LITHOLOGICAL AND STRUCTURAL CONTROL ON ITALIAN MOUNTAIN GEOHERITAGE: OPPORTUNITIES FOR TOURISM, OUTDOOR AND EDUCATIONAL ACTIVITIES

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Abstract: Mountain landscapes are generated by the interplay of endogenous and exogenous processes, whose reciprocal importance changes over times. The Italian relief reflects a high geomorphodiversity and an overview on iconic mountain landscapes, representative of the lithological-structural diversity of the Italian relief, is presented. The study cases, located along Alps and Apennines and in the Sardinia island, are exemplary for the comprehension of the role of the substratum in shaping mountain landscapes and of the deriving risk scenario. Moreover, mountain landscapes are characterized by a high potential for use in terms of: i) ideal open-air natural laboratories for multidisciplinary educational purposes including geological-geomorphological, historical and ecological topics; ii) possibility of specific outdoor activities that take advantage of outdoor sports (e.g., climbing, canyoning, speleology). These feasible and versatile opportunities favour the enhancement of such environments under different perspectives as well as the involvement of local communities and the socio-economic return deriving from mountain geoheritage management.

Key words: Italian relief, lithostructural landscapes, geomorphosites, outdoor activities

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Introduction and aims

Italy is a country with a great variety of beautiful and highly scenic landscapes deeply connected with the lithological-structural diversity and the long-term modelling action of exogenous and endogenous processes, whose reciprocal importance has changed over times (Soldati, Marchetti 2017). The wide latitudinal extent of the Italian territory and the articulated altitudinal ranges are mainly responsible for a marked climatic diversity which plays a fundamental role in making Italy a country with such a great landscape variability (i.e. *geomorphodiversity* sensu Panizza 2009, see also Melelli et al. 2017). Different lithologies may outcrop within the range of a few kilometres in complex structural contexts like those of the two main mountain chains of the Italian peninsula, the Alps and the Apennines (Bigi et al. 1990). These two main ranges are elongated spreading mainly from West to East and from North to South respectively, covering a great part of the national territory and being characterised by different climatic conditions, from the Alpine to the Mediterranean morphoclimatic environments. Since morphosculptures are strictly controlled by geological structures and lithology, on which surface processes act, being in turn mainly climate related and/or climate conditioned, in the most sensitive areas climate change impacts are very acute and play a fundamental

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role in landscape shaping and evolution. Among these sensitive areas, mountain environments are particularly vulnerable to disturbance and prone to change, (Beniston 2003, Garavaglia et al. 2010, Reynard, Coratza 2016). Considering water action in different physical states, it is possible to investigate changes in the climate-related processes along altitudinal transects on reliefs characterized by altitude variations. Areas at the higher altitudes are mainly characterized by glacial and periglacial processes and landforms, while running water action prevails in glacier forelands, in areas at lower altitudes and characterized by milder climate (e.g. Bollati et al. 2017a). Where glacial and karst processes combine, some of the most spectacular landscapes are generated, like those characterizing the most eastern portion of the Alps (e.g. Cucchi, Finocchiaro 2017). Instead, at lower altitudes where, for example, widespread shales outcrop along the Apennines, badlands (i.e. *calanchi* in Italian, Bucciante 1922) are common and popular, while on the Alps impressive earth pyramids have been modelled on glacial heterometric deposits (Bollati et al. 2017a) being distinct features within the Italian landscape (e.g. Bollati et al. 2016a).

Besides the main mountain ranges, Italian islands are characterized by other kind of mountainous relief, often linked with active or relict volcanic activity (e.g. *Mount Etna* and Aeolian islands in Sicily, *Giare* plateaux in Sardinia), or with large outcrops of granitic (*Mount Capanne* on the Elba Island) and calcareous (*Tavolara* island in Sardinia) massifs and where also the articulated coastal landforms increase in importance (e.g. Lucchi et al. 2017).

Geosites are defined as *portions of the geosphere that present a particular importance for the comprehension of Earth history* (Reynard 2004). Among the different type of geosites, *geomorphosites* (Panizza 2001), i.e. sites of special geomorphological significance, are often the most spectacular. Geomorphosites may be essentially single, isolated landforms (e.g. a waterfall, an erratic boulder, etc.) or groups of landforms encompassing fairly large geomorphological landscape (Grandgirard 1997, Reynard 2009a, b) and their outlines can take various forms and trends (Coratza and Hobléa 2018). Recently, Migoń and Pijet-Migoń (2017) proposed a new category of geosites, i.e. *viewpoint geosite*, as localities which offer a wider look at the surrounding landscape, and hence suitable for interpretation of scenery. Recent decades have witnessed an exponential growth of scientific interest and, consequently, of research on geomorphosites located in mountain areas (i.e. *mountain geomorphosites*) (Reynard, Coratza 2016, Bollati et al. 2017a, b), as part of *geoheritage* (sensu Osborne 2000).

Mountain environments, due to their peculiar characteristics, provide key sites for the comprehension of Earth surface evolution through space and time (Reynard, Coratza 2016), while also offering a great potential for the development and promotion of tourism and leisure activities by planning ideal outdoor laboratories with scientific and educational purposes (e.g. Pelfini et al. 2016). Detailed analysis aimed at identifying and quantifying different values characterizing geomorphosites (see a review by Brilha 2016, Bollati et al. 2017b, Brilha 2018, Coratza, Hoblea 2018), for the selection of the most valuable ones both for conservation and promotion purposes, are currently becoming mandatory. If the aesthetic value represents the fundamental value for raising interest towards the physical landscapes, among the values usually assessed through specific methodologies there are also the scientific, including the ecologic support role, the cultural and the socio-economic values.

Moreover, potential for use of each site may include the possibility of practicing various outdoor activities (e.g. climbing, canyoning or speleology) (Bollati et al., 2016b, 2017b), linked with geomorphological features and based on lithological and structural variety. Outdoor activities, field works, field trips are in fact considered very important for getting in touch with Geosciences (e.g. Sturani et al. 2018 and references herein). Concerning climbing, this diversity deeply affects routes styles and difficulty (i.e. *climb-diversity*; Bollati et al. 2014, 2016b, García-Rodríguez et al. 2017). As indicated by Gray (2013), rock climbing sites – but this concept may encompass in general outdoor activities – may be considered, in fact, producers of abiotic ecosystem services (i.e. *17. Cultural services, Geotourism and leisure*) deriving from their geodiversity. In the case of canyoning, fluvial modelling and structural conditions allow the formation of different streams morphologies suitable for different types of canyon exploration (Ortega-Becerril et al. 2017), while turbulence of water-flow controls sport feasibility (Panizza, Manca 2006). Finally, in the case of speleology, in presence of soluble bedrocks generating endokarst systems, this outdoor activity, in the education perspective, may be very diversified (Schut 2006, De Waele 2010, Ballesteros et al. 2015).

