GEOHERITAGE AND SPORT CLIMBING ACTIVITIES: USING THE MONTESTRUTTO CLIFF (AUSTROALPINE DOMAIN, WESTERN ALPS) AS AN EXAMPLE OF SCIENTIFIC AND EDUCATIONAL REPRESENTATIVENESS

IL PATRIMONIO GEOLOGICO E L'ARRAMPICATA SPORTIVA: LA FALESIA DI MONTESTRUTTO (DOMINIO AUSTROALPINO, ALPI OCCIDENTALI) COME ESEMPIO DI RAPPRESENTATIVITÀ SCIENTIFICA E DIDATTICA

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ABSTRACT

Numerous sites of geological and geomorphological interest (i.e., geosites or geomorphosites) have been recently individuated around the Alps, testifying to the great geodiversity that characterises this mountain range. Some rock cliffs that have been locally equipped as sport climbing sites may also be considered as sites of geological and geomorphological interest: the combination of features such as educational exemplarity and geohistorical importance increase the scientific value of these sites. Progression along climbing routes is intimately connected with the geological and geomorphological features of the cliff; thus, it may be possible to interest typical climbers in the area of the Earth Sciences.

A research study was conducted at the Montestrutto climbing wall (Western Alps, Italy), which is located in the Eclogitic Micaschist Complex of the Austroalpine Domain, with the following objectives: i) to reconstruct the deformation stages at local scales along the sport climbing wall and in the surroundings; ii) to analyse how geological elements are related to the physical elements needed for vertical progression to strengthen the link among geology, morphology and the grade of the routes, and finally iii) to use previous results to evaluate the potential of Montestrutto as a geosite. The detailed study consisted of the quantitative analysis of five routes of varying degrees of difficulty, which produced an interesting relationship among the level of difficulty of the routes and the geological and geomorphological features of the sport climbing wall. The Montestrutto cliff is considered to be a valuable geosite because of the scientific importance (e.g., representativeness, educational exemplarity and geohistorical importance) associated with its high cultural and socio-economic value and high potential for use. Sport climbing in sites such as Montestrutto, which are both scientifically significant and accessible, also in terms of the level of climbing difficulty, could be considered as a possible vehicle for stimulating public interest in the Earth Sciences.

RIASSUNTO

I siti di interesse geologico e geomorfologico, che sono stati individuati nell'arco alpino negli ultimi anni, sono numerosi e rappresentano la testimonianza della grande geodiversità che caratterizza questa catena montuosa. Alcune falesie di roccia, come in certi casi i siti per l'arrampicata sportiva, possono essere considerati siti di interesse geologico-geomorfologico (i.e., geositi e geomorfositi) perché caratterizzati da attributi come l'importanza geostorica e l'esemplarità didattica, che determinano il valore scientifico del sito, e anche da un significativo valore culturale e da una buona accessibilità. Inoltre la progressione lungo le pareti di arrampicata è strettamente connessa con gli aspetti geologico-geomorfologici della parete, un elemento che può aiutare per trovare un punto di contatto con il popolo dei climbers.

Una ricerca è stata condotta presso la falesia di arrampicata di Montestrutto (Piemonte, Italia), situata nel Complesso dei Micascisti Eclogitici del Dominio Austroalpino (Zona Sesia-Lanzo), nelle Alpi Occidentali, al fine di i) ricostruire gli stadi deformativi a scala locale lungo la falesia di arrampicata selezionata e nelle aree limitrofe; ii) analizzare l'associazione tra gli elementi geologici e gli elementi utili per la progressione verticale per mettere in evidenzia la connessione esistente tra geologia, morfologia della parete e grado di difficoltà degli itinerari di salita, e infine, iii) valutare la potenzialità di Montestrutto in termini di geosito. Più in dettaglio l'analisi di cinque itinerari di diverso grado di difficoltà sportiva ha evidenziato una stretta corrispondenza tra la difficoltà degli itinerari stessi e le caratteristiche geologiche e geomorfologiche della falesia. La falesia di Montestrutto ha ottenuto alti valori come sito di interesse geologico-geomorfologico in termini di importanza scientifica (e.g., rappresentatività, esemplarità didattica, importanza geostorica) ed è caratterizzata da alti valori culturali e socio-economici ed anche da un alto potenziale di utilizzo. L'arrampicata sportiva può essere considerata come un possibile veicolo per attrarre un pubblico verso la divulgazione delle Scienze della Terra che a Montestrutto sembra un obiettivo possibile in virtù sia dell'importanza scientifica che della buona accessibilità anche in termini di difficoltà degli itinerari sportivi.

Parole chiave: siti di interesse geologico-geomorfologico, geologia strutturale, Zona Sesia-Lanzo, arrampicata sportiva.

INTRODUCTION

The Alps are one of the most studied mountain ranges and possess varied and complex lithological and structural features. Some of these features are fairly accessible for scientific as well as cultural, touristic and educational purposes. The geomorphological features of the Alpine environment exhibit spatially heterogeneous morphogenetic and morphoclimatic factors and vary in time because of climatic changes (PELFINI *et alii*, 2009). There are numerous records of both current and past climatic and geological conditions of the Alpine region. Thus, geoheritage studies in recent years have primarily focused on geological and geomorphological features to select the most representative sites for understanding the Earth's evolution (i.e., *geosites,* sensu GRANDGIRARD, 1999). Recently, attention has been primarily been directed towards *geomorphosites*, which are classified with a category of geosites that is defined as "a landform to which a value can be attributed" that represents "a geomorphological resource if it can be used by society" (sensu PANIZZA, 2001). Numerous methodologies have been developed to evaluate and select sites of geomorphological interest (e.g., REYNARD *et alii*, 2007; PEREIRA & PEREIRA, 2010; BOLLATI *et alii*, 2012) using criteria that are based on the final selection goal (e.g., cultural, educational or scientific valorisation).

Cliffs (e.g., rock cliffs and ice cliffs) have already been defined as geosites for their exemplarity (e.g., Rocca del Montone, Sangonetto Valley; PROVINCIA DI TORINO, 2004), but a new approach can be used for rock cliffs and rock walls that are suitable for sport climbing. These geological and geomorphological locations may have attributes that make them worthy of consideration as geosites or geomorphosites and that may influence the use of the sites for valorisation, promotion and education (e.g., BOLLATI *et alii*, 2013). Sport climbing is practised throughout the Alps and has been increasingly attracting attention since the 1980s (MORGAN, 1998). There are several reasons why these climbing sites could be considered as sites of geological interest.

Climbing walls are ideal locations for studying lithologies and structures because they are maintained for sport climbing use and therefore usually have wide outcrops that are free from vegetation. This condition is important for both scientific and educational purposes. A vast amount of geological and geomorphological information has become available for studies in Earth Sciences (i.e., *geohistorical importance*; BOLLATI *et alii*, 2012; see the criteria adopted for this study in table 1). In addition to their scientific value, sport climbing sites also have significant *aesthetic* and *cultural* attributes (sensu BOLLATI *et alii*, 2012; tab. 1). From an aesthetic perspective, sport climbing sites, such as the famous Mello Valley or the Greek site of Meteora, are unequivocally magnificent. The latter site is also valuable in encompassing geology, sport and cultural elements: its sandstones and conglomerate towers provide an important site for both orthodox worship and sport climbing. In addition, some sites are considered to be the birthplaces of the current climbing culture, whose evolution during the 20th century has been deeply influenced by the typology of available rocks and the resulting micro and macro landforms. The *cultural value* of erratic blocks, used for climbing too (i.e. bouldering), is enhanced also in literature (MOTTA & MOTTA, 2007). Growing interest in this sport has resulted in the most popular sport climbing areas planning for service areas (e.g., restoration huts, campsites). In general, sport climbing may be an ideal vehicle for information dissemination (i.e., *potential for use*; sensu BOLLATI *et alii*, 2012; tab. 1) because the different styles of routes and difficulty levels generally depend on lithology, structures, and especially in the Alpine environment, on the geomorphological processes responsible for bedrock modelling. The rock cliffs and rock walls used for sport climbing can serve to “translate” the geological structures into educational tools. While it is important to select the most suitable sites that can foster an interest in learning, it is equally important to find “effective” points of contact between potential educational targets and geological and geomorphological subjects.

The term *geo-diversity* (sensu GRAY, 2004; table 1) is reflected in *climbing diversity* i.e., different levels of difficulty in climbing. The wide lithological and structural variety of climbing areas in Italy around both the Alps and the Apennines makes it possible to find a representative sport climbing site for several geological and geomorphological conditions. Sedimentary, magmatic and metamorphic rocks are found in equipped sport climbing walls with varying grades and styles of climbing.

Recently, climbing walls that serve as touristic resources have been studied. Methodologies to assess the potential of sport climbing walls primarily for sport purposes have recently been developed (MOTTA & MOTTA, 2005). In particular, MOTTA & MOTTA (2005) developed the "Tourist-Sports Potentiality Index" (IPTS) as an objective estimate of the potential of a site for sport climbing.

There may be a very high vulnerability component in touristic contexts in which human beings come into direct contact with a dynamic environment. Thus, the assessment of geomorphological hazards along climbing walls has become a subject of research (e.g., JORDAN, 1996; PANIZZA & MENNELLA, 2007; MOTTA *et alii*, 2009). These hazards combined with high vulnerability may result in critical risk scenarios (BRANDOLINI *et alii*, 2004; 2006).

