those reported in Table 1. The cliffs resulting from the first phase of macro-selection are shown in light blue, while the three sites used for the educational project are reported in dark blue.

Id		NAME	Lit	Cr.	Id		NAME	Lit	Cr.
1		*SAN GIANO*	*M-Chk*		31		OIRA	Ogn-LP	A, B, D
2		MADONNA DEL SASSO	P-Gr	A, B, D	32		VAL BOGNANCO	Ogn-LP	A, B, D
3		MOTTARONE	P-Gr		33		PILASTRI DI TUGLIAGA	Ogn-LP	A, B, D
4	a	I CAVALIERI	P-Gr	A,C	34	a	BALMA 1	Ogn-LP	B
	b	SASSO CANTONACCIO	P-Gr	B, C		b	BALMA 2	Ogn-LP	B
	c	LO SPIGOLO	P-Gr	B, C		c	BALMA 3	Ogn-LP	B
	d	SASSO NERO	P-Gr	A, C	35		SAN DOMENICO	Ogn-LP	A,B,D
	e	L'ATELIER	P-Gr	B	36		PONTE CAMPO	Cls-Vls	
	f	LA BALMA	P-Gr	B, C	37		LA BOLLA	MSch-BV	
5		MONTORFANO	P-Gr	A	38		SOLCIO	Per-CG	A, B, D
6		ROVEGRO	Phy-SA	D	39		PIZZO BONI	Cls-Vls	A, B, D
7		SASSO CORBE'	Ogn-SA	B	40		CISTELLA	Sch-LP	A, B, D
8		ORNAVASSO	Mb/Mp-IV		41	a	PREMIA -BALMAFREGIA	MSch-BV	
9		MIGIANDONE	Mp-IV	B		b	PREMIA-ANTENNE	MSch-BV	C
10		ANZOLA	Mp-IV		42		CASCATA DI RIO D'ALBA	MSch-BV	B, D
11		BORGORATTO	Mb-IV	C, D	43		PIZZO PIODA	Cls-Vls	A, B, D
12		BETTOLA	Mb-IV	A, B, D	44		CADARESE	Ogn-LP	A, B
13	a	NIBBIO-SETTORI PRINCIPALI	Mb-IV	B, D	45		RIVASCO	Ogn-LP	A, B, D
	b	NIBBIO-LA PANORAMICA	Mb-IV		46	a	BUDDINO	Sch-LP	A1
14	a	CUZZAGO-SETTORI PRINCIPALI	Mb/Mp-IV			b	VANNINO-PRIMI PASSI	Sch-LP	A1
	b	CUZZAGO-IL GIARDINO	Mp-IV	B		c	PARETE DELLE FARFALLE	Sch-LP	A1
15		COLLORO	Mp-IV	B		d	PIZZO MARTA	Sch-LP	A1
16		FOMARCO	Ogn-SL	B		e	PILASTRI BOMBA	Sch-LP	A1
17		PIEDIMULERA	Ogn-SL	A, B, D		f	ROCCIODROMO	Sch-LP	A1
18	a	PALESTRA BURGENER	MGr-MR			g	VANNINO-SASSO SCUOLA	Sch-LP	A1
	c	SKARTEBODEN	MGr-MR	A1		h	IL CASTELLO	Sch-LP	A1
	d	PALESTRA BETTINESCHI	MGr-MR	B, D		i	CLOGSTAFEL	Sch-LP	A1
	e	PECETTO ALTA	MGr-MR	A1, A, D		j	TRIANGOLO DI TALETE	Sch-LP	A1
	f	SPONDE DI BACH	MGr-MR	A, B, D	47		CROVEO	Ogn-LP, 18	
	g	PALESTRA RIF. ZAMBONI	MGr-MR	A1	48		YOSESIGO	Ogn-LP	A,B,D
	b	MACUGNAGA-BORCA	MGr-MR	B	49		OSSO	Ogn-LP	A,B
19		PALLANZENO	MGr-MR		50		ESIGO	MSch-BV	B
20		PILASTRO GULLIVER	MGr-MR	B	51		PIODA CALVA	Ogn-LP/MSch-BV	A, B, D
21		MITTLERUCK	MGr-MR	A, B	52		GOLE DEL DEVERO	Cls-Vls	A, B, D
22		LA PINETA	MGr-MR	B, C, D	53	a	AGARO-MIRROR LAKE	Cls-Vls	A, B, D
23		VILLETTE	MGr-MR	B		b	AGARO-PINNACLE	Cls-Vls	A, B, D
24		PUNTA SERGIO	Ogn-SL	A, B, D		c	AGARO-LA NUDA ROCCIA	Cls-Vls	A, B, D
25		CURSOLO-ORASSO	Um.IV	A, B, C	54		CORNERA	Ogn-LP	A, B, D
26		ROCCE DEL GRIDONE	Um-IV7	A, B	55		PIZZO PIODELLE	Ogn-LP	A, B, D
27		FORT APACHE	Cls-Vls	A, B	56	a	CODELAGO-BUSIN STANGE	Ogn-LP	
28		VALLETTA	Ogn-LP			b	CODELAGO-LA LOBIA	Ogn-LP	B
29		PLACCHE DI VAL PUJER	Ogn-LP	A, B, D	57		CRAMPIOLO-PIZZO FIZZI	Per-CG	A, B, D
30	a	PONTEMAGLIO 1	Ogn-LP	A, B, D	58		ESMERALDA	Per-CG	A, B, D
	b	PONTEMAGLIO 2	Ogn-LP	A, B, D	59		LA ROSSA	Per-CG	A, B, D

Table 4. Results of the quantitative assessment of the cliff values. In the first column the code for the attribute is reported according to the codes listed in Table 2.