This possibility of educational versatile approaches, including outdoor activities, favours also the involvement and socio-economic return for local communities coming from geoheritage management (Bollati et al. 2018). It is important to underline also that all these opportunities should not disregard the risk scenario assessment due both to active geomorphic processes, especially when they are changing under changing climatic conditions (e.g. Diolaiuti et al. 2006, Bollati et al. 2013), and to the practice of extreme sports (e.g. Panizza, Mennella 2007, Motta et al. 2009).

An overview on some iconic mountain landscapes, that may be considered hot-spots of Italian geomorphodiversity, will be presented in this paper. The structural and lithological heterogeneity together with the different types of climate, that underpin such a diversity of landscapes and the development of a rich and varied tourist offer, especially when linked with outdoor activities, will be underlined. Their inclusion in the regional and national Italian geosites catalogues will be also analysed.

Italian geomorphological relief diversity and related services

In this paragraph a selection of some of the most important Italian mountain landscapes is

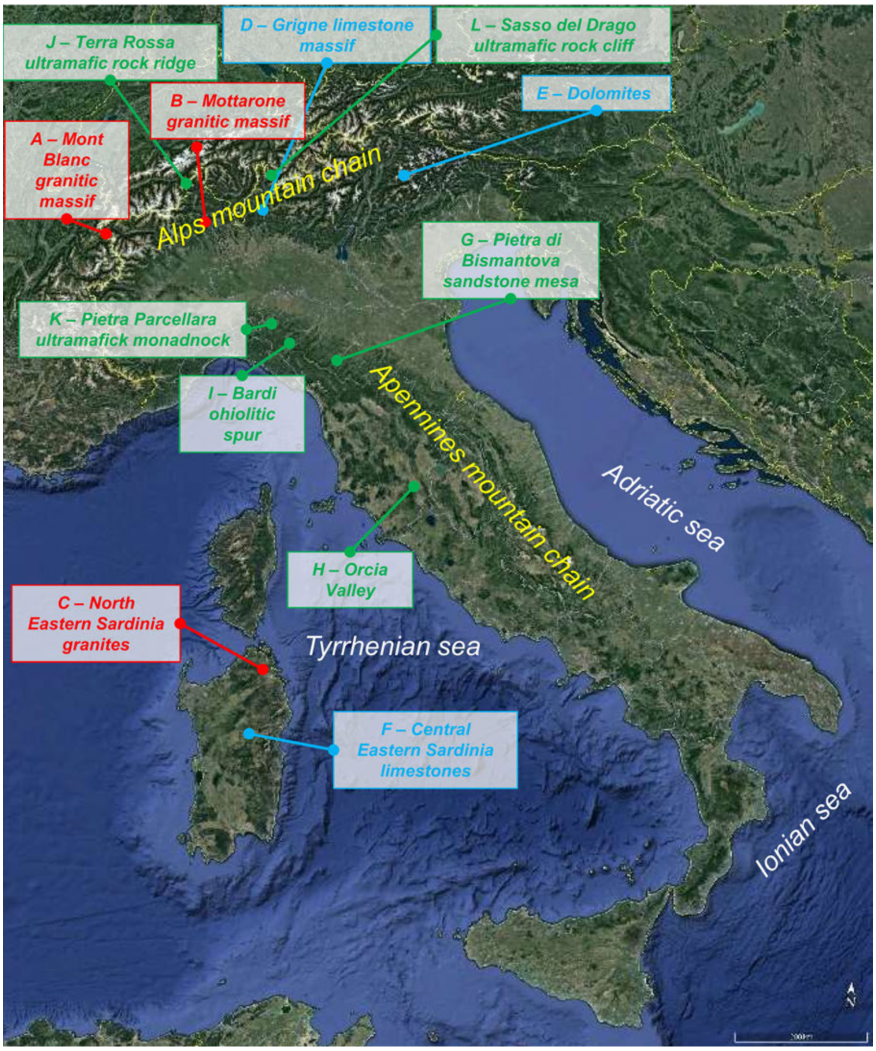

Fig. 1. Location of the selected landscapes in the Italian context (the background image is courtesy of Google Earth).

Table 1. Summary of the analysed features of the proposed study areas.

Code	Study case	Italian Region	Mountain range/ region	Other form of official recognition and protection	Geosites Catalogues	Litholo-gy/ies	Geomorphological features			Outdoor activities	Other relevant values
							Primary processes	Secondary processes	Landscape features		
A	Mont Blanc Massif	Aosta Valley	Western Italian Alps	Espace Mont Blanc, SIC IT1204010	ISPRA	Granites	Glacial & gravity action	Chemical weathering	Steep slopes	Climbing	Cultural: transboundary area and alpinism history
B	Mottarone Massif	Piedmont	Western Italian Alps		Regione Piemonte (for other aspects)	Granites	Chemical weathering	Water action	Residual relief with tors and inselbergs	Climbing	Cultural and socio-economic: cave and mines
C	Gallura	Sardinia	North Eastern Sardinia	Regional protection on some specific sites	ISPRA	Granites	Chemical weathering	Water runoff, gravity	Residual reliefs with inselbergs, tors, rounded blocks and tafonis	Climbing, canyoning	Cultural, archaeological, socio-economic: quarries
D	Grigne Massif	Lombardy	Central Italian Prealps	Regional Park of the Grigne	ISPRA, Regione Lombardia	Limestones	Karst	Glacial	Glacio-karstic ipo- and epi- landforms	Climbing, speleology	Cultural: Leonardo Da Vinci artistic works, tradition of climbing
E	Dolomites	Trentino-Alto Adige	Eastern Italian Alps	UNESCO World Heritage List	/	Dolomites	Gravity	Cryoclastism, glacial	Towers and scree slopes	Climbing	Cultural: painting, photography, poetry, history of Alpinism; socio-economic: tourism
F	Supramonte	Sardinia	Central Eastern Sardinia	Regional protection on some specific sites	ISPRA	Limestones, dolostones	Karst	Gravity, fluvio-karst	Hypogeum and surface karstic landforms	Climbing, speleology, canyoning	cultural, archaelogical, socio-economic

Table 1. continued.

Code	Study case	Italian Region	Mountain range/ region	Other form of official recognition and protection	Geosites Catalogues	Lithology/ies	Geomorphological features			Outdoor activities	Other relevant values
							Primary processes	Secondary processes	Landscape features		
G	Pietra di Bismantova mesa	Emilia Romagna	Northern Apennines	National Park of the Tuscan-Emilia Apennine	ISPRA, Emilia Romagna Region	Sandstone	Selected erosion & gravity	Weaathering	Mesa, landslides	Climbing	Cultural: Dante Alighieri's description, history of Alpinism; Archaeological: Bronze Age and early Iron Age settlements; Ecologic support role: endemic species
H	Orcia Valley	Tuscany	Central Apennines	UNESCO World Heritage List	ISPRA (not Radicofani case)	Shales	Water runoff	Gravity	Calanchi, shallow landslides		Cultural: Radicofani Castle; Ecologic support role: endemic species
I	Bardi ophiolitic spur	Emilia Romagna	Northern Apennines		ISPRA, Emilia Romagna Region	Basalts and red jaspers	Differential erosion	Gravity	Steep slopes		Cultural: Bardi Medieval Castle; Ecologic support role: endemic species
J	Terra Rossa	Piedmont	Western Italian Alps	Veglia Devero Natural Park	/	Serpentinite	Chemical weathering	Gravity	Residual ridges	Alpinism	
K	Pietra Parcellara	Emilia Romagna	Northern Apennines	Regional Natural Reserve	ISPRA, Emilia Romagna Region	Serpentinite	Differential erosion	Gravity	Monadnocks/Residual ridges		Ecologic support role: endemic species
L	Sasso del Drago	Lombardia	Central Italian Alps			Serpentinite	Differential erosion		Rocky cliff	Climbing	