The primary purpose of the present study is to evaluate a representative site in the Western Italian Alps, Montestrutto, as a potential geosite in terms of its scientific value as a structural "hot-spot" in the Austroalpine Domain. The goals of the study are given below.

i) Reconstruction of the deformation stages along a selected sport climbing wall and in the surrounding areas at a local scale by individuating ductile and fragile structures and landforms derived from different metamorphism stages and glacial modelling

ii) To associate geological elements with the physical elements required by climbers for vertical progression to strengthen the links between geology s.s., morphology and the grades of the routes

iii) To use available data to evaluate Montestrutto as a potential site of geological and geomorphological interest for information dissemination and educational purposes

THE STUDY AREA

The selected site is “La Turna”, a sport climbing location in Montestrutto (Piemonte, Italy; fig. 1a). La Turna is easily accessible by car, famous among climbing communities, highly frequented and situated in an area dense with sport climbing walls. New climbing routes are continuously being added to this sport climbing site: the first phase of the installation of fixed anchors was completed in 2009 when the tourist area and the first ten sectors were opened to the public, and five additional sectors were equipped for sport climbing in 2012 (fig. 1c) (PREDAN, 2012). Montestrutto is a site with a geomorphological relief that was primarily formed by the Balteo Glacier in the Eclogitic Micaschist Complex of the Sesia-Lanzo Zone and derives its name from its role as an obstruction (i.e., Mons Obstructus) along the Dora Baltea Valley. The selected region also includes several cultural elements (e.g., vineyard terraces, Via Francigena, and Montestrutto Castle; see fig. 1b) that were influenced by the presence and aspect of the geomorphological elements.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The Sesia-Lanzo Zone (SLZ) is a 100 km-wide portion of the Austroalpine domain, formerly the African plate, of the Western Italian Alps, which underwent subduction-related metamorphism before the onset of the Alpine collision between the European and African continental plates (e.g., BABIST *et alii*, 2006; COMPAGNONI *et alii*, 1977; DAL PIAZ *et alii*, 1972; MEDA *et alii*, 2010; POGNANTE, 1991; RODA *et alii*, 2012; ZUCALI & SPALLA, 2011).

The SLZ is composed of four main tectono-metamorphic units (fig. 2), which can be classified in terms of their lithostratigraphy, structural features and metamorphic evolution (ZUCALI & SPALLA, 2011): i) the Eclogitic Micaschists Complex (EMC) can be considered to be the most important unit in terms of the extent of its area (fig. 2) and consists of pre-Alpine metapelite, metabasite, marble and Permian intrusive rock (DELLEANI *et alii*, 2013; ZUCALI, 2011) that were deeply transformed during the evolution of the alpine eclogite facies; ii) the Gneiss Minuti Complex (GMC) reflects a high-pressure, low-temperature metamorphism of Alpine age that is commonly found as relict within a more pervasive green-schist facies metamorphic imprint and fabric; iii) the

II Zona Dioritico-Kinzigitica (IIDK) is a relict of the pre-Alpine continental crust that mostly escaped the Alpine high-pressure re-equilibration; and iv) the Rocca Canavese Thrust Sheet (RCT) experienced a high-pressure imprint under eclogite facies conditions but has been pervasively replaced by a blue schist imprint that is associated with a penetrative, km-scale, mylonitic foliation (ZUCALI *et alii*, 2012) consisting of rock fragments of contrasting provenance, such as mantle-derived gabbro, serpentinite and crustal orthogneiss.

The age of the Alpine eclogitic metamorphic evolution of the SLZ has been dated as Late Cretaceous-Early Palaeocene and ranges from 53–85 Ma (INGER, 1996; RUFFET, 1997; DUCHENE *et alii*, 1997; RUBATTO *et alii*, 1999; 2011). During the early-Alpine HP, the P-T conditions ranged from 500–625°C and 1.3–2.5 GPa (RODA *et alii*, 2012, and references therein). The EMC protoliths consist of high-grade paragneisses, granulites, amphibolites, minor marbles, quartzites, country rocks of Permian granitoids, and gabbros (BUSSY *et alii*, 1998; CALLEGARI *et alii*, 1976; CENKI-TOK *et alii*, 2011; COMPAGNONI *et alii*, 1977; OBERHAENSLI *et alii*, 1985; ZUCALI, 2011).

The aforementioned area belongs to the EMC, which has a deformation history that consists of various numbers of different Alpine deformational phases (e.g., BABIST *et alii*, 2006) because of large-scale heterogeneous strain partitioning. In general, these phases are characterised by folds and foliation that are associated with high-pressure mineral assemblages (eclogite facies minerals) and with blueschist- to greenschist-facies assemblages, of which the latter have been commonly recorded during retrograde evolution (ZUCALI *et alii*, 2002; ZUCALI, 2002; ZUCALI & SPALLA, 2011).

The cliff is located on the alluvial plain of the Dora Baltea River (fig. 3a), a few km before the outlet of the river into the Po Plain. Aosta Valley, which extends as far as the area that is currently occupied by the Ivrea Morainic Amphitheatre (IA) (GIANOTTI *et alii*, 2008) (fig. 3b), was formed by the ancient Balteo Glacier that underwent different pulsations that produced the different portions of the IA and have been recorded all along the Aosta Valley. GIANOTTI *et alii* (2008) identified the halts of the retreat phases of the Balteo Glacier from the Po Plain into the Dora Baltea Valley area in which the Montestrutto cliff is located. During the Pavone Stadial, which has been dated to 20.8±1.5 ka, the Montestrutto spur was completely covered by the Balteo Glacier (FORNO *et alii*, 2010), as evidenced by its classic roche moutonnée morphology with traces of subglacial formations on the top of the spur. By the time of the Germano Stadial (17.4±2.6 ka, GIANOTTI *et alii*, 2008; fig. 3a), morainic evidence of which is located approximately 15 km towards Ivrea, the Balteo Glacier had definitively left the IA area and retreated into the Dora Baltea Valley. At Torredaniele (fig. 3a), GIANOTTI *et alii* (2008) identified one of the LGM–Late Glacial stadials (fig. 3b) dating back to the glacial retreat between the Torredaniele Stadial and the Bard Stadial to the time between 14.6±1.2 ka and 14.0±0.9 ka.

The rock cliff is located down-valley from the 90° deviation of the Dora Baltea River, whose course was modified by the emergence of the resistant micaschist spur that was abraded by the glacier on which the Montestrutto Castle was strategically built (figs. 3a and 1a).

METHODS

RECONSTRUCTION OF DEFORMATIONAL PHASES IN THE EMC IN THE MONTESTRUTTO AREA

A geological survey of the "La Turna" sport climbing wall was undertaken and extended into the surrounding area to place the rock cliff within the geological context of the Sesia-Lanzo Zone. During the survey, approximately 30 rock samples were collected from different outcrops and qualitatively and quantitatively analysed. Geological structures (e.g., foliations, mineral lineations, axial planes and fractures) were identified, photographed and measured, and the main deformational phases were individuated. Geomorphological features (e.g., micro-reliefs resulting from differential weathering and glacial striae) resulting from surface modelling were also analysed.

Finally, a geological map based on the Piemonte CTR 1:10,000 was produced, showing the structures and their relative chronology and metamorphic conditions. The map was digitised and integrated with information from other maps.

ANALYSIS OF SPORT CLIMBING ROUTES

In phase “b”, fundamental information on the rock cliff structural evolution was collected to identify the most appropriate routes that could be used to correlate sport climbing with the geological structures. The selection was made using two criteria. First, the routes had to be geologically significant, i.e., the structures identified during the geological survey had to be extant and easily distinguishable on the wall. Second, medium- to low-grade routes were selected to facilitate access to the geo-information by a wide audience.

Five sport climbing routes in both the old and the newly equipped sectors of the La Turna sport climbing wall were chosen for detailed analysis. The grades are ranked using the French sport climbing rating system and are reported in the official sport climbing guide for the area (PREDAN, 2012).

First, the sport climbing routes were photographed as closely as possible. The distance at which the route was photographed depended on both the wall size and its position; thus, short and low-elevation routes were captured from approximately 3 m away, whereas longer and higher routes were captured from approximately 10 m away. Hence, the necessary sport climbing elements for progression were easily recognisable. Nine climbers were observed during their vertical progression along the selected routes, and several sport climbing elements and sport climbing styles were precisely marked on the printed photos (fig. 4). In particular, all of the observed sport climbing elements were identified and classified according to their typology (i.e., footholds or handholds) and climbing style (i.e., technical progression on rock lists, progression along cracks, and grip progression) following the sport climbing handbook (e.g., ANTONIOLI, 1996; LUEBBEN, 2004).

CORRELATION BETWEEN GEOLOGICAL AND CLIMBING ELEMENTS

In this synthesis stage, tracing paper was used to combine the geological, geomorphological and sport climbing elements that were surveyed in the previous phases. Each hold was associated with its related geological or geomorphological feature (e.g., lithological contrast and structure). A table was compiled to summarise all of the collected data, which were sorted by the type of hold (footholds or handholds), the size of the hold, the technique for using the hold, notes about style and related geological features.

The purpose of this categorisation was to determine which geological and geomorphological elements and deformational phases played the most significant role in the formation of the holds.

ANALYSIS OF ATTRIBUTES OF A SITE OF GEOLOGICAL AND GEOMORPHOLOGICAL INTEREST

The study site was evaluated to quantify the attributes usually used in the selection of geomorphosites. The attributes (i.e., *scientific* and *additional values* and *potential for use*; tab. 1) were evaluated following BOLLATI *et alii* (2012). The original methodology includes the geological s.s. attributes in the assessment; however, modifications were introduced to weight the geological s.s. and the geomorphological features equally. Thus, the degree of *representativeness* of these two characteristics was evaluated separately. The features related to *accessibility* on foot, which was developed by BOLLATI *et alii* (2012), were not reported because these features are used to assess touristic paths on natural ground and are therefore not relevant in this case. All of the parameters used in the quantitative evaluation are reported in table 1.