ATT.	*1*	*3*	*8*	*10*	*13b*	*14a*	*18a*	*19*	*28*	*36*	*37*	*41a*	*47*	*56a*	MAX	MIN	AVE	STD DEV	Var
RGmP	0.67	1.00	0.67	0.00	0.00	0.00	0.67	0.00	1.00	1.00	1.00	1.00	0.67	0.67	**1.00**	**0.00**	**0.60**	0.40	0.17
RGP	1.00	1.00	1.00	0.67	1.00	1.00	0.67	0.67	1.00	1.00	1.00	1.00	1.00	0.67	**1.00**	**0.67**	**0.91**	0.15	0.02
EE	1.00	1.00	0.67	0.67	0.67	0.67	0.67	0.67	1.00	1.00	1.00	1.00	1.00	0.67	**1.00**	**0.67**	**0.84**	0.17	0.03
SE	0.50	0.75	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.50	0.75	0.50	0.75	**0.75**	**0.50**	**0.57**	0.11	0.01
Gd	1.00	0.50	1.00	0.50	0.50	1.00	0.50	0.50	0.50	0.50	0.00	1.00	1.00	0.50	**1.00**	**0.00**	**0.64**	0.29	0.09
GI	0.33	0.67	0.67	0.67	0.67	0.67	0.00	0.00	0.00	0.33	0.00	0.67	0.67	0.00	**0.67**	**0.00**	**0.38**	0.31	0.10
ES	0.00	0.67	0.67	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.67**	**0.00**	**0.14**	0.27	0.08
In	1.00	1.00	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	**0.50**	**0.93**	0.17	0.03
Ra	0.50	0.00	0.50	0.50	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.50**	**0.00**	**0.18**	0.24	0.06
SV	**6.00**	**6.59**	**6.18**	**4.01**	**5.51**	**5.34**	**4.01**	**3.34**	**5.00**	**5.58**	**4.50**	**6.42**	**5.84**	**4.26**	**6.59**	**3.34**	**5.18**	0.98	1.03
Cu	0.00	0.00	0.50	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.50**	**0.00**	**0.07**	0.17	0.03
Ae	0.50	1.00	0.00	0.00	1.00	0.00	0.50	0.00	0.50	1.00	1.00	1.00	0.00	1.00	**1.00**	**0.00**	**0.54**	0.44	0.21
Sec	0.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	0.67	0.67	0.00	1.00	0.67	0.67	**1.00**	**0.00**	**0.62**	0.42	0.19
AV	**0.50**	**2.00**	**1.50**	**0.00**	**2.50**	**1.00**	**1.50**	**0.00**	**1.17**	**1.67**	**1.00**	**2.00**	**0.67**	**1.67**	**2.50**	**0.00**	**1.23**	0.72	0.56
GV	**6.50**	**8.59**	**7.68**	**4.01**	**8.01**	**6.34**	**5.51**	**3.34**	**6.17**	**7.25**	**5.50**	**8.42**	**6.51**	**5.93**	**8.59**	**3.34**	**6.41**	1.48	2.37
IU	**2.00**	**2.75**	**1.17**	**1.17**	**2.17**	**1.17**	**1.67**	**1.17**	**2.00**	**2.75**	**2.50**	**2.75**	**1.50**	**2.42**	**2.75**	**1.17**	**1.94**	0.61	0.40
TA	0.75	0.50	0.75	0.75	0.75	0.75	0.50	0.75	0.50	0.50	0.50	0.50	0.50	0.50	**0.75**	**0.50**	**0.61**	0.12	0.02
SAc	0.40	0.40	0.40	0.40	0.20	0.60	0.80	0.80	0.60	0.40	0.40	0.80	0.40	0.40	**0.80**	**0.20**	**0.50**	0.18	0.04
Vi	0.60	1.00	0.80	0.60	1.00	0.80	1.00	0.80	0.80	1.00	1.00	1.00	0.80	1.00	**1.00**	**0.60**	**0.87**	0.14	0.02
Se	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	**1.00**	**1.00**	0.00	0.00
NT	0.50	1.00	0.50	0.00	0.00	0.50	1.00	0.50	0.50	1.00	0.00	1.00	0.50	1.00	**1.00**	**0.00**	**0.57**	0.37	0.15
SA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	**1.00**	**1.00**	0.00	0.00
LC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**	**1.00**	**1.00**	0.00	0.00
UGI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	**1.00**	**0.00**	**0.07**	0.26	0.07
UAI	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	**0.00**	**0.14**	0.35	0.13
SGs	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	**1.00**	**0.00**	**0.79**	0.41	0.18
PU s.s.	**7.85**	**8.25**	**8.22**	**6.52**	**8.92**	**7.82**	**8.97**	**7.02**	**7.40**	**9.25**	**8.00**	**11.05**	**7.30**	**8.92**	**11.05**	**6.52**	**8.25**	1.10	1.29
PU	**8.18**	**8.63**	**8.68**	**6.94**	**9.12**	**7.82**	**8.97**	**7.02**	**7.40**	**9.45**	**8.27**	**11.05**	**7.60**	**9.17**	**11.05**	**6.94**	**8.45**	1.06	1.21
SIn	**0.67**	**0.89**	**0.78**	**0.45**	**0.56**	**0.56**	**0.45**	**0.22**	**0.67**	**0.78**	**0.67**	**0.89**	**0.78**	**0.45**	**0.89**	**0.22**	**0.63**	0.19	0.04
EIn	**0.61**	**0.79**	**0.38**	**0.36**	**0.62**	**0.36**	**0.66**	**0.42**	**0.77**	**0.73**	**0.76**	**0.93**	**0.43**	**0.64**	**0.93**	**0.36**	**0.60**	0.18	1
TS	**14.68**	**17.22**	**16.36**	**10.95**	**17.13**	**14.16**	**14.48**	**10.36**	**13.57**	**16.70**	**13.77**	**19.47**	**14.11**	**15.10**	**19.47**	**10.36**	**14.86**	2.35	5.95