proposed, examining the relations existing between geological and geomorphological features (i.e. scientific value) and the development of both some popular outdoor activities (i.e. potential for use) and other relevant values of geomorphosites (e.g. cultural, socio-economic, ecological support role). The selected cases are characterized by the common high aesthetic value that represents the foundation for promoting tourism, leisure and also outdoor education ideas. In Figure 1 the distribution of the study cases is illustrated. For each lithological landscape type, after a general introduction, a brief overview of individual cases will be provided, focusing on:

- the most relevant processes and related landforms as fundamentals in assessing landscape scientific values,
- the influence of geomorphic processes on other assessment values and the peculiarities of each site considering these additional values (i.e. cultural, socio-economic, potential for use),
- the site potentiality for further opportunities in tourism, outdoor and recreational activities,
- the insertion in the national geosites catalogue (ISPRA 2018) or in Regional geosites databases.

In Figure 1 granite landscapes are indicated in red, limestone and dolostone landscapes are indicated in light blue and, finally, silt, sandstones and ophiolitic landscapes are reported in green.

In Table 1 data regarding the study cases are summarized.

Granites landscapes

Granites produce very famous landscapes all over the world (Migoń 2006). These magmatic rocks generate in context of active plate boundaries and, successively, as a consequence of uplift and exhumation of batholites formed in the depth, peculiar landscapes originate in correspondence of their outcrop. The exhumation of batholites favours the development of extensional fractures (i.e. exfoliation) that usually set up following the structures of the magmatic rocks (e.g. flow lines). Chemical composition of the most common families of granites allows for specific weathering processes (i.e. hydrolysis of feldspars) whose intensity may vary as a function of the climatic context and the duration of the exposure to the meteoric agents and it is in some case used as a proxy for dating surfaces (Matsukura, Matsuoka 1991). In the Alpine climate contexts, like the one of the *Mello Valley* (Central Italian Alps), the granitic massif appears high and with steep slopes modelled by glaciers and gravity action, while in other regions of the Italian territory, characterized by warmer climate conditions, as in Sardinia, they undergo intense weathering that took place mainly during the humid-warm periods with the production of typical residual formations like saprolite. This weathering mantle has been subject to physical removal mainly by water and gravity action, leaving residual landforms (e.g. tors and inselbergs, castle koppies, tafoni and rounded blocks) (Melis et al. 2017). Hydrolysis and haloclastism, the last one especially active in coastal areas, produces particular landforms too (i.e. honeycomb sculptures, tafoni, and many famous rock animal features like the *Bear of Palau*, North-Eastern Sardinia). All these landforms, developing on granular rocks, may have different dimensions, from the micro to the macro spatial scale. García-Rodríguez et al. (2017), focusing on climbing activities in protected areas in Spain, examined in detail how fractures and morphology, due to unloading and exfoliation, are common elements used for the climbing progression. Moreover, granites, due to the granular texture and to differential weathering on quartz and less resistant minerals, have high grip property, requesting a precise and peculiar climbing technique (Bollati et al. 2016b). Moreover, perfect fracturing of granites along great walls (e.g. *Yosemite Valley*, USA; *Mello Valley*, Northern Italy) favours the progression along multi-pitch routes, using traditional techniques, well appreciated by the old-style climbers. In other cases, unloading features are overcome through famous and frequently climbed *vie ferrate,* as at the *Half Dome* in the Yosemite (Pettebone et al. 2013).

Granite-related geosites (e.g. Migoń et al. 2017) are very famous and cultural aspects linked to granites (Migoń, Latocha 2008) may change from one region to another, implying relationships with human settlements and territorial boundaries. Moreover, their cultural value increased, as recently underlined in literature (see a review by De Wever et al. 2017), for the re-evaluation of exploitation of granites in the framework of ornamental materials and resources of a territory.

In the following paragraphs a comparison among granites landscapes in the Western Italian Alps and in Sardinia is proposed, delineating different features related to their own morpho-climatic context.

Granites of the Western Italian Alps (case study A and B)

The *Mont Blanc Massif* (case study A, Fig. 1, Fig. 2a) is located at the border between Italy, France and Switzerland, in the Western Italian Alps and it is famous for its most elevated peaks in Europe. The Mont Blanc peak in particular, with its height of 4,810 m a.s.l., represents the highest European peak. The granites of the Mont Blanc Massif are intruded within the Helvetic Units crystalline basement, mainly made by paragneiss and amphibolites, that underwent only a weak metamorphic imprint during the Alpine orogenesis.

In this area, the aesthetic value is universally recognized by tourists that may visit the area using a recently modernized cable-lift that allows to cross the massif from the Italian side to the French side. Moreover, alpinism represents an important attraction due to the relatively long tradition. Every year thousands of alpinists from all over the world approach these areas for mountain ascents and climbing activities.

The cultural value of the area has been recently put under attention by the Transboundary Cooperation Project between Italy, France and Switzerland (Espace Mont-Blanc 2018). The Mont Blanc Massif is inserted in the ISPRA catalogue, even if, by now, only some elements of its geo-history are considered: the moraines related to debris covered Miage glacier. The latter, that may be considered as a part of the very huge glacial system of the Mont Blanc Massif, is important due to the ecologic support role represented by vegetation growing on the supraglacial coverage (Pelfini et al. 2012, Bollati et al. 2013, 2015). Moreover, for this and others reasons, the *Glacial environment of the Mont Blanc Massif* on the Italian side, in the western part, is labelled as Site of Community Importance included under the Rete Natura 2000 (SIC – IT1204010 – Région Autonome Vallée d'Aoste 2018).

On Alpine granites, many educational activities related to climbing have been already developed, similarly to the already cited cases of Spain (García-Rodríguez et al. 2017), and the *Mottarone Massif* (case study B, Fig. 1) (Novara and Verbano-Cusio-Ossola Province) represents a very significant spot in this sense (Bollati et al. 2016b). The climbing walls modelled within Permian granites, differently from the Mont Blanc area, are equipped to be climbed also by beginners. For this reason and for the easy accessibility of the walls, the Mottarone was considered in the framework of the *Gekologia project* (Bollati et al. 2018), an educational initiative addressed to students of different ages and aimed at using climbing to approach geology and geomorphology. Indeed, the Mottarone climbing wall underwent a quantitative evaluation (see Bollati et al. 2016b) to assess its global value and the potential for use of the climbing wall in the perspective of Earth Sciences education. Grip climbing, taking advantage of granular structure of granitic rocks and of their differential weathering, is very popular, a distinctive trait that is easily associated with this kind of rocks more than with, for example, smooth limestone cliffs. The climbing wall was scored among the most valued in the framework of all the climbing walls of the Verbano-Cusio-Ossola Province in Piemonte (updated to 2015) considering all the climbing walls of the Province. According to the obtained results, considering the peculiarities of each selected climbing wall, a great involvement and improvement in Earth Sciences by students was achieved.