RESULTS

RECONSTRUCTION OF DEFORMATIONAL PHASES IN THE EMC IN THE MONTESTRUTTO AREA

The D1 and D2 deformations cause the development of isoclinal folding that is associated with axial plane foliations and the extensive transposition of lithological boundaries. The S1 and S2 foliations are marked by eclogite facies minerals, such as phengitic mica, omphacite, garnet, rutile, zoisite and quartz in metapelites and omphacite and glaucophane in eclogite boudins. The D1 and D2 orientations are shown in fig. 5, where a gentle girdle distribution can be observed that most likely resulted from a large-scale folding event associated with the D3 deformation (ZUCALI & SPALLA, 2011). D3 is also accompanied by a widespread re-equilibration under blueschist-facies, and it is commonly localised along metric mylonitic shear zones (fig. 5). D4 is associated with ductile-brittle faults (F4) and fractures (K4), whose features and orientations are shown in fig. 5.

ANALYSIS OF SPORT CLIMBING ROUTES

Five routes were selected for analysis: “Carboncella” (5c), “Moresca” (6a+) and “Sant’Agostino” (4a; fig. 4b) in the recently opened sector La Sass Est (fig. 1b, d), and “Vezzosa” (6a+) and “Picche” (5a; fig. 4a) in the western sector, Carnevale (fig. 1b, c).

The difference in the grades for Vezzosa and Picche can be observed at first sight. Overall, on both these routes, 48 holds were individuated. They required a different progression style (see the table in fig. 6). A threshold value of 2 cm delineates the point at which holding requires the use of fingers with different techniques, thereby affecting the difficulty of the progression.

Vezzosa (6a+) is a more technical route with several smaller holds consisting mostly of lists and slightly open fractures (i.e., which are technically known as blind cracks) for both hands and feet. The larger features of the Picche route (i.e., 10 in fig. 6) can only be used for local progression on the right side of the route. The steepness of the wall diminishes in the upper part of both routes, and a grip progression technique is required.

The routes are also graded differently in the La Sass Est sector. The Sant’Agostino route (4a) is easy and is initially characterised by grip progression followed by a low inclined platy section on which small lists and flakes are present. The route then becomes vertical with fractures and horizontal lists. In contrast, Moresca (6a+) is considered to be a more difficult route because the cracks are rounded and blind and thus there are no obvious handholds. Carboncella (5c) first develops vertically and then along an oblique dihedral and an open fracture, and finally, where the steepness of the wall diminishes, a grip progression is required once again.

CORRELATION BETWEEN GEOLOGICAL AND SPORT CLIMBING ELEMENTS

The elements that facilitate progression are clearly related to those resulting from the geological setting and the geomorphological modelling of the cliff. Fig. 6 provides an example of the results of the analysis.

Note that the start of the Picche route is facilitated by the presence of a basal step (i.e., 3; fig. 6), which is a kinematic indicator that originates from faulting and is classified as a brittle deformational phase D4. Progression along the entire route occurs primarily along the brittle deformation features, especially the oblique, open fractures (e.g., 10, 23, 25–27; fig. 6). Thus, the D4 phase generally has the greatest influence on progression. D1 also influences progression, especially in terms of the eclogite boudins that derive from the D1 deformational phase. As noted above, differential weathering resulting from the different chemical compositions of these elements causes the formation of localised discontinuities at the contact between the micaschist and the boudins (e.g., 24, 29, 31–33; fig. 6). The climber perceives the S1 foliation, which is referred to as the D1 deformational phase, as micro-holds for hands and feet, mostly along 6a+ and especially when micro-fracturing is present.

The decrease in steepness, which results primarily from glacial modelling of the wall, allows for a grip progression in the upper part of the routes (e.g., 37, 38, 42, 44–47; fig. 6).

The three investigated routes in the La Sass Est sector contain the D2 deformational phase that produces isoclinal folds of the S1 foliations and the lithological boundary between the micaschist and the gneiss that are absent in the first sector. Both lithotypes are well-exposed and characterised by different relief features. The Sant'Agostino route (4a) passes through the hinge of the folding, where the deformation is greater than that along the flank, a feature that influenced the superficial modelling. The list corresponds in part to the S1 as well as to the slight crenulation observed in the hinge, which is most likely associated with D3. In the lower part, the thick gneissic level is characterised by exfoliation and a rounded morphology, and progression is aided by the presence of a saw-tooth quartz vein. The central portion of the Moresca route (6a+) that passes through the hinge area with crenulation features is easier and allows the climber to rest before continuing on to the more difficult section along the flank above. The percentage of each route passing through the hinge area affects the difficulty level of the route. Moreover, the D4 fractures in the upper gneissic part are rounded and less useful than those developing on the right in the micaschist level. The Carboncella route (5c) starts on small holds, and quartz holes can be used to overcome this section. The climber then proceeds along an open fracture, and in the final section, once again, the rounded morphology of the gneiss allows only for a grip progression. Very visible glacial striae are present on the upper part of both the 6a+ and the 5c routes but only on the vertical part of the wall and thus do not aid in progression in any way.

ANALYSIS OF ATTRIBUTES OF A SITE OF INTEREST FOR GEOLOGICAL AND GEOMORPHOLOGICAL PURPOSES

After collecting information on the structural and climbing elements along the cliff, the site was evaluated numerically to quantify the fundamental attributes used to define the site as a geosite. The numerical evaluation is given in table 2.

We discuss the analysed features in more detail below.

i. *Scientific value:* The site was given high ratings for *geological* (1/1) and *geomorphological representativeness* (1/1) and *educational exemplarity* (1/1) because structural and geomorphological features were clearly evident. The lithologies and structures are well-exposed and detectable (fig. 7) from the micro- (i.e., minerals) to the macro- (i.e., outcrop) scale. From a geomorphological perspective, the micaschist spur corresponds to a classic roche moutonnée (figs. 8a and b) and shows evidence of glacial erosion (subglacial potholes and glacial striae; figs. 6c and d) from Balteo Glacier modelling. The morphology of the cliff is dominated by conjugated fracture systems (figs. 8a and e), which have an orthogonal orientation that influences the current morphology of the area (GHISELLI *et alii*, 2005). Slope deposits are present at the foot of the largest fractures, (fig. 8a), which have resulted in isolated pinnacles that are prone to rock-falling; therefore, the local administration has made specific and periodic interventions to stabilise these pinnacles to reduce risk scenarios. Differential weathering is apparent, especially with respect to the eclogite boudins that confer different roughness grades to the sport climbing wall sections. The exfoliation process is also visible, especially at the outcrop of the gneiss layers. Maximum values were also attributed to the *integrity* (1/1) and *rarity* (1/1) features. With regard to rarity, other outcrops of the same lithology and with the same regional meaning exist; however, the accessibility, the quality of the outcrop and the spatial extension of this site have resulted in visits and studies by many researchers. Hence, the site is also relevant in terms of its *geohistorical importance* (1/1) at the Alpine chain level because of the outcropping of lithotypes, which show in the HP metamorphism that is typical of subduction areas that have been studied in detail. The *scientific value* was ranked 7.67 out of 9.

ii. *Additional value:* The natural site is enriched by the presence of valuable cultural elements associated with the Via Francigena, a pilgrimage path that runs along the Dora Baltea River. The *cultural value* (1/1) is first increased by the presence of a castle that is located strategically on the spur, close to the sport climbing wall that obstructs access to the Aosta Valley. The SE sectors of the sport climbing wall also develop side by side with a series of recently restored olive terraces that date back to the 18th–19th centuries. The site has *socio-economic value* (1/1) because the developed area along the Via Francingena crosses Europe from Rome to Canterbury and is a well-developed touristic path. Despite its large width, the wall has no *aesthetic value*, resulting in an *additional value* score of 2 out of 3. The additional and scientific values are summed to produce the *global value* of 9.67 out of 12.

iii. *Potential for use:* The sport climbing area is easily accessible, i.e., the site has *primary accessibility* (1/1) and *services* (1/1), along with *sport activities* (1/1) that are directly related to the geologic-geomorphological elements and are available to climbers of different ages and experience levels (which confers *secondary accessibility* onto the site). A refreshment hut and an information point are also on site. There are also different cultural initiatives associated with the present cultural heritage in the area (*use of additional interests*; 1/1). The most important site in the category of the *presence of other sites of interest in the surroundings* (1/1) is the Ivrea Serra, which is evolutionarily linked to the Montestrutto spur by the glacial action of the Balteo Glacier and is included in the National Geosites Database of ISPRA. The *potential for use* ranks 11.5 out of 13 because the *Index of use* includes parameters of scientific value (*educational exemplarity, aesthetic value* and *spatial accessibility*) and provides a rapid indication of potential site use by tourists.

The *global value* and the *potential for use* are added to produce a total score for the Montestrutto geosite of 21.17 out of 25. The *Scientific Index* has a high value (0.89/1), whereas the *Educational Index* (0.66/1) has a lower value because of the effect of the aesthetic parameter (see table 2).