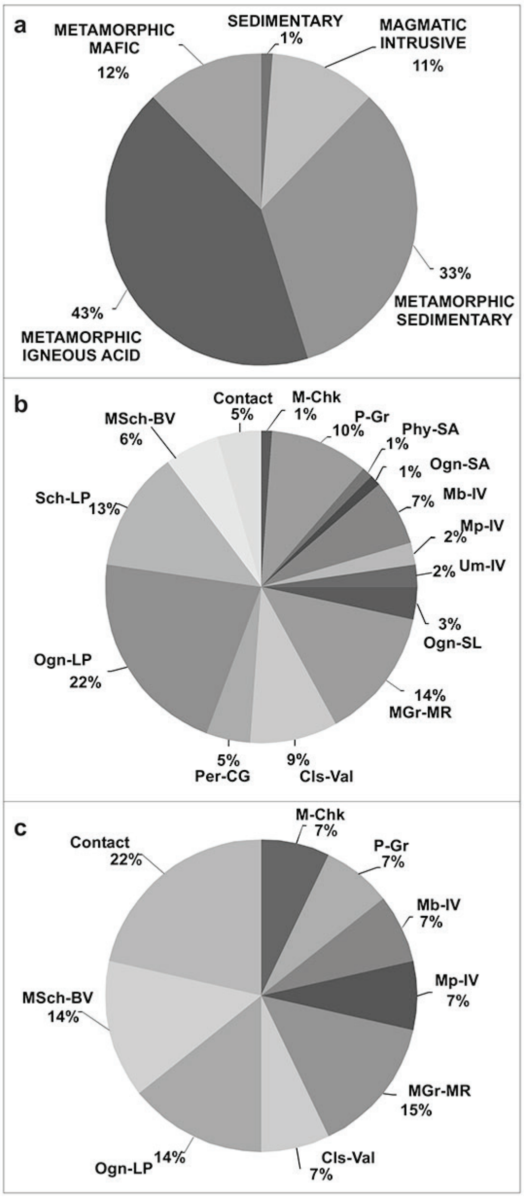

Figure 9
Percentages of the cliffs grouped according to genetic process (a) and lithology (b). In graph (c) the percentage of rocks constituting the 14 analyzed cliffs is reported. The codes in (b) and (c) correspond to those in Figure 3.

ture systems, offering smooth edges.

The second most valued site is represented by the Mottarone cliff (no. 3, Table 3 and Figs. 3 and 6d). The cliff is constituted by the Permian granites of the Southern Alpine Domain (P-Gr). They are well known in Northern Italy as Baveno pink granite, because the k-feldspar confers a characteristic pink color to the rock. The Mottarone area is a good representative of a granitic landscape (i.e., RGmP; RGP; Fig. 6d), with all the landforms deriving from the unloading of the pluton, the exfoliation joints and planes, and hydrolysis of the feldspars. The Mottarone cliff reached the following values: TS = 17.22 out of 25, SIn = 0.89 over 1, EIn = 0.80 out of 1, and PU = 8.63 out of 13. In particular, EI and PU are slightly penalized mainly by the parameter Sac, which indicates the need to walk along a path rather than offering direct access by car as for the Premia site. The climbing style is very peculiar and strictly linked with the presence of smooth cracks and grooves and a grip progression.

Other sites obtained ranking values that are slightly lower than those of the two previously described sites, in some cases relative to specific parameters. For example, Nibbio–La Panoramica (no. 13b, Table 3 and Figs. 3 and 7,b) obtained a TS value of 17.13 out of 25, especially due to PU (9.12), which exceeds the corresponding value for the Mottarone cliff (8.63). The Cultural Value (Cu) associated with the cliff due to the presence of the "Strada Cadorna" and the corresponding Use of Additional Value (UAI) contributes to this difference. This climbing cliff consists of metabasites of the Ivrea-Verbano Zone (Mb-IV). Other highly valued cliffs (i.e., TS above at least 15) are Ornavasso (16.36 out of 25; no. 8; Table 3 and Figs. 3 and 6e) and Ponte Campo (16.70 out of 25; no. 36, Table 3 and Figs. 3 and 7a), of which the first is characterized by the contact between the metapelites (Mp-IV) and the metabasites (Mb-IV) of the Ivrea-Verbano Zone and the second is modeled in the calcschists of the Valais Units (Cls-Val). The first site gains high values of SIn (0.78 out of 1) and SV (6.18 out of 9) for the importance of the site as an object of scientific research within the Ivrea-Verbano Zone (i.e., GI and Gd) both due to the contact between the two lithotypes. The second site is characterized by high values of both SIn and EIn (0.78 and 0.73 out of 1, respectively).

The Sangiano site (1 in Fig. 3 and 5b) was chosen as representative of sedimentary rocks. The rocks are calcilutites with chert nodules of the sedimentary covers of the Southern Alps (M-Chk), characterized by very noteworthy sedimentary structures (e.g., prominent bedding and stylolites) and a modeling mainly due to CaCO3 dissolution (e.g., alveolar landforms) or deposition (e.g., columns). The cliff obtained values above the mean values for almost all of the composite attributes: SV (6.00 out of 9), GV (6.50 out of 12), PU (8.18 out of 13), SIn (0.67 out of 1), EIn (0.61 out of 1), and finally TS (14.68 out of 25). The geological and geomorphological features clearly influence the difficulty of the climbing routes. For example, the section is characterized by deposition rather than dissolution of CaCO3 and the formation of cannelures is almost overhanging, with harder climbing grades in comparison to those of the other sections of the cliff.

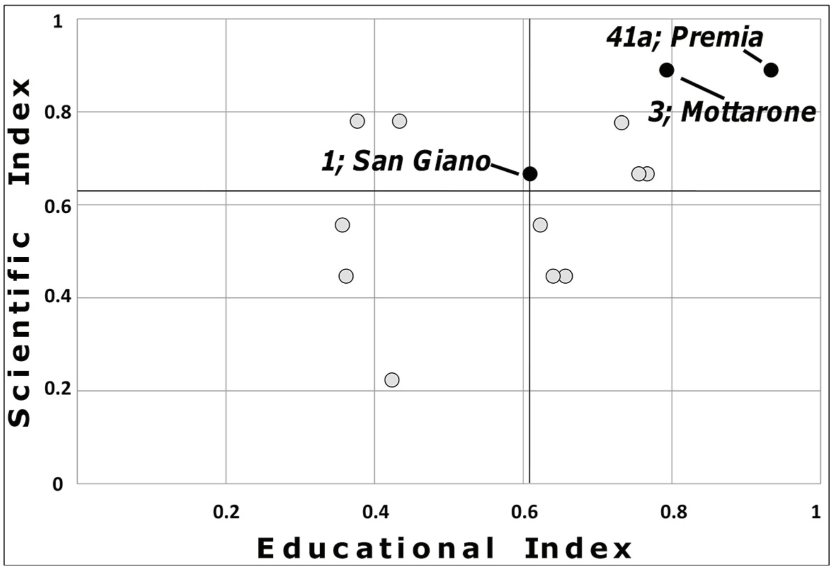

Figure 10
Relation between SIn and EIn of the analyzed sites. Bold lines indicate the average values of SIn an EIn. All sites are in the middle and upper bands of the Scientific Index. The three sites selected for the educational experience are indicated (San Giano, Mottarone, and Premia) and are located in the uppermost part of the graph, testifying their high value.