Besides the typical pink granites of Mottarone Massif, in the surroundings areas other varieties of Permian granites, genetically related, crop out. Among them, Montorfano granites are characteristically white, and also equipped for climbing, while the green variety outcrops in the surroundings of Mergozzo village (Boriani et al. 1988). The Verbano-Cusio-Ossola Province district is well known and relevant from a socio-economic and cultural point of view due to the presence of several and varied rock extraction spots, among which granites are very relevant (Cavallo, Dino 2014). Extraction of rock material offers, at first, resources for the territory, used as building and ornamental stone for cultural assets (Fig. 2b) but also, especially in recent times, cultural opportunities. Indeed, ancient extraction sites are now geotourism attractions (e.g. in the cited area: *Baveno, Agrano, Alzo, Candoglia*).

The Mottarone massif is not included in any of the geosite list covering the Italian territory, but the Piemonte Region catalogue of naturalistic and

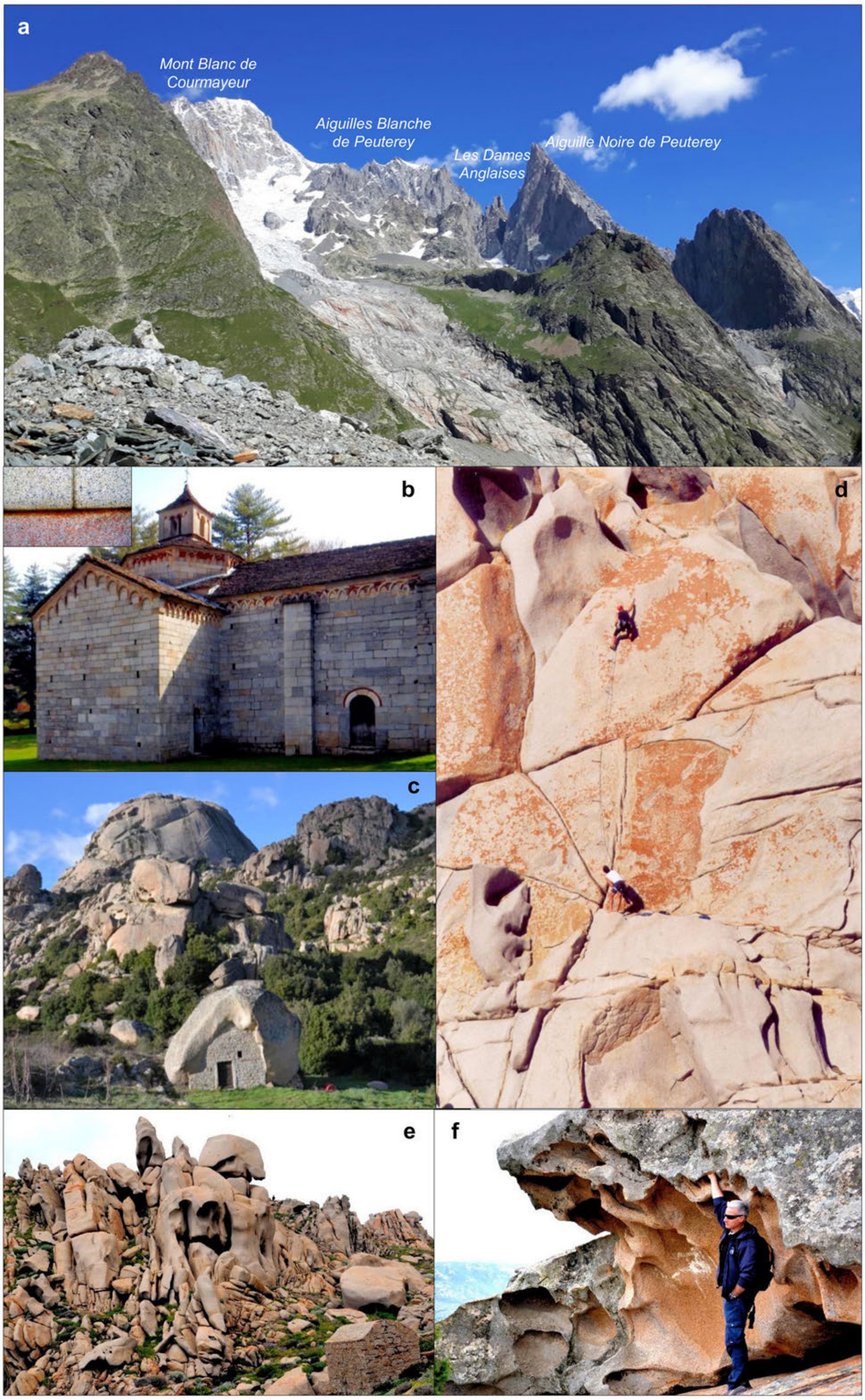

Fig. 2. Comparison among Italian granites landscapes characteristic of the Alpine areas and of the Sardinia island. a) View on the Mont Blanc Massif (case study A, Fig. 1) taken from the debris covered surface of the Miage Glacier in the Veny Valley, b) San Giovanni Battista Church (V century B.C.) in the Montorfano village (Verbano-Cusio-Ossola province) and a detail of pink and white granites extracted in the surrounding areas and used also for buildings in Milan city centre (e.g. San Carlo al Corso Vittorio Emanuele), c) the inselberg of Mount Pulchiana with, in the foreground, a tafone used as a shelter (Aggius, North Eastern Sardinia) (case study C, Fig. 1), d) climbing on the granitic walls and tafonis of Capo Testa (North Eastern Sardinia) (case study C, Fig. 1), e) columns and blocks defined by erosion along the net of fractures in the granite of Capo Testa (Gallura, North-eastern Sardinia), f) a big tafone in the area of the Bear of Palau where, inside the most hidden cavities, the granite is altered by hydrolysis.

cultural assets within the Regional Landscape Plan contains other naturalistic sites (i.e. peat-bogs) located within the massif.

The granitic Gallura region (North Eastern Sardinia) (case study C)

The Sardinian granitic batholith widely crops out along the eastern side of the island. It was intruded in the poly-deformed and metamorphosed Palaeozoic basement during the Variscan Orogeny, from 350 to 290 Ma BP (Carmignani et al. 2001, Rossi et al. 2009). During this long time period, changes occurred in the geodynamic framework, leading to a great diversity in the structural and compositional characteristics of the various intrusions. Uplift of the Variscan chain provoked the dissection of the granite basement and led to partial erosion of the granite plutons. Later, the Oligo-Miocene anticlockwise rotation movement of the Corso-Sardinian block and the Alpine collision, produced major faulting and tilting in the granite batholith.