DISCUSSION

The Montestrutto site was first analysed from a structural point of view, followed by correlating the structure with the climbing progressions, and finally, available data were used to evaluate the site as a geosite: these analyses established the clear potential for the area to serve as a site of geological and geomorphological interest. The acquisition of scientific data enabled the spatial distribution of the features to be better defined. The wide *spatial extension* of this sport climbing wall was important for illustrating the different deformational phases that are heterogeneously distributed all around the cliff. Hence, the structural survey was necessary at this level because each element that is useful for the climber's progression was associated with a defined structural element (i.e., *sport activities* were classified within the *potential for use*). In addition, the site has a high *potential for use* for people who climb or would like to try climbing because the site is easily accessible (i.e., corresponding to the *primary accessibility* of the site) and is characterised by heterogeneous climbing grades that allow both beginners and experts to acquire scientific information (i.e., corresponding to *secondary accessibility*). Moreover, *spatial accessibility* was one of the attributes used to calculate the *Educational Index* (see table 2). Finally, the typically irrelevant *aesthetic value* should be reconsidered from the climber's perspective, for whom aesthetics is generally defined in terms of the "beauty of the climbing routes". In the jargon of climbers, a route may be considered as "aesthetic" because of climbing movements and the quality of the rocks. Such an interpretation may make the site more attractive and increasing its *Educational Index* value.

All of these positive results indicate that the on-site information point may be used as a geo-station for educational activities to develop the geological and geomorphological interest of the site. These types of activities are already on-going and involve other sport activities that could be combined with geo-climbing.

This positive assessment from a geosite perspective may appear to contrast with the evaluation resulting from the methodology developed by MOTTA and MOTTA (2005). Nevertheless, the current assessment has been used to determine the "Tourist-Sports Potentiality Index" (IPTS), which is useful for quantitatively evaluating the site from a sport perspective. In terms of sport climbing only, the IPTS for the Monestrutto site is decreased by the low suitability of this type of rock, the windy climate and the position of the site near the road. Nonetheless, the site is highly frequented. However, aspects that are considered undesirable for the purposes of sport, such as the vicinity of other sport climbing walls, are positive attributes for disseminating information about the Earth Sciences: for example, a network of geo-climbing walls could be created.

The surveyed features show that the Montestrutto area is a potential site for educational field activities (*Educational Index*: 0.66/1) that focus on direct experimentation on the geological and geomorphological features of the landscape: these educational activities are considered to be powerful tools for obtaining good results (DAVIS, 2002; BOLLATI *et alii*, 2011; GARAVAGLIA & PELFINI, 2011; HINTZ & THOMPSON, 2012). In fact, field work, field trips and outdoor lessons have been recognised as important educational tools, especially for the dissemination of information about the Earth Sciences (DAVIS, 2002; BOYLE *et alii*, 2007). Practical experience allows people to develop their abilities to observe the landscape (GOLLEDGE, 2002; LEWIS, 2007), to get in touch with their environmental responses (e.g., SERRANO *et alii*, 2011; BOLLATI *et alii*, 2011) to factors such as global climate change (GARAVAGLIA & PELFINI, 2011) and to be involved in active learning (DAY, 2012), and outdoor activities can serve as vehicles for enhancing learning (JARRETT and BORNLEY, 2010). Finally, sport climbing is an attractive discipline for all ages, which is an aspect that may also enable its application to other fields of research (e.g., EWERT, 1990; SUTHERLAND & STROOT, 2010).

CONCLUDING REMARKS

A scientific field survey was conducted in the Montestrutto area for geo-data collection as a starting point for developing the role of geo-features in the vertical progression of climbers and the value of Montestrutto as a geosite. The results show that the site has a high *scientific value* and include the educational attributes and the *potential for use* of the site, among other attributes. This finding demonstrates that sport climbing is a powerful means of disseminating complex scientific information (e.g., conditions for rock formation, types of deformation, surface modelling and geological time) because the sport is intimately connected with and dependent on rock structures and involves different senses. The different progression grades may be compared to the different difficulties of geo-topics to associate *sport activities* with geological information.

Interest in geological topics and their relation to sport climbing is reflected in the large number of thematic organised meetings, for example, meetings of alpinism groups in Italy, such as the CAI (Italian Alpine Club), and in associated literature, such as books (ANTONIOLI, 1996; GARLICK, 2009) and magazines (e.g., GAROFANO & ROCCATI, 2002). However, no previous studies have explicitly considered teaching the Earth Sciences through sport climbing.

The results presented here, together with the documented importance of field work as an educational tool, demonstrate the potential of using climbing sites as an open laboratory for the Earth Sciences. Obviously, it is important to consider the legal management of sport climbing walls in different countries, the regulation of scholar and student field activities and the legal role of mountain guides. In a “critical” touristic context such as Montestrutto (BRANDOLINI *et alii*, 2006), tourists’ experience of climbing and the dynamicity of the natural environment could become educational opportunities (BOLLATI *et alii*, 2013).

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REFERENCES

ANTONIOLI F. (1996) – Arrampicata libera. Muoversi con sicurezza in parete con 100 esercizi progressivi. Arnoldo Mondadori, Milano.

BABIST, J., HANDY M.R., KONRAD-SHMOLKE M. & HAMMERSCHMIDT K. (2006) - *Precollisional, multistage exhumation of subducted continental crust: The Sesia Zone, Western Alps*. Tectonics, **25**, 1-25.

BOLLATI I., PELFINI M., PELLEGRINI L., BAZZI A. & DUCI G. (2011) - *Active geomorphosites and educational application: an itinerary along Trebbia River (Northern Apennines, Italy)*. In: REYNARD E., LAIGRE L. & KRAMAR N. (Eds), Les géosciences au service de la société. Actes du colloque en l'honneur du Professeur Michel Marthaler,. Lausanne, 24-25 Giugno 2010, Lausanne: Institut de Géographie de l'Université de Lausanne, Géovision, **37**, 219-234.

BOLLATI I., PELFINI M. & PELLEGRINI L. (2012) - *A geomorphosites selection method for educational purposes: a case study in Trebbia Valley (Emilia Romagna, Italy)*. Geogr. Fis. Din. Quat., **35**, 23-35.

BOLLATI I., SMIRAGLIA C. & PELFINI M. (2013) - *Assessment and Selection of Geomorphosites and Trails in the Miage Glacier Area (Western Italian Alps)*. Environ. Manage., **51** (4), 951-967, doi: 10.1007/s00267-012-9995-2.

BOYLE A.P., MAGUIRE S., MARTIN A., MILSOM C., NASH R., RAWLINSON S., TURNER A., WURTHMANN S. & CONCHIE S. (2007) - *Fieldwork is good: the student perception and the affective domain*. J. Geogr. Higher. Educ., **31** (2), 299-317.

BRANDOLINI P., MOTTA M., PAMBIANCHI G., PELFINI M. & PICCAZZO M. (2004) - *How to assess geomorphological risk in tourist areas*. 32nd International Geological Congress, Florence, 1, 29.

BRANDOLINI P., FACCINI F., PICCAZZO M. (2006) - *Geomorphological hazard and tourist vulnerability along Portofino Park trails (Italy)*. Nat. Hazard Earth Sys., **6**, 1-8.

BUSSY F., VENTURINI G., HUNZIKER J. & MARTINOTTI G. (1998) - *U-Pb ages of magmatic rocks of the western Austroalpine Dent-Blanche-Sesia Unit*: Schweiz. Miner. Petrog., **78**, 163-168.

CALLEGARI E., COMPAGNONI R., DAL PIAZ G. V., FRISATTO V., GOSSO G. & LOMBARDO B. (1976) - *Nuovi affioramenti di metagranitoidi nella zona Sesia-Lanzo.* Rend. Soc. It. Miner. Petrol., **32**, 97-111.

CANADIAN LANDFORM INVENTORY PROJECT (2012) - http://libwiki.mcmaster.ca/clip/index.php/Main/HomePage.

CENKI-TOK B., OLIOT E., RUBATTO D., BERGER A., ENGI M., JANOTS E., THOMSEN T. B., MANZOTTI P., REGIS D. & SPANDLER C. (2011) - *Preservation of Permian allanite within an Alpine eclogite facies shear zone at Mt Mucrone, Italy: Mechanical and chemical behavior of allanite during mylonitization*. Lithos, **125**, 40-50.

COMPAGNONI R., DAL PIAZ G.V., HUNZIKER J.C., GOSSO G., LOMBARDO B. & WILLIAMS P.F. (1977) – *The Sesia-Lanzo Zone, a slice of continental crust with alpine high pressure- low temperature assemblages in the Western Italian Alps*. Rend. Soc. Ital. Miner. Petrol., **33** (1), 281-334.

DAL PIAZ G.V., HUNZIKER J.C. & MARTINOTTI G. (1972) - *La Zona Sesia e Lanzo e l'evoluzione tettonico-metamorfica delle Alpi Nordoccidentali interne*. Mem. Soc. Geol. Ital., **11**, 433-460.

DAY T. (2012) - *Undergraduate teaching and learning in physical geography*. Prog. Phys. Geog., **36** (3), 305-332.

DAVIS R.L. (2002) - *The value of teaching about geomorphology in non-traditional settings*. Geomorphology, **47**, 251-260.

DELLEANI F., SPALLA M. I., CASTELLI D., & GOSSO G. (2013) - *A new petro-structural map of the Monte Mucrone metagranitoids (Sesia-Lanzo Zone, Western Alps)*. Journal of Maps, **9** (3), 1-15.

DUCHENE S., BLICHERT T. J., LUAIS B., TELOUK P., LARDEAUX J. M. & ALBAREDE, F. (1997) - *The Lu-Hf dating of garnets and the ages of the Alpine high-pressure metamorphism.* Nature, **387**, 586-589.

EWERT A. (1990) - *Reducing levels of trait anxiety through the application of wilderness-based activities*. General Technical Report - Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, **193**, 105-111

FORNO M. G., GIANOTTI F. & RACCA G. (2010) - *Significato paleoclimatico dei rapporti tra il glacialismo principale e quello tributario nella bassa valle della Dora Baltea.* Ital J Quaternary Sci., **23** (1), 105-124.

GAROFANO M. & ROCCATI C. (2008) - *Arrampicata e litologia*. Rivista CAI, **2/2008**, 55-59.