TEST OF THE METHOD: A PILOT EDUCATIONAL PROJECT ON CLIMBING SITES FOR EARTH SCIENCES DISSEMINATION

A pilot educational project was designed including 3 out of 14 of the most valued sites (dark blue in table 3) to test the efficacy of the assessment methodology. In fact, for the educational project, a climbing crag was chosen for each main family of rocks. For the magmatic and metamorphic rocks, the choice was completely guided by the results of the quantitative evaluation methodology. Instead, for the sedimentary rocks the crag was first selected and then assessed to verify its high quality by comparison with the results obtained by the other evaluated crags. Reconsidering Figure 10, the three climbing crags that are the most representative of the three families of rocks are located in the uppermost part of the graph. Among the analyzed climbing routes in the three sites selected for the educational project, those that are also easy and suitable for beginners and may best represent the geological and geomorphological features of the rock were identified. The selected routes were:

i) Sangiano: “La valanga” (3a, French scale -Fs) and “Lo spigolo” (4b, Fs);

ii) Mottarone: “O sole mio” (5b, Fs) and “Via col vento” (6a, Fs);

iii) Premia Balmafregia: “Tango” (5b, Fs) and “Joshua tree” (5c, Fs).

Figure 12 shows the sample outputs of the image analyses connecting geo- and climbing features for dissemination purposes.

The pilot project, structured as reported in Table 6, was aimed at a third year lower secondary school (100 students, 13-14 aged), where, in accordance with the teaching programs, the families of rocks are studied during the third year. The project was implemented in four classes of a school located about 80 km far away from the study region. The classes had slightly different backgrounds in Earth Sciences but all the students had been previously involved in indoor climbing experiences. The educational project was welcomed by students during all phases of the experience. This was articulated at different moments of the test, whose results are reported in Figure 13. It must be specified that even though the main goal of this work was to test the efficacy of the site evaluation method, an educational project usually requires more goals and a more articulate structure. We report the result of all the tests as a tool to better address future applications.

The pilot project was based on the use of both traditional/laboratorial (e.g. with rock samples) and innovative/digital (e.g. visualization and analysis of virtual tours, videos, photos, Web-based source of information), that are currently highly appreciated by the young people and demonstrated great efficacy in the learning experience (Harris and Rea, 2009; King, 2008 and reference herein; Sherer and Shea, 2011; Magagna, 2013). They were used to arise curiosity about and interest in the study of Earth Science through focusing on the sense of observation (Mayer, 2009). Moreover, the combination of digital with traditional activities has been recently discussed as a potential tool to improve students’ interest and knowledge through innovation and inquiry-based activities (Magagna, 2016 and reference therein).

Videos of climbers progressing along the three selected routes were shot in the field (https://www.dropbox.com/sh/p4835xns81ouonr/AABQCn-1PPWuXVE5jLuGyvs5Ia?dl=0). It was hoped that the “remote” approach, based on the use of rock samples and simple amatorial videos of climbers progressing along the selected routes, would help students direct their attention towards the foot- and hand-holds used by climbers and as a conse-

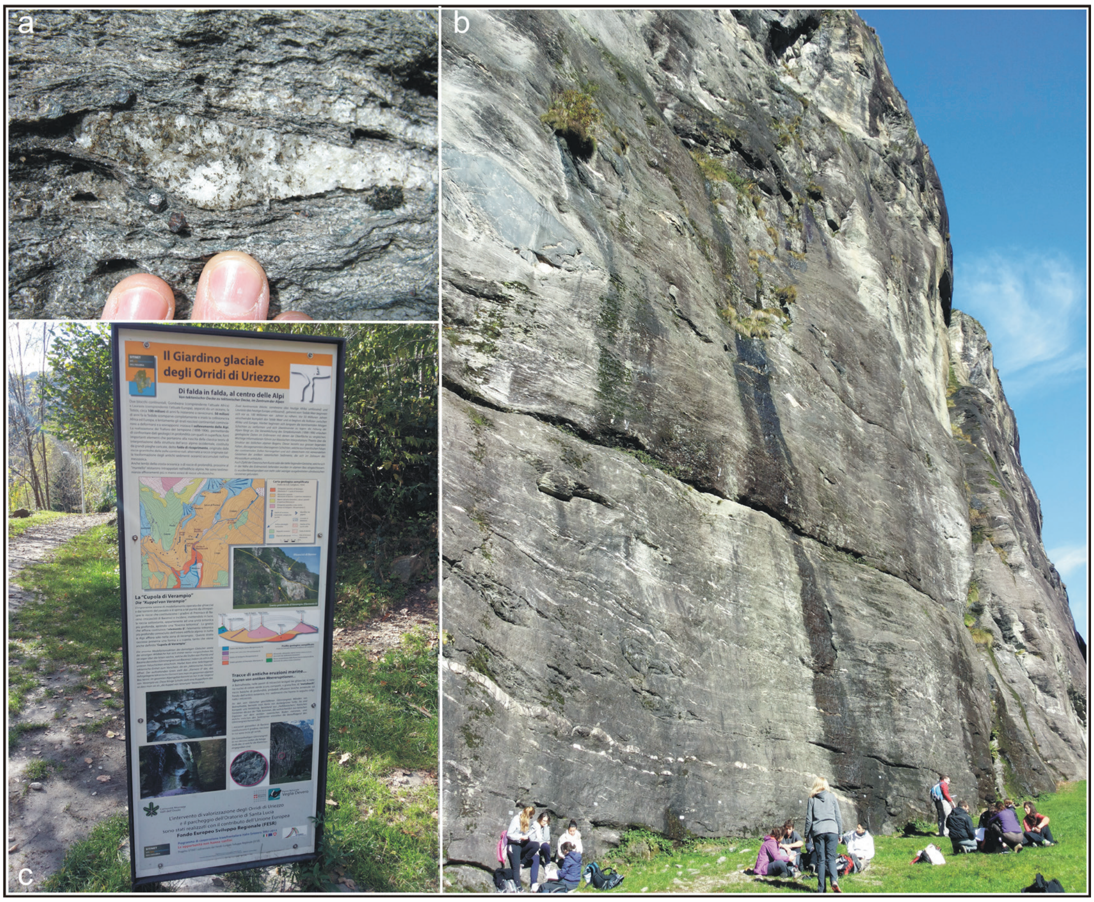

Figure 11
The climbing cliff of Premia. a); b) The Baceno micaschists geological and geomorphological features. They are well exposed and display garnets (a), quartz lenses (a), and amphibolite boudins (b). The glacial modeling of the cliff is evident too. All these attributes are used for calculating the scientific value (e.g., RGmP, RGP, Se, Gd, In; see Table 6), additional values (e.g., Ae; see Table 6), and potential for use (e.g., Vi, SA; see Table 6); c) example of panels located along a geotouristic path starting near the climbing wall that contribute to the assessment of both additional value and potential for use (e.g., Sec, UGI, SGs; see Table 6)

quence encourage them to observe their shapes and ask questions about their genesis. Web-based virtual tools (i.e., sources: Youtube and Vimeo videos) were also selected and proposed. The additional use of the Web-based videos as an educational tool allowed to:

i) stimulate the curiosity of students by virtually visiting spectacular places;

ii) virtually visit climbing locations that were far from the study area or not easy accessible and thereby include more climatic contexts and rock types