The granitic Gallura landscape is characterized by jagged profile reliefs following the major fractures lines, rounded and often isolated landforms, wide depressions, horizontal or gently inclined plateaux determined by tectonics and by the alternation of morphogenetic processes, also in relation to different climate conditions. Along the dense joint network, intense modelling of relief took place, giving the landscape its characteristic features, modelled at a small to medium scale by physical and chemical processes, giving rise to inselbergs, rounded boulders, tors and tafoni (Fig. 2e). The main modelling of the granitic basement occurred during past periods of intense weathering, mainly related to climatic context (Melis et al. 2017). Currently, chemical and physical processes act at a lower intensity, but their activity can be tested inside the cavities within blocks and tafoni, where the granular surface often appears wet and weathered (Fig. 2f).

Granitic relief of the Gallura region has always been strictly interconnected with culture and life of the local communities, giving this area high cultural significance through time. Strong relationships have always occurred between people and granitic landscapes. Resistant building materials, often already available in blocks isolated by the joint network, were of great importance to the local population. Also the impressiveness of the relief (Fig. 2e) has become part of daily life, socio-economic needs and human imagination. Natural cavities have always been a geographic factor accompanying people throughout history, serving as shelters, burial sites or stabling for animals (Fig. 2c).

Peculiar geographical and geomorphological features of Sardinia granitic region offer opportunities for *active tourism* like climbing (Fig. 2d) and canyoning. One of the advantages is the possibility of practising climbing on granite, all over the year. In particular, specific geomorphological characters of the Sardinian granitic environment allow for outdoor activities like bouldering, on the many rounded blocks resulted from progressive erosion along fractures, and canyoning. The latter is practised along the representative granitic stream valleys, characterising the highest parts of the area and incised in the solid rock. In the Sardinia context, researches focused on methodology to quantify geomorphological hazard on climbing walls (Panizza, Mennella, 2007). These kind of information, like a correct knowledge of the rocks different behaviour towards weathering, could be considered an educational resource with the aim of raising awareness in people on the way to approach to outdoor activities.

Currently some of the Sardinian granitic landscapes are protected and included in official regional lists of protected areas. The inselberg of *Monte Pulchiana (Aggius)* is the only granitic landform included in the Geosite database of ISPRA.

Limestone and dolostones landscapes

Limestones and dolostones are rocks differently susceptible to chemical dissolution. Limestone is particularly prone to dissolution of calcium carbonates in hypogenic and epigenic conditions, favoured by high temperatures and availability of water. The content of CO_2 in water, also varying for the mixing from different sources, is another factor, together with secondary porosity, that allows faster and more efficient chemical reactions. Besides these aspects, vegetation coverage may favour the process too (i.e. biodissolution). The specific term of *karst* is currently used to refer to landscapes generated by dissolution of calcium carbonates and characterized by hypogenic (e.g. caves) and epigenic landforms (e.g. different karren types, sinkholes, uvalas) developing at different spatial scales. In some cases, other processes combine with pure karst: for example, spectacular glacio-karst landscapes derive from the interplay between chemical dissolution and glacial exharation that were, or are still active in mountain areas. Where carbonates are less susceptible to chemical dissolution, like in dolostones, and fracturing is significant due to cryoclasty, typical wide talus slopes develop generating peculiar landscapes, usually referred to as *dolomitic landscape*.

From the outdoor activities point of view, limestones and dolostones provide a double offer addressed to different tourist and sport targets. Concerning the epigenic modelling, limestone, especially when not smoothed by the frequent passage of climbers, is a really appreciated rock for climbing activities. Karst landforms like furrows known as rinnenkarren or small hollows require a high technique degree and precision: very impressive are the landforms of the *Carso* plateaux in the North Eastern Alps (Bini et al. 1998), an area from which the name of the modelling process (i.e. *karst*) derived (Cucchi, Finocchiaro 2017). Speleology is the second kind of outdoor activity based on the presence of limestone landscapes. The development of more or less articulated hypogenic karst systems provides opportunity of exploring a subsurface territory with different degree of difficulties.

Geosites, modelled in limestone and dolostones, may vary widely in a spatial scale in terms of both hypogenic and epygenic landforms (e.g. De Waele et al. 1998, Soldati 2010, Coratza et al. 2012). Two cases from the Central and Eastern Italian Alps, together with a case in Sardinia, will be described in the following paragraphs.

The Grigne Massif (case study D)

One of the most representative and well known glacio-karst landscape of the Central Italian Prealps characterizes the *Grigne Massif*, located on the eastern side of Como Lake. The Triassic Esino carbonatic platforms of the Grigne Massif (Upper Anisian–Ladinian), thrusted along structural planes visible also in the landscape, forms two most important peaks (Grigne): the Northern (2,399 m a.s.l.) and the Southern Grigna (2,181 m a.s.l.). The landscape is typically characterised by karst landforms at different scales: sinkholes, hills and depressions, karren. The past glacial modelling (during the Late Glacial Maximum), mainly exharation, allowed for the formation of glacio-karst landscape, somewhere reworked also by the currently active processes linked with running waters or snow activity, the last one currently effective during a few months in the year (Santilli et al. 2005). The Moncodeno area (Fig. 3a), in particular, is the most famous part of the Massif concerning hypogenic aspects. The deep karst systems formed in the past and successively cut by Quaternary glacial erosion, are famous from a speleological point of view and this kind of activity is common among the amateurs. Among the deepest and most famous caves, there is the *Abisso W le Donne* (1,160 m deep). In some of these caves, ice is still present and it has been investigated for $\delta^{18}O$ and ionic content relative to depth (Citterio et al. 2004). The ice presence inside the caves represents a peculiar feature, reported firstly by Leonardo Da Vinci. He also represented a particular of the Grigne in a beautiful painting (e.g. *Vergine delle rocce*, 1483–1486) and in drawings included in the *Codice Windsor* (e.g. code 12410) adding cultural value to this landscape.

The Grigne Massif that, moreover, is only 1,5 hours by car from the Milan metropolitan area, is defined by Corti, Anghileri (2003) as a *open-air laboratory* for styles and ethics in climbing. Indeed, the Grigne Massif, and in particular, the Southern Grigna, represented the object of interest for several generations of climbers who, starting from the second half of the XIX century, equipped hundreds of traditional and alpinist climbing routes. The *Ragni della Grignetta* Sport Group and School, born after the Second World War, has contributed significantly to the development of alpinism in this calcareous massif. Indeed, this long tradition resulted in 30 equipped rock pillars with routes of different difficulties both for beginners and expert alpinists, where some of the most famous alpinists (e.g. among the others Riccardo Cassin) had herein trained during times. Besides the potential for use deriving from linking Geosciences and sport activity, this feature represents an additional cultural-historical heritage.

The regional geosites catalogue of Lombardia and the interregional list (Various Authors 2008) considered the area for its stratigraphic and glaciokarstic importance. Also the ISPRA catalogue includes the Moncodeno hypogenic system as geosite.