GARAVAGLIA V. & PELFINI M. (2011) - *Glacial Geomorphosites and Related Landforms: A Proposal for a Dendrogeomorphological Approach and EducationalTrails*. Geoheritage, **3**, 15–25.

GHISELLI A., BINI A. & ZUCALI M. (2005) - Structural analysis of "roches moutonnees" in western Orobic Alps (Lombardia). Suppl. Geogr. Fis. Din. Quat., **7**, 163--177.

GARLICK S. (2009) – Flakes, jugs & Splitters. A rock climber's guide to geology. Falcon Guides, Guilford, Connecticut.

GIANOTTI F., FORNO M.G., , IVY -OCHSB S. & KUBIK P. W. (2008) - *New chronological and stratigraphical data on the Ivrea amphitheatre (Piedmont, NW Italy)*. Quatern. Int., **190**, 123–135.

GOLLEDGE RG (2002) - *The nature of geographic knowledge*. Ann. Assoc. Am. Geogr., **92** (1),1–14.

GRANDGIRARD V. (1999) - *L'évaluation des géotopes*. Geologia Insubrica, **4**, 59-66.

GRAY M. (2004) - Geodiversity, valuing and conserving abiotic nature. Wiley Ed., Chicester.

HINTZ R. & THOMSON B. (2012) - *Geoscience Education in the Boy Scouts of America*. J. Geoscience Educ., **60**, 159–167.

INGER S., RAMSBOTHAM W., CLIFF R. A. & REX D. C. (1996) - *Metamorphic evolution of the Sesia-Lanzo Zone, Western Alps: time constraints from multi-system geochronology*. Contrib. Mineral. Petrol., **126**, 152-168.

JARRETT O. S. & BURNLEY P. (2010) - *Lessons on the Role of Fun/Playfulness from a Geology Undergraduate Summer Research Program*, J. Geoscience Ed, **58** (2), 110-120.

JORDAN D. (1996) - *Risk management*. J. Phys. Ed. Recreation Dance, **67** (7), 29-35.

LEWIS A.R. (2007) - *Teaching glacial geomorphology in the field: linking fieldwork to global-scale scientific questions*. 2007 GSA Denver Annual Meeting, 28–31 October 2007, Denver, Colorado. Geol. Soc. Am. Abstr. Programs, **39** (6), 622

LUEBBEN C. (2004) - *Rock Climbing: Mastering Basic Skills*. Mountaineers Books, Seattle.

MEDA M., MAROTTA A.M., SPALLA M.I. (2010) - *The Role of Mantle Hydration in Continental Crust Recycling in the Wedge Region. Advances in Interpretation of Geological Processes*. Spec. Publ. Geol. Soc. London, **332**, 149-171.

MORGAN D. (1998) - *Up the wall: the impact of the development of climbing walls on British rock climbing*. In: COLLINS M. F. & COOPER I. S., Leisure management: issues and applications, 255-262.

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: TERRANOVA R., BRANDOLINI P., M. FIRPO (Eds), La valorizzazione turistica dello spazio fisico come via alla salvaguardia ambientale, Collana di Geografia e Organizzazione dello sviluppo territoriale, Studi Regionali e Monografici, **36**, Patron, Bologna, 263-278 pp.

MOTTA L. & MOTTA M. (2007) - *Erratic blocks: from protector beings to geosites to be protected*. In: PICCARDI L. & MASSE W. B. (Eds), Myth and Geology. Spec. Publ. Geol. Soc. London, **273**, 315–327.

MOTTA M., PANIZZA V., PECCI M. (2009) - *Geomorphological hazard assessment on natural rock wall for free climbing practice*. Mem. Descrittive Carta Geol. Ital., **87**, 109-122.

OBERHAENSLI R., HUNZIKER J.C., MARTINOTTI G. & STERN W.B. (1985) - *Geochemistry, geochronology and petrology of Monte Mucrone: an example of Eo-alpine eclogitization of Permian granitoids in the Sesia-Lanzo Zone, Western Alps, Italy*. Chem. Geol., **52**, 165–184.

PANIZZA M. (2001) - *Geomorphosites: concepts, methods and examples of geomorphological survey*. Chinese Sci. Bull., **46**, 4-6.

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

PELFINI M., DIOLAIUTI G. & SMIRAGLIA C. (2009) - *Geomorfositi glaciali e turismo: evoluzione,pericolosita` e rischi. Il caso del Ghiacciaio del Miage (Monte Bianco), Valle D'Aosta*. In: Coratza P. & Panizza M (eds), "Il patrimonio geomorfologico come risorsa per un turismo sostenibile", S.A.P. Ed., Mantova, 105–124.

PEREIRA, P. & PEREIRA (2010) - *Methodological guidelines for geomorphosite assessment*. Geomorphologié, **2**(2010), 215-222.

POGNANTE U. (1991) - *Petrological constraints on the eclogite- and blueschist-facies metamorphism and P-T-t paths in the Western Alps*. J. Metam. Geol., **9**, 5-17.

PREDAN G. (2012) – *Statale 26. Arrampicate su roccia nella Valle Dora Baltea Canavesana*. – Tip. Gianotti, Montalto Dora (TO).

PROVINCIA DI TORINO (2004) – *I geositi della Provincia diTorino* - 2 Vol., Litografia Geda, Nichelino, Torino.

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.

RODA M., SPALLA M. I. & MAROTTA A. M. (2012) - *Integration of natural data within a numerical model of ablative subduction: a possible interpretation for the Alpine dynamics of the Austroalpine crust.* J. Metamorph. Geol., **30**, 973–996.

RUBATTO D., GEBAUER D. & COMPAGNONI R. (1999) - *Dating of eclogite-facies zircons; the age of Alpine metamorphism in the Sesia-Lanzo Zone (Western Alps)*. Earth Planet. Sc. Lett., **167**, 141-158.

537 RUBATTO D., REGIS D., HERMANN J., BOSTON K., ENGI M., BELTRANDO M. & MCALPINE S. R. B. (2011) - *Yo-yo subduction recorded by accessory minerals in the Italian Western Alps, Nature*. Geoscience, **4**, 338-342.

540 RUFFET G., GRUAU G., BALLEVRE M., FERAUD G. & PHILIPPOT P. (1997) - *Rb-Sr and (super 40) Ar- (super 39) Ar laser probe dating of high-pressure phengites from the Sesia Zone (Western Alps); underscoring of excess argon and new age constraints on the high-pressure metamorphism*. Chem. Geol. , **141**, 1-18.

544 SERRANO E. ; JOSE J. & TRUEBA G. (2011) - *Environmental education and landscape leisure. Geotourist map and geomorphosites in the Picos de Europa National Park*. GeoJournal of Tourism and Geosites, **8** (2)**,** 295-308.

547 SUTHERLAND S. & STROOT S. (2010) - The Impact of Participation in an Inclusive Adventure Education Trip on Group Dynamics J. Leisure Res., **42** (1), 153-176.

549 ZUCALI M. (2002) - *Foliation map of the "Eclogitic Micaschists Complex" (Monte Mucrone – Monte Mars – Mombarone, Sesia-Lanzo Zone, Italy)*. Mem. Sc. Geol., **54**, 86-100.

551 ZUCALI M., SPALLA M. I. & GOSSO G. (2002) - *Strain Partitioning And Fabric Evolution As A Correlation Tool: The Example Of The Eclogitic Micaschists Complex In The Sesia-Lanzo Zone (Monte Mucrone – Monte Mars, Western Alps Italy)*. Schweiz. Miner. Petrog., **82**, 429-454.

554 ZUCALI M. & SPALLA M. I. (2011) - *Prograde Lawsonite During The Flow Of Continental Crust In The Alpine Subduction: Strain Vs. Metamorphism Partitioning, A Field-Analysis Approach To Infer Tectonometamorphic Evolutions (Sesia-Lanzo Zone, Western Italian Alps)*. J. Struct. Geol., **33**, 381-398.

558 ZUCALI, M., 2011. *Coronitic microstructures in patchy eclogitised continental crust: the Lago della Vecchia pre-Alpine metagranite (Sesia-Lanzo Zone, Western Italian Alps).* In: Forster M.A. & Fitz Gerald J.D.(eds.), "The Science of Microstructure - Part II, Journal of the Virtual Explorer", **38** (5). doi:10.3809/jvirtex.2011.00286.

562 ZUCALI, M., CANTÙ, M., & SPALLA, M. I. (2012) - Contrasting tectonometamorphic evolutions in the southern Sesia-Lanzo Zone (Rocca Canavese Thrust Sheets, Western Austroalpine domain) inferred by multiscale structural analysis: Rendiconti online della Società Geologica Italiana, v. 22, p. 247-250.

FIGURE CAPTIONS

Fig. 1 – La Turna sport climbing area. a) Geographic location in the Northern Italy; b) Frangivento sector, one of the area where the analysis have been focused on; c) Sketch of all the sectors of the La Turna sport climbing area,; d) Carnevale sector, one of the area where the analysis have been focused on. b, c, d are modified from PREDAN (2012).

Fig. 2 – Subdivision of the Sesia-Lanzo Zone modified from ZUCALI & SPALLA (2011).

Fig. 3 – Maps of the area in which the "La Turna" sport climbing wall is located. a) Detail of the Montestrutto area; b) Geomorphological sketch map modified from GIANOTTI *et alii* (2008) where the position of the Torredaniele Stadial is indicated by the black arch crossing the Dora Baltea River.

Fig. 4 – Observation of climbers during their progression on the selected sport climbing routes: Picche (a) and Sant'Agostino (b). Observation of their movements has provided information about used holds and climbing style, indicated with symbols in the pictures.