Results of the pilot educational project

The elaboration of tests data was performed using the following marking scheme: a score of 0 for the wrong answer, 1 for the correct answer but the wrong terminology, and 2 for the correct answer. The percentages were then calculated with respect to the maximum value. Also, questions that may be influenced by subjectivity were included in the tests but were considered separately and described qualitatively.

Globally, the percentage of correct answers of the first test on previous knowledge was between 29 and 44% (Fig. 13b). The detailed results for each class are reported in Figure 13a. It is interesting that the question that was answered correctly by a higher percentage of students among all the classes was the one on the mutability of rocks over time. The open questions concerned personal experience with rocks (i.e., What is a rock? Where

Table 5. Example of evaluation of the Premia rock cliff using the proposed methodology.

SCIENTIFIC VALUE		
RGmP	1	Exemplar representativeness of a morphogenetic system
RGP	1	Exemplar representativeness of a geological process
EE	1	Representativeness with excellent educational value
SE	0.,75	Landscape
Gd	1	> 1 lithologies, n-landforms
GI	0.67	Relevant topic for scientific research
ES	0	Without any connection with the biologic element
In	1	Essential geomorphological elements are intact
Ra	0	Frequent also at level of the study area
SV	***6.42***	
ADDITIONAL VALUES		
Cu	0	Any cultural feature in the surroundings
Ae	1	Strong contrasts in landforms, lithologies and colours
SEc	1	Element inserted in an economic-touristic circuit
AV	***2***	
GV	***8.42***	
POTENTIAL FOR USE		
TA	0.5	Except in winter
SAc	0.8	Allowed to means of transportation
Vi	1	Excellent visibility for all geomorphological elements
Se	1	Hotels and services far from 5 Km
NT	1	Abundant
SA	1	Yes, correlated with geomorphological features
LC	1	No protection or limitation in use
UGI	1	With divulgation and use as geo(morpho)site
UAI	0	Any divulgation or use
SGs	1	Sites in the neighbourhood and genetically correlated
IU	***2.75***	
PU	***11.05***	
OVERALL VALUE		
SIn	***0.89***	
EIn	***0.93***	
TS	***19.47***	

have you seen one before?), and many students associated them with mountains and rocky beaches. In general, from the second test it emerged that minerals and rocks are something different: the former are considered something precious, but not always thought to be natural; the latter may be of different origins. In the class that had already been introduced to the topic, the distinctions between the three main categories (magmatic, sedimentary, and metamorphic) emerged.

The second test regarded the identification of everyday objects (cotton, wood, tin; see Table 6) and was completed successfully by more than 60% students in each class. Everyday objects were recognized more easily than rocks. Anyway, in some particular cases, the personal experience that students had acquired during previous journeys or, in the specific case of one student, during climbing outdoors, helped them to identify not only rock in general but the specific lithotype (e.g., granite).

The third test concerned the analysis of the cliffs through virtual tools like home-made and Web-based videos. Correct answers were given in 39.2 to 59.8% of cases (Fig. 14a). The questions on the Mottarone cliff had the best scores, with an average of 58% of questions being answered correctly (Fig. 14b). Students observed and recognized the different forms characterizing the illustrated portions of the cliff along the proposed climbing route. For both Premia and Sangiano, 37% of questions were answered correctly on average. On observing the Premia cliff, students detected the presence of elongated holes and portions of different materials because they were differently colored and shaped (i.e., quartz, micaceous layers, amphibolitic boudins) and also perceived the consequential differing difficulty levels of the routes. A difference between Mottarone and Premia was detected in terms of the different scales of roughness of the surfaces and a consequent higher difficulty in progression along the granitic routes was perceived. The stratification and differential erosion present and visible on the Sangiano cliff led students to believe that the cliff was composed of different rocks, neglecting the possibility that different portions of a rock may be generated in a single sedimentary environment. The next test, proposing the association of a hand sample with the rocks observed in the video, gave, instead, scarce results.

The final test, which reconsidered almost the same questions as the pre-knowledge test, was correctly completed by a greater percentage of students than the pre-test (Fig, 15): 49–75.8% (29–44% before the learning experience). The improvement in the students' knowledge on the proposed Earth Science topics with respect to the pre-test may be considered evident (the percentage of correct answers approximately doubled).

DISCUSSION AND CONCLUSIONS

According to Gray et al. (2013), geodiversity, in the form of geodiversity sites equipped for climbing, provides cultural services to society in terms