Fig. 3. Selection of Italian limestone and dolostones landscapes in Alps and in Sardinia island. a) Moncodeno karst landscape (case study D, Fig. 1), towards North, taken from the Brioschi Hut on the Northern Grigna (2399 m a.s.l.) (Central Italian Prealps), b) panoramic view of Sasso Lungo Group (Val Gardena, Dolomites, Eastern Italian Alps) (case study E, Fig. 1), c) canyoning down the Flumineddu river (Supramonte, Central Eastern Sardinia) (case study F, Fig. 1), d) Erosional landform down the Doronè canyon and stream (Supramonte, Central Eastern Sardinia) (case study F, Fig. 1).

The Dolomites, a UNESCO World Heritage Site (case study E)

The juxtaposition of contrasting lithologies and geological structures, such as dolomite rocks overlying clayey rock types, undergoing cryoclastic and gravity processes, is responsible for the peculiarity of the *Dolomites Massif* (Eastern Italian Alps). In 2009 UNESCO recognised 9 different mountain systems, contained in an approximately 142.000 hectares, as a serial property to be included in the World Heritage List (Giannolla et al. 2009, Soldati 2010). Besides their universally recognised outstanding aesthetic value, the Dolomites are a site of exceptional scientific value from a geological-stratigraphic and geomorphological viewpoint. The geomorphology of this mountain range is the result of different morphogenetic agents that have acted in shaping the landscape through time. Tectonics has strongly affected the sedimentary sequences of limestones and dolomites, generating large synclines and anticlines. Monoclinal reliefs are also a distinctive feature. Depending on the lithology, different litho-structural landforms have developed: dolomitic outcrops have been highly fractured under tectonic pressure, developing large and deep valleys that cut through the massifs, and a dense network of several fracture systems, that amplify cryogenic processes. Limestones have been mainly subject to karst processes that have created wide surfaces sculptured by karren (mainly solution runnels and toothed blades), especially on the top of structural surfaces of strata, but also on roches moutonnées and on landslide blocks. Valley glaciers, which have repeatedly occupied the area starting from the Pleistocene, have left their clear signs with frontal moraines, scattered drift, roches moutonnées, glacial lakes and depressions of glacial erosion, the latter reshaped most of the times by karst action. The most common and widespread Quaternary deposits in the area are talus cones and talus slopes, located at the base of dolomite cliffs and on the top of the mountain groups. Important phenomena are landslides of different type and size related to the indirect effect of glacier retreat combined with the lithological, stratigraphic and tectonic conditions of the mountain range.

This area, besides its outstanding scientific and educational value, has important additional values. The aesthetic value is mainly linked with verticality, variety of forms, monumentality and colour contrasts, and it is also responsible for the socio-economic interest in the landforms. In fact, the Dolomites are one of the most attractive mountainous areas in the world, enjoyed by thousands of visitors every year (Gianolla et al. 2009). The dense network of climbing and hiking paths, developed during the last decades, makes this range one of Europe's most complete and varied destinations for mountaineers and climbers (Panizza 2009, Soldati 2010, Marchetti et al. 2017). Dolomites are particularly famous for providing some of the longest traditional multi-pitch and sport climbing routes in the world. Moreover, several hiking trails and fixed-rope routes, ranging from easy to demanding, are offered as well. These peaks, hosting about 170 historic *vie ferrate*, has the highest concentration of this kind of routes in the world. The majority of these climbing routes, now popular tourist attraction, were equipped by both the Italian and the Austro-Hungarian armies, to defend key position during the First World War (Rushforth 2014). Concerning the cultural value, in art, both in painting and photography, as well as in poetry, music and others arts, the shape of these mountains has inspired many visions (Panizza, Piacente 2017).

The calcareous massif of Supramonte (Central Eastern Sardinia) (case study F)

Supramonte is one of the most important karst areas in Sardinia, with high naturalistic and historical value recognized at national level. It is a carbonate massif covering a surface of 170 km^2 and constituted by dolostones and limestones of Middle Jurassic-Upper Cretaceous age. The carbonatic cover lies on the peneplained Variscan metamorphic and granite basement (Carmignani et al. 2001). The metamorphic rocks prevalently crop out along the western and south-western borders of the Supramonte while granites characterise most of the entire eastern border.

The Supramonte area covers a range of landscapes that goes from the characteristic eastern rocky coast to the inland mountainous relief towards the west, reaching heights of more than 1,000 m a.s.l. (Mt. Corrasi, 1,463 m a.s.l.). Intense karst processes have generated spectacular hypo- and epigenic landforms and have developed, mainly controlled by tectonics, during the Eocene, with the emersion of the Mesozoic sediments, during the Oligo-Miocene tectonic phases, and in the course of Middle Pleistocene in more wet and warm interglacial periods. The karst processes are still active, but the more intense phases and deepening of many canyons characterizing the surface hydrographic system, took place with the beginning of the Mio-Pliocene sea regression, about 5 M years BP (Antonioli, Ferranti 1992).

Supramonte as a whole constitutes a unique landscape unit in which natural aspects largely overrule the human imprint on the environment and its great naturalistic value has been recognised at a national level. The area was inserted in the National Park of Gennargentu, legally defined but unfortunately never put into practice.

Nowadays, Supramonte is a mountainous uninhabited region bordered by small villages. Nevertheless, many signs of past and recent human presence are found all around the region. The archaeological research discovered traces of ancient settlements going back to the Upper Paleolithic. Among the many sites of interest, many caves can be mentioned: *Sa Oche, Corbeddu, Tiscali*. Witnesses of Nuragic Age settlements are the rests of several towers spread all over the territory. Due to the geomorphological character of the area, traditional use of land and soil is mainly pastoral. Many sheepfolds are present, some of them still utilized, others restored for tourism; they are originally made of calcareous stones, covered with juniper and used seasonally by shepherds. The very known value of the region, both from a cultural and from an environmental point of view, is increased by the concentration of underground and surface landforms of high scientific significance and connected with karst processes. The Supramonte karst area includes some of the most important underground systems in Italy, like the one of *Codula Illune*. The fluviokarstic net of the Supramonte massif is characterised by deep and narrow canyons (Fig. 3c, d); the runoff waters draining the calcareous massif are diffusely captured along the streams by several sinkholes and return to the surface in a series of springs (Cabras et al. 2008). The drainage pattern is probably inherited from wetter and warmer periods and it is strongly guided by tectonics.

The rich diversity of surface and subterranean landforms and the quite wilderness of the whole area, make it a strong call for the lovers of the active tourism and of some extreme sports. The harsh rocky relief and high vertical cliffs, controlled by tectonics and lithology, are widely known and frequented by climbers from all over the world during all the year. A multipitch and very difficult route (*Hotel Supramonte*), very famous all over the world and located in the Gola di Gorroppu, was opened in 1999 and the name was assigned taking inspiration from the song of one of the most appreciated Italian artist (Fabrizio De Andrè).