Fig. 5 - Features and orientations of main structural elements. A) S1 foliation wrapping eclogite boudins; B) S2 foliation marked by glaucophane, white mica and quartz deflecting the S1 foliation defined by omphacite and glaucophane; C) D3 shear zone; D) D4 fractures at metre-scale; E) D4 fractures at sport climbing scale; F, G, H) Stereographic projections of the main structural elements.

Fig. 6 – Example of synthesis of analysis on holds along the routes Vezzosa and Picche in the Carneval sector emphasizing the correspondence between the outcrop features and vertical

progression. The individuated holds, observing climbers in progression, are indicated in red. In particular, the striped areas are characterized by grip progression.

Fig. 7 - Examples of the eclogite boudins, that are easy detectable mainly for the different colour and roughness (a, b). Also the most abundant minerals are visible (c, omphacite; d, quartz and fengite) that can be considered meaningful also from a scenic point of view.

Fig.8 – Panoramic view of the Montestrutto spur. The sport climbing wall develops on the right flank of the roche moutonnée (a). b) Sketch of a roche moutonnée modified from Canadian Landform Inventory Project (2012), that similarly reproduces Montestrutto geomorphological setting. c) Evidences of glacial modelling: subglacial potholes on the upper surface; d) glacial striae on one of the examined sport climbing routes; e) conjugated fractures systems on the upper surface of the spur. Photo by I. Bollati.

TABLE 1

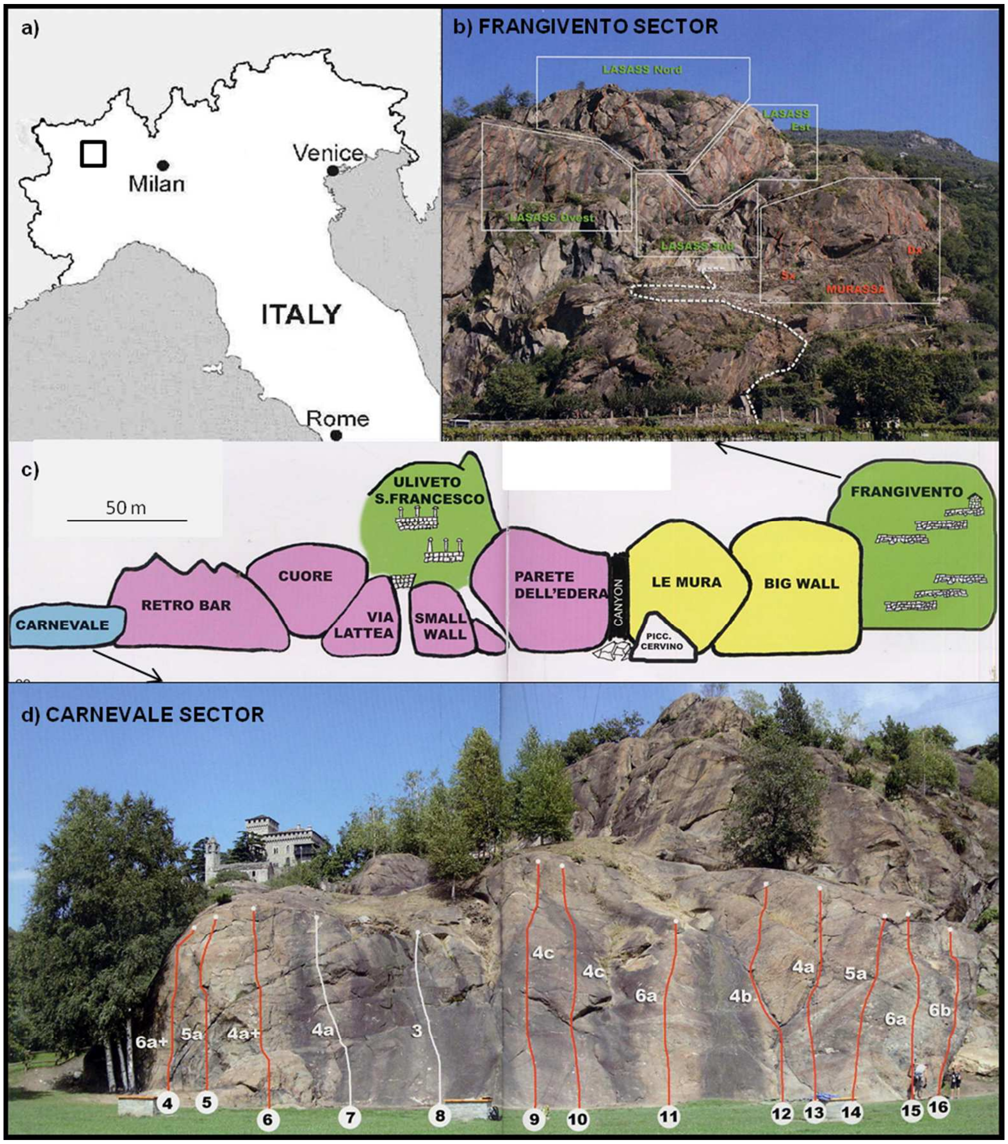
List of the attributes applied for the evaluation of the site. The methodology for geomorphosites evaluation according to BOLLATI *et alii* (2012) has been slightly modified in order to assess both geological s.s. (i.e. structural) an geomorphological features.

ATTRIBUTES FOR GEOMORPHOSITE EVALUATION (modified from Bollati *et alii*, 2012)	
Scientific value	1. Representativeness of geomorphological process
	2. Representativeness of geological process
	3. Educational exemplarity
	4. Spatial extension
	5. Geodiversity
	6. Geohistorical importance
	7. Ecological support role
	8. Integrity
	9. Rarity
Additional values	10. Cultural value
	11. Aesthetic value
	12. Socio-economic value
Potential for use	13. Temporal accessibility
	14. Spatial accessibility (primary accessibility)
	15. Visibility
	16. Services
	17. Number of tourists
	18. Sport activities (secondary accessibility)
	19. Legal constraints
	20. Use of geological/geomorphological interests
	21. Use of additional interests
	22. Presence of geosites of interests in the surroundings

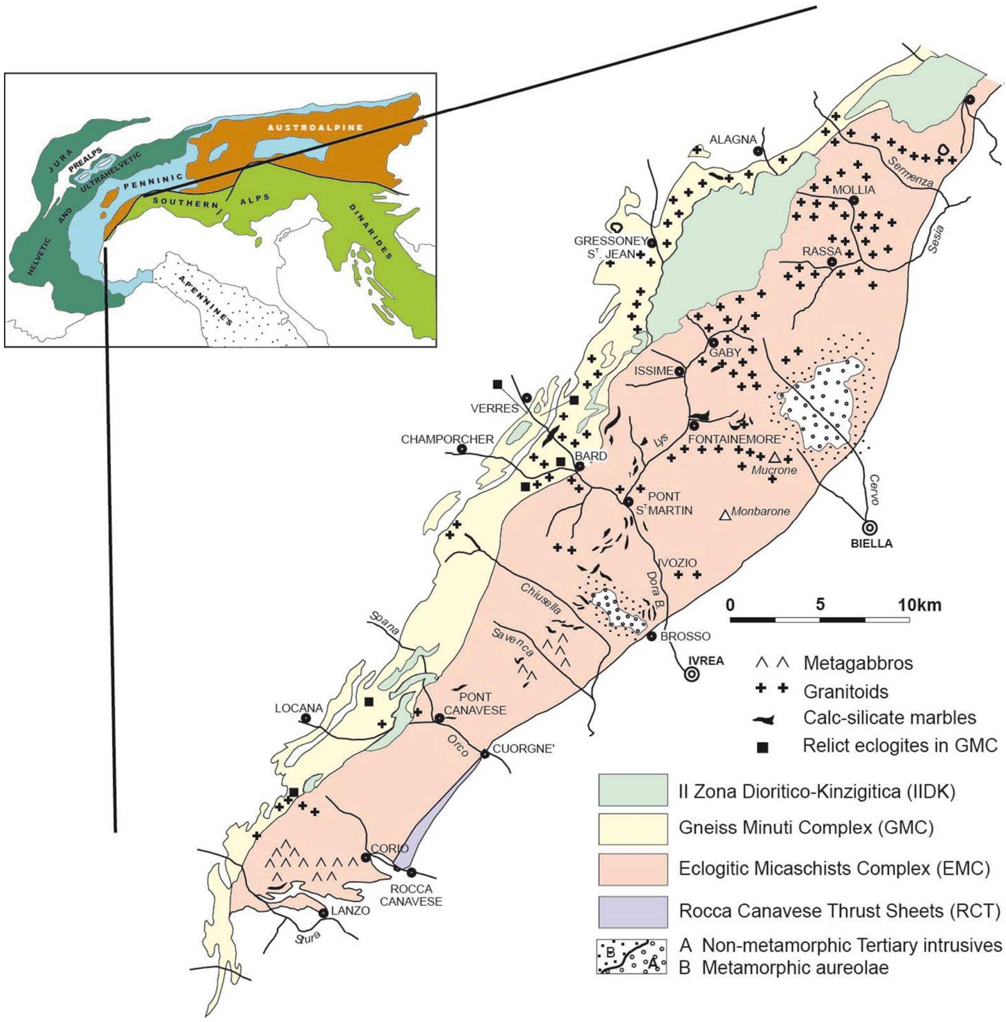
TABLE 2

Results of the evaluation of the attributes for determining the value of the site of geological and geomorphological interest.