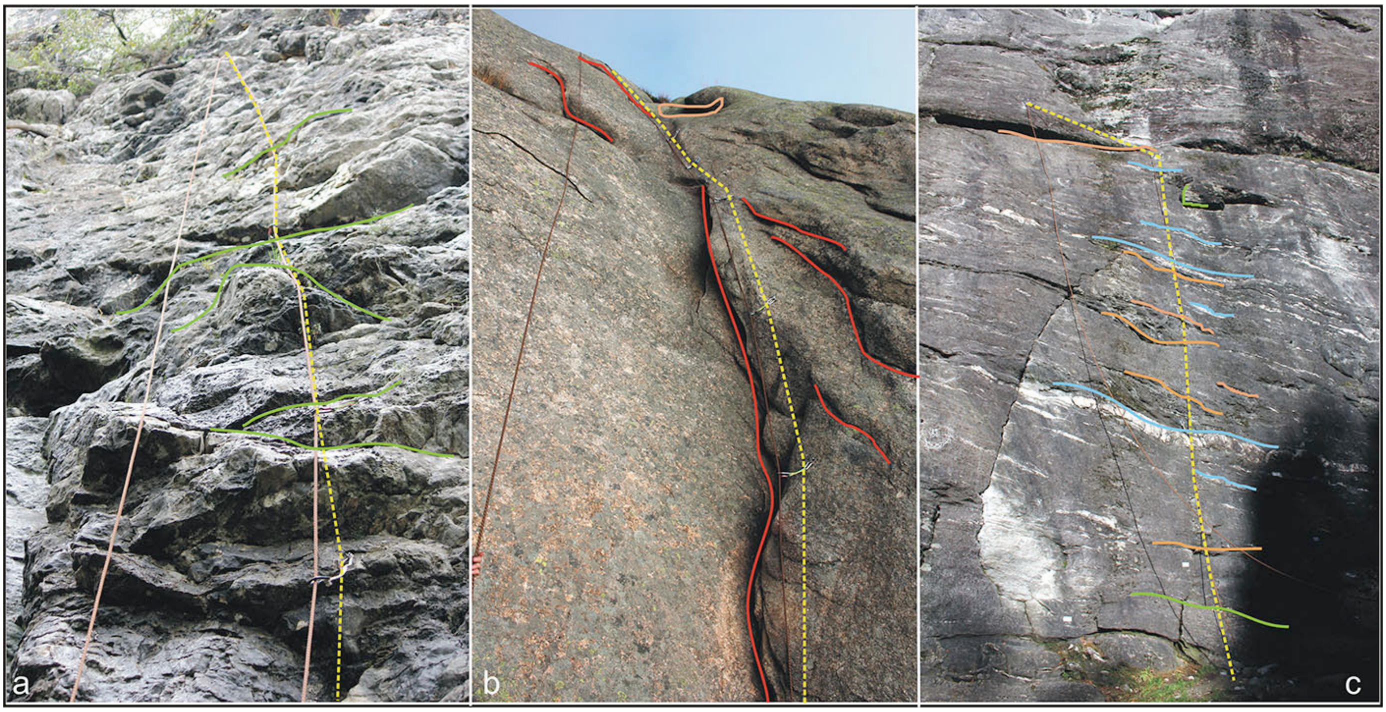

Figure 12
Examples of image analysis of three of the six selected routes. The yellow dashed lines indicate the path of the climbing route. The other colored lines indicate the geological and geomorphological elements identified and involved in climbers progressions (green: structural landforms due to foliation or stratification; red: flow structures and unloading fractures; orange/light blue: holes/notches for various types of physical and chemical weathering on minerals).

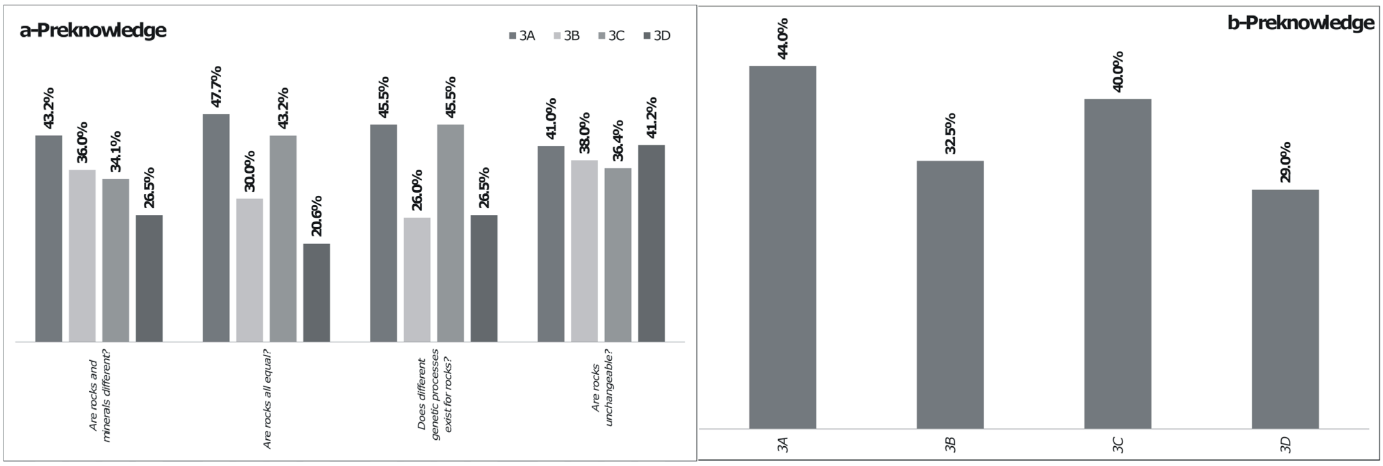

Figure 13
Results of the educational experience of all four classes involved in the project expressed as the percentage of correct answers. a); b) Detailed and global results of the test on the previous knowledge for each question.

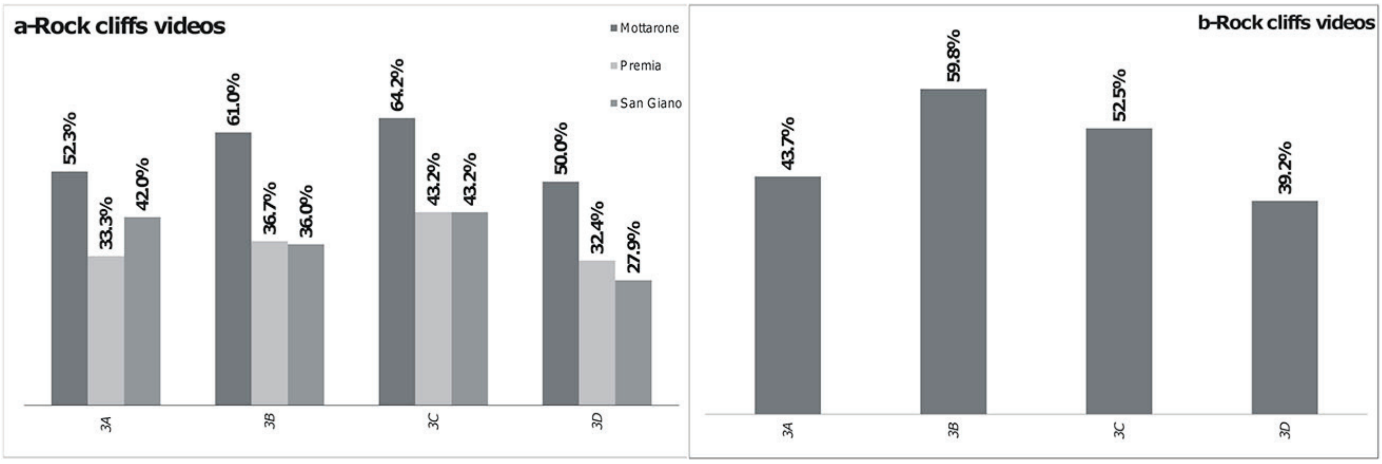

Figure 14
Results of the educational experience of all four classes involved in the project expressed as the percentage of correct answers. a); b) detailed and global results of the test using videos for each cliff.