Along the many gorges, canyoning outdoor activity is largely practised. The prevalent underground water flows, and the climate, make this area suitable for canyoning during quite all seasons of the year. Several guide books concerning canyoning and climbing in this area of Sardinia are published and frequently re-edited and updated.

Many of the underground and surface forms of this territory undergo different kinds of regional protection. The *Supramonte of Oliena, Orgosolo e Urzulei – Su Suercone*, for example, is one of the Sardinian *Rete Natura 2000* Sites. We find some of the most spectacular surface and underground landforms also in ISPRA geosites catalogue.

Sandstones, clays and ophiolites landscapes

Sedimentary rocks, characterized by different grain size components, allow for the development of different landscapes mainly related to their different susceptibility to erosion. Water runoff on clays is responsible for the generation of disordering in drainage systems, mainly characterized by networks of rills and gullies named *calanchi* (i.e. Italian term for badlands) (Bucciante 1922). Sandstone, characterized usually by thicker stratification patterns and by systems of joints and fractures, allows for the development of landforms evidently controlled by structure, with the contribution of gravity action (e.g. mesas). These kinds of granular lithologies, especially when feldspar components are abundant, undergo to modelling processes similar to those affecting granites generating analogue landforms (e.g. *Ayers Rock*, Australia).

Climbing activity on sedimentary rocks, particularly on conglomerates and sandstones, is popular especially if accompanied by scenic and/or cultural features like religious spots (e.g. *Montserrat* in France and *Meteora* in Greece (Della Dora 2012).

Pure clays are usually affected by intense water runoff and, for this reason, stability problems are common along slopes. Nevertheless, in some cases in Central Italy, historical settlements associated with these geomorphological settings and relevant cultural assets are located on the slopes (e.g. *Monte Oliveto Maggiore Abbey*) (Bollati et al. 2012).

Besides the local outcrops of ophiolites in the Alps, representing the remnants of ancient oceans obducted within mountain ranges during orogenic phases, big boulders of these ultramafic rocks are often spread within marine clays (i.e. olistolithes) in the Apennines. In the latter contexts, the scattered kilometric ophiolitic boulders are usually highly resistant to erosion and isolated monadnocks emerge from the less resistant surrounding clays (Pellegrini, Vercesi 2017). These rocks have a high scientific value from a paleogeographical point of view. Locally, the modelling of these rocks favours the development of blades, following the schistosity, or of hollows of different dimensions and shapes, while chemical weathering of femic minerals results in the origin of a peculiar red coloured patina due to ferric minerals oxidation. Ophiolitic walls morphologies (i.e. hollows and blades), deriving from the ultramafic rock weathering, may represent suitable elements that favour climbers, especially the beginners. From a scientific point of view also the ecological value is relevant since the colonization of particular ecosystems is favoured (Roberts, Proctor 2012). Cultural aspects are in some case linked with the development of legends and particular names conferred to ophiolites localities. As geosites, ophiolitic rocks have always represented attractive features (e.g. El Hadi et al. 2011) and their scientific value is high, as previously explained. The same happens for *calanchi* landscape in Italy (Bollati et al. 2016a) and all over Europe (Zgłobicki et al. 2017). Sandstones, especially pillars, isolated or in group, as the impressive *Ayers Rock* (*Uluru* for the natives) in Australia (Joyce 2010), enriched with culture and traditions features, or the sandstones pillars of Chinese geoparks (Yang et al. 2011), are also considered frequently for valorisation and geoconservation (Alexandrowicz 2008). The study cases illustrated in the following paragraphs are located both in the Apennines and in the Alps.

The Pietra di Bismantova mesa (case study G)

The *Pietra di Bismantova* is a wide biocalcarenite rock slab overlying marls and clay shales, and represents an iconic landmark of the National Park of the Tuscan-Emilia Apennine (Conti, Tosatti 1994). This unique morphologic feature in the Emilia Apennines encompasses significant scientific, cultural s.l. and socio-economic values. The general morphology of this area is strongly conditioned by lithology, stratigraphy and tectonics and consequently by differential erosion on outcropping formations. The Pietra di Bismantova is a representative example of a mesa. The summit level surface of this rhombohedral-shaped calcarenite rocky slab is due to high resistance of caprock. It is bordered by sub-vertical cliffs, pervasively affected by systems of vertical joints and intensively remodelled by ongoing degradation processes (Fig. 4a). Intense jointing, severe weathering processes, that affect the rock slopes since the end of the last glaciation (GSUE 1976), and high relief energy have favoured the onset of almost all landslide types in the area (Borgatti, Tosatti 2010). Particularly hazardous, in terms of velocity, are rock-falls, the last one occurred in February 2015, posing serious problems for the conservation of this geosite and for the safety of visitors, settlements and infrastructure.

From a cultural point of view, the Pietra di Bismantova and its surroundings have received high degree of attention since long time ago and remains of early human settlements are dated back to the late Bronze Age and early Iron Age. The verticality and monumentality of this slab, clearly visible even from plain, have inspired many artists through the centuries. The Dante's description of his ascent to the mount of Purgatory, compared to the trail going up the Pietra di Bismantova, can be quoted as an example. The Pietra is also characterised by high value for the history of alpinism: the first ascent is dated 1922 along the path called *Via degli Svizzeri* (Motta et al. 2009). Nowadays the site is one of the highly appreciated popular and challenging rock climbing routes of the Emilia Apennines, as confirmed by the organization of climbing competitions, which draws top climbers from all over northern Italy and beyond. In total there are around 250 routes extending for 130 meters from bottom to top, both for beginners and expert climbers. Here there are some long bolted multi-pitch climbing

Fig. 4. Sandstones, clay and ophiolites Italian landscapes in Apennines and Alps.
a) Northern slope of Pietra di Bismantova rock slab (case study G, Fig. 1), b) calanchi and shallow landslides characterizing the surrounding of Radicofani in the Orcia Valley (case study H, Fig. 1), c) Bardi castle (Parma Apennines) build on ophiolite outcrop (case study I, Fig. 1), d) "Sasso del Drago" climbing wall (case study L; Fig. 1), e) Punta Terra Rossa (or Waserhorn) from Bocchetta d'Aurona/Kaltawasser Gletcher (Verbano-Cusio-Ossola Province, Western Italian Alps; photo courtesy of E. Zanoletti) (case study J, Fig. 1), f) Pietra Parcellara (Trebbia Valley, Northern Apennines) (case study K, Fig. 1).

routes of which, the majority extend between 100 to 150 m of length. Several are also the single pitch sport routes. In order to increase the safety of this world-famous tourist area, analysis and modelling of possible rock fall trajectories have been recently developed (Migliazza, Giani 2005, Borgatti, Tosatti 2010). Moreover, a monitoring system has been put in place and detailed studies for the quantitative hazard and risk assessment and zonation of the whole area is being carried out (Corsini et al. 2016).

The Pietra di Bismantova is part of the territory of the National Park of the Tuscan-Emilia Apennines and its importance as geosite is recognised at national and regional level, being listed in both the ISPRA and Emilia-Romagna region geosite lists.