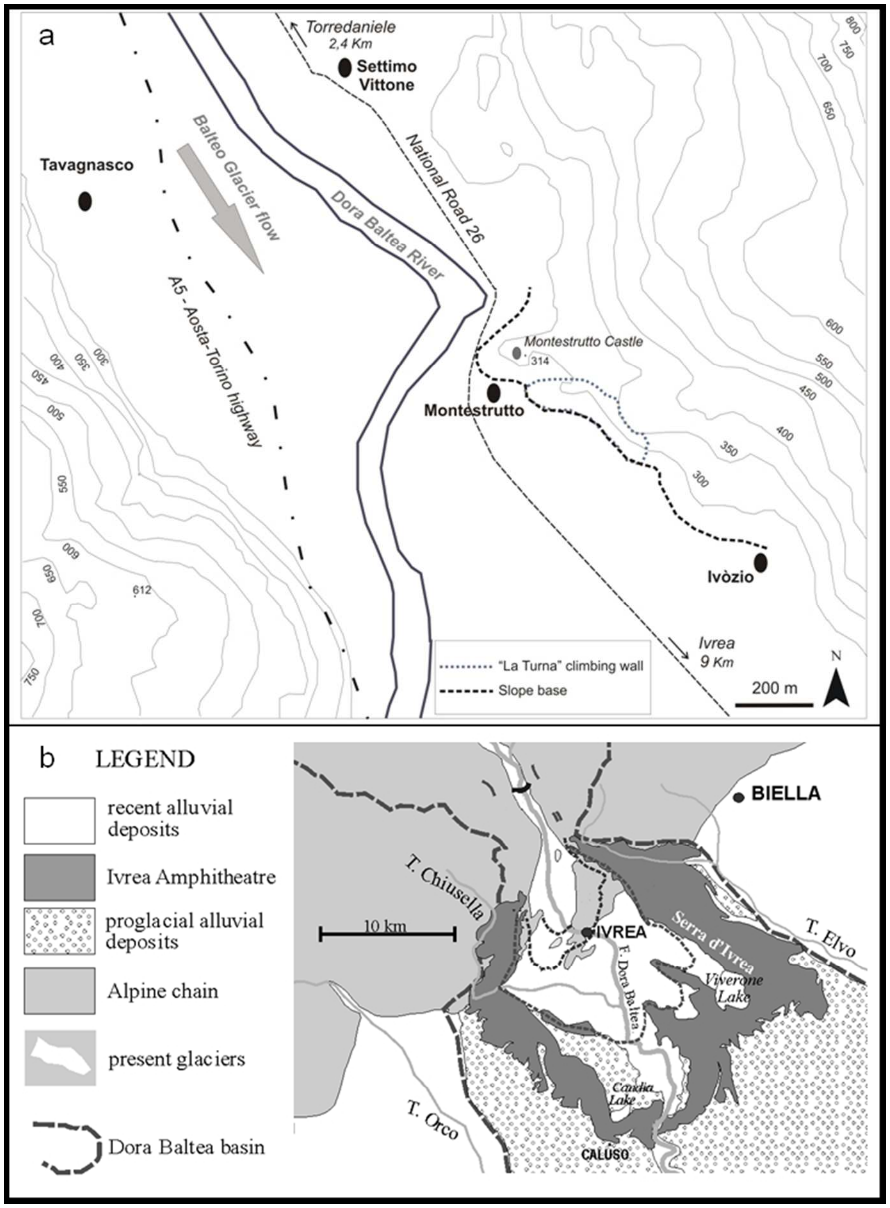
Composite Values		Attributes	Score over the Maximum
Scientific value	1.	Exemplar representativeness of a morphogenetic system	1/1
	2.	Exemplar representativeness of a morphogenetic system	1/1
	3.	Representativeness with good/excellent educational value	1/1
	4.	Landscape and punctual sites	1/1
	5.	2 lithologies and many glacial and gravity landforms	1/1
	6.	Relevant topic for scientific research	0.67/1
	7.	Without any connection with the biologic element	0/1
	8.	Essential geomorphological elements are intact	1/1
	9.	Rare at national level	1/1
		A. Scientific value = (1+2+3+4+5+6+7+8+9)	**7.67 / 9**
Additional values	10.	Presence of cultural assets correlated with geo-features	1/1
	11.	Not relevant	0/1
	12.	Element inserted in an economic-touristic circuit	1/1
		B. Additional value = (10+11+12)	**2 / 3**
		C. Global value = (A+B)	**9.67 / 12**
		D. Index of Use = (3+4+11)	**2 / 3**
Potential for use	13.	All over the year	1/1
	14.	Presence of means of transportation, access also to disables	1/1
	15.	Excellent visibility for all the elements in the foreground	1/1
	16	Hotels and services far from less than 5 Km	1/1
	17.	Abundant	1/1
	18.	Yes, correlated with geo-features, useful for arousing interest	1/1
	19.	No protection or limitation in use	1/1
	20.	Use in academic ambit	0,5/1
	21.	Presence of sites of interest in the study area	1/1
	22.	Naturalistic or cultural paths already started	1/1
		E. Potential for use = (D+13+14+15+16+17+18+19+20+21+22)	**11.5 / 13**
		F. Scientific Index = (1+2+6) / 3	**0.89 / 1**
		G. Educational Index = (3+11+14) / 3	**0.66 / 1**
		TOTAL SCORE = (C+E)	**21.17 / 25**



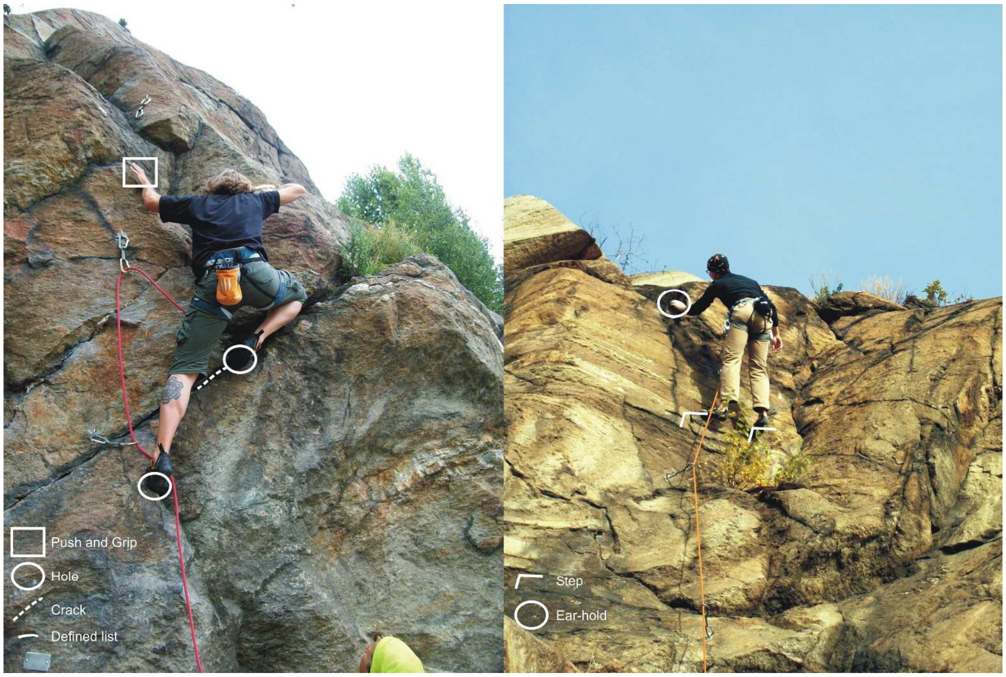
La Turna sport climbing area. a) Geographic location in the Northern Italy; b) Frangivento sector, one of the area where the analysis have been focused on; c) Sketch of all the sectors of the La Turna sport climbing area,; d) Carnevale sector, one of the area where the analysis have been focused on. b, c, d are modified from PREDAN (2012).
172x195mm (150 x 150 DPI)



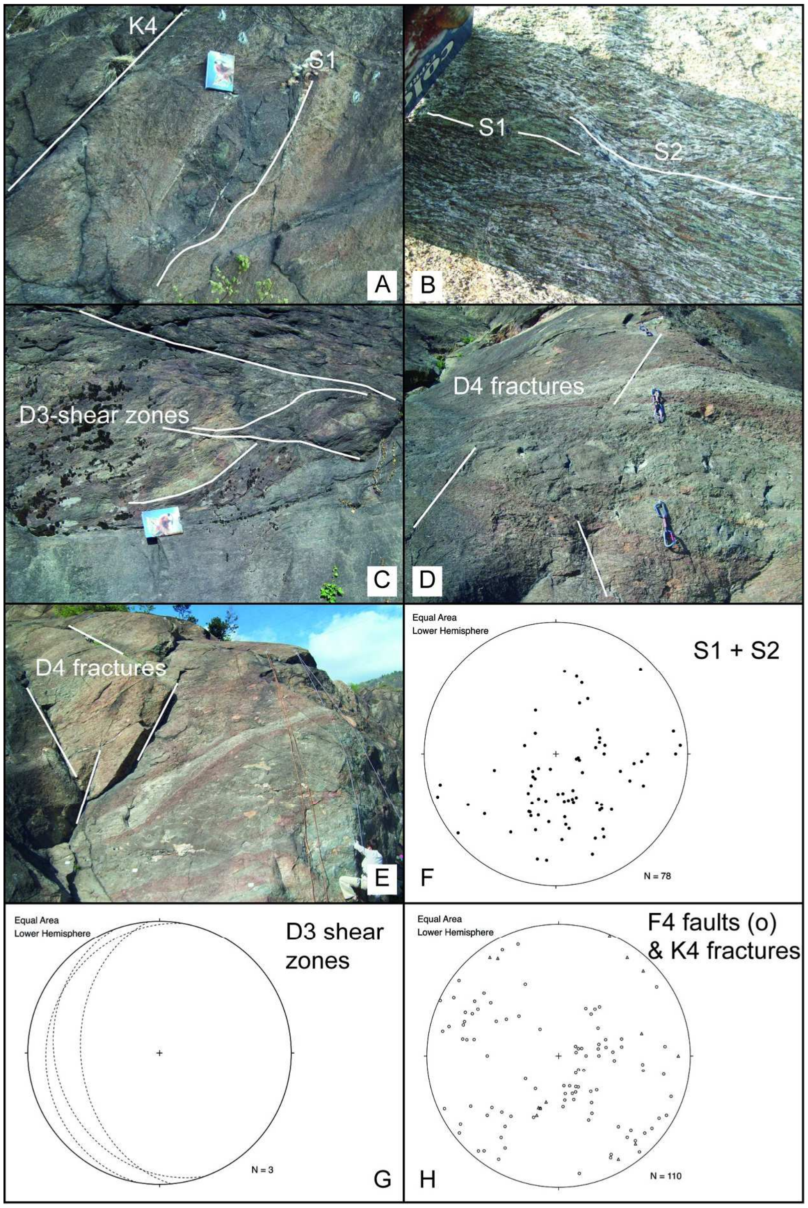
Subdivision of the Sesia-Lanzo Zone modified from ZUCALI & SPALLA (2011).
508x522mm (72 x 72 DPI)