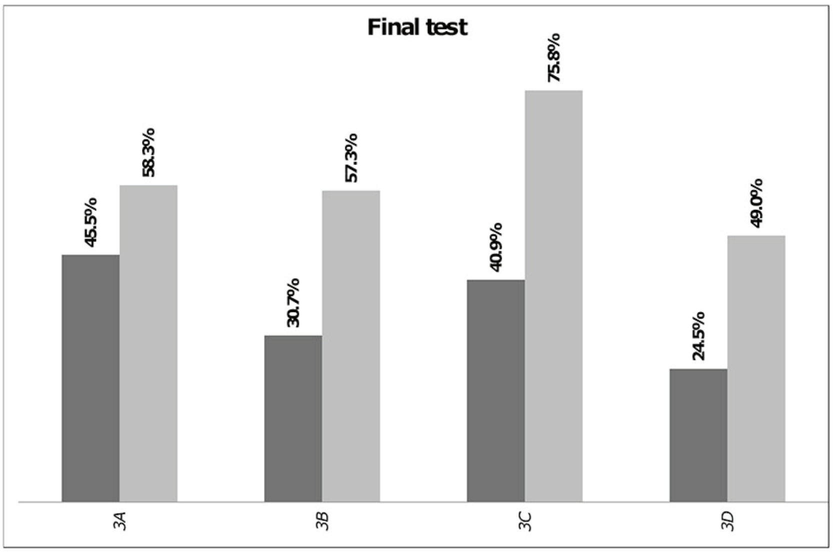

Figure 15
Results of the educational experience of all four classes involved in the project expressed as the percentage of correct answers. The final comparison between the results of the pre-test and the post-test.

of “geotourism and leisure” and indirectly “education and employment”. Moreover, climbing has been demonstrated to be very helpful in promoting social relationships among young people (De Leseleuc et al., 2002). It follows that the phase of selection of the most suitable climbing geosites for educational purposes as a way of popularizing Earth Sciences is very important. Climbing geosites represent both an instrument for climbing progression and also a bedrock that allows people to get in touch with geological structures, lithology, and landforms formed by geomorphological modeling (e.g weathering, glacial erosion). A correct and precise methodology is, consequently, a key starting point in the dissemination of Earth Science. In the VCO region, the analyzed geodiversity sites equipped for climbing are a component of the regional geoheritage and in particular some of them have been demonstrated to be of high value; they offer dominantly metasedimentary and metaigneous rocks. The qualitative selection carried out among all these climbing sites indicated about 24% of the total number of analyzed geodiversity sites as valid for quantitative assessment. They were ranked according to macrocriteria (SV, AV, PU, GV, EIn, SIn, TS). The obtained values are similar to those determined for the pilot sites of Montestrutto (see details in Bollati et al., 2014). The three cliffs selected for the pilot educational application and the results obtained from student tests (based on distinguishing major families of rocks) confirmed the efficacy of the assessment methodology used to identify sites for different purposes, in this specific case an educational one. In this first experimentation “from remote”, the results of the educational experience are promising since students achieved an increase in knowledge about rocks, especially among students who had not yet dealt with this topic. Moreover, the results of the educational tests were promising and suggested further field experimentations. In fact, the terminology mistakes, which were one of the negative aspects emerging from the final tests, could be mitigated through a wider and more articulated project that includes fieldwork experience at sites (i.e., climbing experience under the supervision of Earth Science specialists and mountain guides). Moreover, field trips could allow students to get a wider landscape view, considering possible hazards and risks along the trail (see, e.g., Bollati et al., 2013).

The involvement of the secondary school students in the region in these kinds of experiences, where indoor multimedia activities, field work, open laboratories, and cultural itineraries are proposed, may nurture the growth of the sense of place in students. The use of multimedia tools in the field of Earth Science education is demonstrated to be a valid support, rather than a substitute, for the traditional learning method (e.g., Magagna, 2013; 2016).

Finally, the assessment methodology may be considered valid for ranking geodiversity sites equipped for climbing and may represent good practice for detecting the most suitable sites for different purposes.

ACKNOWLEDGMENTS

The authors would like to thank: Guido Gosso for improvements of the manuscript structure; students and teachers of the Cadorago lower secondary school of first level in Como Province; Federico Tomasella and Davide Tagliabue for permitting the authors to be filmed during climbing activities. The authors are also grateful to A.S.D. Geam Climbing for sharing information and climbing pictures and for assistance during the search for new climbing crags over many years.

REFERENCES

Argand, E., 1911, Les nappes de recouvrement des Alpes Pennines et leur prolongement structuraux: Mat. carte géol. Suisse, N.S., XXXI livr.

Benito-Calvo, A., Pérez-González, A., Magri, O., Meza, P., 2009, Assessing regional geodiversity: the Iberian Peninsula: Earth Surface Processes and Landforms, 34(10), 1433-1445.

Bigioggero B., Colombo A., Cavallo A., Aldighieri B., Tunesi A., 2006 Schema geologico-strutturale dell'area val d'Ossola-Sempione in scala 1:50.000.

Bollati, I., Pelfini, M., Pellegrini, L., 2012, A geomorphosites selection method for educational purposes: a case study in Trebbia Valley (Emilia Romagna, Italy): Geografia Fisica e Dinamica Quaternaria, 35(1), 23-35.

Bollati, I., Smiraglia, C., Pelfini, M., 2013, Assessment and selection of geomorphosites and trails in the Miage Glacier Area (Western Italian Alps): Environmental Management, 51(4), 951-967.

Bollati, I., Zucali, M., Giovenco, C., Pelfini, M., 2014, Geoheritage and sport climbing activities: using the Montestrutto cliff (Austroalpine domain, Western Alps) as an example of scientific and educational representativeness: Italian Journal of Geosciences, 133 (2), 187-199.

Bradbury, J., 1993, A Preliminary Geoheritage Inventory of the Eastern Tasmania Terrane. A Report to Parks and Wildlife Service, Tasmania.

Brilha, J., 2015, Inventory and quantitative assessment of geosites and geodiversity sites: a review: Geoheritage, 1-16.