Maps of the area in which the "La Turna" sport climbing wall is located. a) Detail of the Montestrutto area; b) Geomorphological sketch map modified from GIANOTTI et alii (2008) where the position of the Torredaniele Stadial is indicated by the black arch crossing the Dora Baltea River.
122x166mm (150 x 150 DPI)

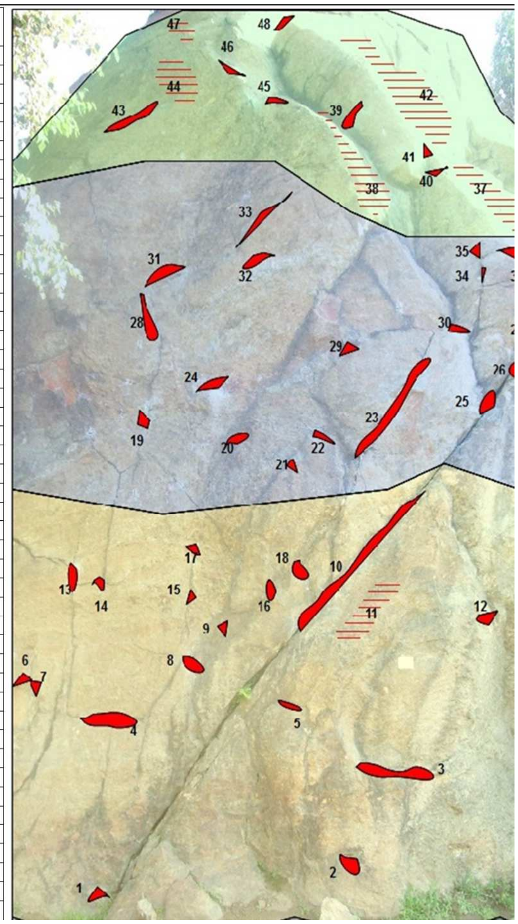


Observation of climbers during their progression on the selected sport climbing routes: Picche (a) and Sant’Agostino (b). Observation of their movements has provided information about used holds and climbing style, indicated with symbols in the pictures.

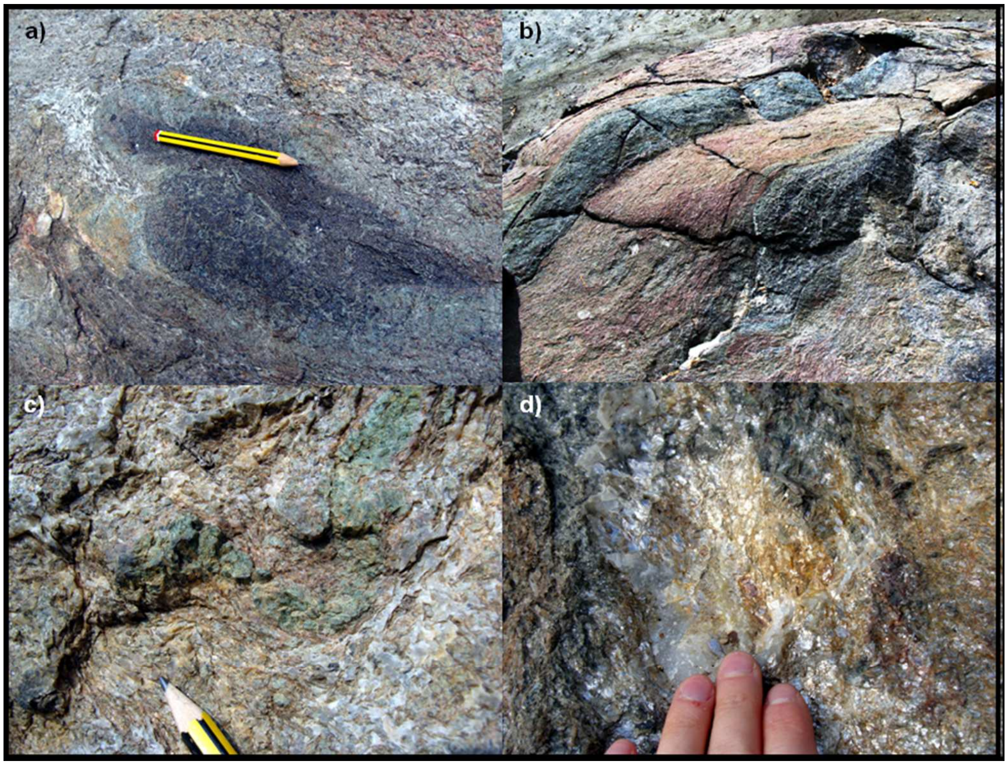


Features and orientations of main structural elements. A) S1 foliation wrapping eclogite boudins; B) S2 foliation marked by glaucophane, white mica and quartz deflecting the S1 foliation defined by omphacite and glaucophane; C) D3 shear zone; D) D4 fractures at metre-scale; E) D4 fractures at sport climbing scale; F, G, H) Stereographic projections of the main structural elements.
139x209mm (300 x 300 DPI)

N°	HANDHOLD	FOOTHOLD	WIDTH (cm)		TYPOLOGY	ROCK FEATURES
			≤ 2	> 2		
1		X		X	small	
2		X		X	small	
3		X		X	big, easy start	D4 – fault (kinematic indicator)
4	X	X		X	small	D4 – fracture
5		X		X	small	
6	X		X		infinitesimal	D4 – fracture
7	X		X		infinitesimal	D4 – fracture
8	X			X	hollow	D4 – fracture
9	X	X	X		small lists	D4 – fracture
10	X	X		X	big	D4 – fracture (open)
11		X		X	oblique, grip	
12	X	X		X	oblique, lateral push	
13	X		X		hole, 1 finger	D4 – fracture
14	X		X		hole, 1 finger	D4 – fracture
15	X		X		vertical, traction	D4 – fracture
16	X	X	X		hollow	
17	X		X		vertical, traction	D4 – fracture
18	X		X		hollow	
19	X			X	vertical, traction	D4 – fracture
20		X	X		small, lateral push	D4 – fracture
21	X		X		infinitesimal	D4 – fracture
22	X	X		X		D4 – fracture
23	X	X		X	small, grip	D4 – fracture
24	X			X	infinitesimal, grip	D1 – boudin
25		X		X	big, open crack	D4 – fracture (open)
26		X		X	small, open crack	D4 – fracture (open)
27		X		X	small, open crack	D4 – fracture (open)
28		X		X	oblique, lateral push	D4 – fracture
29		X		X	infinitesimal, grip	D1 – boudin
30	X	X		X	big	D4 – fracture
31	X			X	horizontal list	D1 – boudin
32		X		X	infinitesimal, grip	D1 – boudin
33		X		X	infinitesimal, grip	D1 – boudin
34	X		X		hollow	D4 – fracture
35	X		X		hollow	D4 – fracture
36	X	X		X	infinitesimal	D4 – fracture
37		X		X	oblique, grip	subrounded morphology
38		X		X	oblique, grip	subrounded morphology
39	X			X	small lists	D4 – fracture
40	X			X	small lists	D4 – fracture
41	X		X		infinitesimal	
42		X		X	oblique grip	subrounded morphology
43	X			X	infinitesimal	D4 – fracture
44		X		X	oblique grip	subrounded morphology
45	X			X	infinitesimal handhold	subrounded morphology
46			X		infinitesimal handhold	subrounded morphology



Example of synthesis of analysis on holds along the routes Vezzosa and Picche in the Carneval sector emphasizing the correspondence between the outcrop features and vertical progression. The individuated holds, observing climbers in progression, are indicated in red. In particular, the striped areas are characterized by grip progression.
545x499mm (143 x 143 DPI)



Examples of the eclogite boudins, that are easy detectable mainly for the different colour and roughness (a, b). Also the most abundant minerals are visible (c, omphacite; d, quartz and fengite) that can be considered meaningful also from a scenic point of view.
149x113mm (150 x 150 DPI)

Panoramic view of the Montestrutto spur. The sport climbing wall develops on the right flank of the roche moutonnée (a). b) Sketch of a roche moutonnée modified from Canadian Landform Inventory Project (2012), that similarly reproduces Montestrutto geomorphological setting. c) Evidences of glacial modelling: subglacial potholes on the upper surface; d) glacial striae on one of the examined sport climbing routes; e) conjugated fractures systems on the upper surface of the spur. Photo by I. Bollati.