Brock, M., Semeniuk, V., 2007, Geoheritage and geoconservation-History, definition, scope and scale. Journal of the Royal Society of Western Australia, 90-2, 53-87.

Cat Berro, D., Mercalli, L., Bertolotto, P. L., Mosello, R., Rogora, M., 2014, Il Clima dell'Ossola superiore: Nimbus, 72, XXII-2, 46-129.

Cavallo, A., Bigioggero, B., Colombo, A., Tunesi, A., 2004, The Verbano Cusio Ossola province: a land of quarries in northern Italy (Piedmont): Periodico di Mineralogia, 73(3), 197-210.

De Leseleuc, E., Gleyse, J., Marcellini, A., 2002, The practice of sport as political expression? Rock Climbing at Claret, France: International sociology, 17(1), 73-90

Dixon, G., 1996, Geoconservation: An International Review and Strategy for Tasmania; A Report to the Australian Heritage Commission, Occasional Paper No. 35, Parks and Wildlife Service, Tasmania

Garlick, S., 2009, Flakes, Jugs and Splitters. A rock climber's guide to geology. Falcon Guides Ed., Helena, Montana, p. 224.

Grandgirard, V., 1999, L'évaluation des géotopes: Geologia Insubrica, 4, 59-66.

Gray, M., 2004, Geodiversity: valuing and conserving abiotic nature (1st Edition). John Wiley and Sons Ed., Oxford, p. 448.

Gray, M., Gordon, J. E., Brown, E. J., 2013, Geodiversity and the ecosystem approach: the contribution of geoscience in delivering integrated environmental management: Proceedings of the Geologists' Association, 124(4), 659-673.

Hantke R., 1988, La formazione delle valli tra Domodossola e Locarno: la Val d'Ossola, la Val Vigezzo (prov. di Novara) e le Centovalli (Ct. Ticino): Bollettino della Società Ticinese di Scienze Naturali, 76, 123-139,

Harris, A. L., Rea, A., 2009, Web 2.0 and virtual world technologies: A growing impact on IS education: Journal of Information Systems Education, 20(2), 137.

King, C., 2008, Geoscience education: an overview: Study in Science Education, 44(2),187–222.

Magagna, A., Ferrero, E., Giardino, M., Lozar, F., & Perotti, L., 2013, A selection of geological tours for promoting the Italian geological heritage in the secondary schools: Geoheritage, 5(4), 265-273.

Magagna, A. 2016, Educational tools for spreading knowledge of geodiversity and awareness of geoscience. University of Turin, Unpublished PhD Thesis.

Manoni, F., Pellizzon, M., Stoppini, P., 2014, Ossola Rock. Versante Sud Ed., Milan, p. 400.

Mazzucchelli, D., (Ed.), 2011, Varese e Canton Ticino Falesie. Versante Sud, Ed., Milan, p. 352.

Mayer, R.E., 2009, Multimedia learning, 2nd Edn. Cambridge University Press, Cambridge, p. 320.

Motta, L., Motta, M., 2005, Valutazione della potenzialità d'uso turistico-sportivo di un sito naturale: l'esempio delle pareti rocciose usate per l'arrampicata, in: La valorizzazione turistica dello spazio fisico come via alla salvaguardia ambientale edited by Terranova, R., Brandolini, P., Firpo, M., 263-278.

Osborne, R.A.L., 2000, Geodiversity: Green geology in action - Presidential address for 1999-2000: Proceedings of the Linnaean Society of New South Wales, 122, 149-173.

Panizza, M., 2001, Geomorphosites : concepts, methods and example of geomorphological survey: Chinese Science Bulletin, 46, Suppl. Bd, 4-6.

Panizza, M., 2009, The geomorphodiversity of the Dolomites (Italy): a key of geoheritage assessment: Geoheritage, 1(1), 33-42.

Panizza, V., Mennella, M., 2007, Assessing geomorphosites used for rock climbing: the example of Monteleone Roccadoria (Sardinia, Italy): Geographica Helvetica, 62(3), 181-191.

Pereira, P., Pereira, D., 2010, Methodological guidelines for geomorphosite assessment: Géomorphologie: relief, processus, environnement, 2/2010, 215-222.

Pirocchi, P., 2012, Rocce e natura senza frontiere: meraviglie geologiche tra Valle Antigorio, Valle Devero e Binntal, Ente di gestione delle Aree protette dell'Ossola Ed., Varzo, p. 120.

Reynard, E., Fontana, G., Kozlik, L., Scapozza, C., 2007, A method for assessing "scientific" and "additional values" of geomorphosites: Geographica Helvetica, 62(3), 148-158.

Reynard, E., Coratza, P., 2013, Scientific research on geomorphosites. A review of the activities of the IAG working group on geomorphosites over the last twelve years: Geografia Fisica Dinamica Quaternaria, 36, 159-168.

Reynard, E., Coratza, P, Hobléa, F., 2016, Current research on Geomorphosites. Geoheritage, doi: 10.1007/s12371-016-0174-3.

Ruban, D. A., 2015, Geotourism—a geographical review of the literature:Tourism Management Perspectives, 15, 1-15.

Semeniuk, V., 1997, The linkage between biodiversity and geodiversity. In: R Eberhard (ed), Pattern and Processes: Towards a Regional Approach to National Estate assessment of geodiversity. Technical Series No. 2, Australian Heritage Commission and Environment Forest Taskforce, Environment Australia, Canberra, 51-58.

Sherer, P., Shea, T., 2011, Using online video to support student learning and engagement. College Teaching, 59(2), 56-59.

Trend, D. R., 2001, Deep Time Framework: A Preliminary Study of U.K. Primary Teachers' Conceptions of Geological Time and Perceptions of Geoscience: Journal of Research in Science Teaching, 38(2), 191-221.

Wimbledon, W. A. P., 1996, Geosites - A new conservation initiative: Episodes, 19, 87-88.

Zanoletti, E., 2012, L'impronta dei ghiacci: osservazioni glaciologiche lungo il percorso dell'Alpe Veglia / Varzo, Ente di gestione delle Aree protette dell'Ossola Ed., Varzo, p. 44.

Zucali, M., Voltolini, M., Ouladdiaf, B., Mancini, L., Chateigner, D., 2014. The 3D quantitative lattice and shape preferred orientation of a mylonitised metagranite from Monte Rosa (Western Alps): Combining neutron diffraction texture analysis and synchrotron X-ray microtomography: Journal of Structural Geology, 63, 91–105.