The Tuscany "calanchi" landscape (case study H)

The Orcia Valley is one of the Italian sites inserted in the UNESCO World Heritage List due mainly to its cultural value. It is located in the Siena Province (Central Apennines). Inside this area, clayey outcrops, related to the Pliocene marine transgression phases, are predominant. They are modelled generating spectacular *calanchi* landscape (Fig. 4b). Locally, the witnesses of the widespread Quaternary volcanic activity, related to the Monte Amiata volcanic complex, are represented by upstanding landforms like the Radicofani neck. It is a more resistant relief in respect to the surroundings clays and it is characterized, at the base of the slopes, by deposits related to rock-falls and lateral spreading processes. On the neck, a castle and a village were built. This kind of human settlements adds a cultural value to the Radicofani area. The village and the castle dominate from above the surrounding landscapes characterized by *calanchi* (Fig. 4b). The water runoff, since recent times, is leaving space to the action of gravity as testified by the development of shallow landslides. This reflects the interplay with human settlements and land use policies that may influence soil erosion rates (Aucelli et al. 2016). Since this landform transformation across times (from gullies to shallow landslides; Fig. 4b) is very evident, the educational and geodiversity value of the site is high. Moreover, in the area specific researches on the ecologic support role of these morphologies were performed in term of presence of endemic species (Maccherini et al. 1998) and response of arboreal vegetation to stress induced by intense erosion (Bollati et al. 2016a).

The Orcia valley includes geosites inserted in the ISPRA database and representative of erosion processes but the Radicofani area is not considered, even if particularly relevant (Bollati et al. 2016a).

Ophiolitic cliffs, ridges and olistholites in the Alps and Apennine as remnants of ancient oceans (case study I, J, K, L)

Ophiolitic green coloured rocks associated with deep-sea sedimentary rocks, the latter less resistant to erosion, offer unique and impressive mountain landscapes in Northern Apennines (case study I, K Fig. 1; Fig. 4c and 4f). In this context, the differential erosion between ophiolites and softer sediments is particularly evident. The stability and difficult accessibility of the ophiolitic ridges favoured the presence of human settlements and strongholds, as they could be easily defended. This can be deduced from some local place names: *petrum* (Pietramogolana) or *saxum* (Sassomorello); *rauca* or *roca* (Roccaprebalza, Roccamurata); or, finally, *castrum* after castle or fort (Sasso di Castro). The Rio Ceno valley, in the province of Parma, is a still unspoiled environment, dominated by medieval castles and military forts, most of them rising on top of ophiolitic cliffs. Among these, the Castle of Bardi (case study I Fig. 1; Fig. 4c) is worthy of note: strategically placed on a rise made up of basalts and red jaspers, it is still a lofty stronghold at the junction of roads linking the Ligurian western coast to Via Emilia (Bertacchini et al. 2002).

Where the ultramafic rocks outcrop as elongated stripes, superficial modelling generates peculiar mountain shapes like extended ridges. This kind of rocks, undergoing typical weathering that favours the development of a red coloured patina, supports impressive landscapes in both the Alps and the Apennines. In the Alpine context, an evident example is represented by the ridge of the *Terra Rossa* ridge (case study J, Fig. 1; Fig. 4e), whose place name derives from the peculiar colours due to weathering of ultramafic rocks. It is located in the territory of the Veglia-Devero Natural Park, in the Western Italian Alps at the border between Switzerland and Italy. Nevertheless, it is not inserted in any of the geosite catalogues covering the Italian territory. Another famous ridge constituted by ophiolites in the Northern

Apennines is the *Pietra Parcellara* ridge, in Emilia Romagna (case study K, Fig. 1; Fig. 4f). Within the hydrographic basin of the Trebbia River, where the Pietra Parcellara site is located, fluvial morphologies are strictly controlled by the alternating lithologies (Pellegrini, Vercesi 2017), changing in a few kilometres, becoming very peculiar from the educational point of view (Bollati et al. 2011): e.g. entrenched meanders in correspondence of the Ponte Barberino ophiolitic spur transform to braided and sinuous patterns where clays prevail.

Chemical composition of serpentinite outcropping at Pietra Parcellara allows for the colonization of an endemic flora (Vercesi et al. 2005), underlining its high ecological support role. Indeed, a special Natural Reserve was set in the area in virtue of this peculiar vegetation and the site is listed in both the ISPRA and Emilia-Romagna region geosite lists.

Serpentinoschists outcrops are scattered inside mountain chains and the recurrence of related climbing walls is rare. A spot located in the Central Italian Alps has been selected as very representative (case study L, Fig. 1; Fig. 4d). It is the *Sasso del Drago – Drake Spur* (Chiavenna Valley, Central Italian Alps). It has an evocative name, as it often happens in the case of serpentinoschists rocky cliffs, and as mentioned before, this is one of the rare examples where climbing activity is practiced. The climbing spot is very accessible and it offers the possibility of climbing on several routes of different difficulty. The lower portion is constituted by ultramafic rocks (Fig. 4d) of the Chiavenna Ophiolitic Complex that are folded within the gneiss of the Tambò Nappe (Pennidic Domain). In this lower portion of the climbing wall, climbing routes are suitable for beginners, while in the upper and northern portion of the climbing wall, where it is incipient the presence of gneisses, routes present higher difficulty. This spot, even if it is not considered as geosite in any catalogue, represents a good and rare site for getting in touch with geology and geomorphology of rocks of oceanic origin through an outdoor activity.

Discussion and conclusions

The 12 iconic selected landscapes, here illustrated at different scale, are representative of geodiversity of the Italian mountains and they clearly show the important role played by lithology, stratigraphy and tectonics, in conditioning the superficial modelling and, as a consequence, the development of leisure and sports activities. They are surely not exhaustive of the geodiversity and geo-richness of the Italian territory, but the recent researches performed at these sites allow to evidence the importance of the geologic and geomorphologic support for promoting geosites, sites of cultural interest, opportunities for outdoor (sport and leisure) and educational activities in the field (Pelfini et al. 2016).

The presented sites have been recognized, under different modalities, as part of the cultural heritage (Panizza, Piacente, 2003), that takes into consideration the geological and geomorphological context of the Italian territory (Soldati, Marchetti 2017). Two of them (i.e. J – *Terra Rossa* peak; K – *Pietra Parcellara*) are included within protected areas, two others (i.e. E – *Dolomites*; H – *Orcia Valley*) are UNESCO World Heritage Sites and one (i.e. A – *Mont Blanc Massif*) is considered for Transboundary initiatives of valorisation and the associated glaciated environments are part of a SIC within the Rete Natura 2000. The selected sites allow to describe the most meaningful values considered in geosite assessment procedures (Brilha 2016). Besides the scientific value, the socio-economic attribute is relevant, where rocks are exploited as building and ornamental materials as in the *Mottarone Massif* case (i.e. B), where also the cultural value of the extraction techniques is being more and more recognized through time (Cavalli, Dino 2014). Cultural value characterizes also sites where litho-diversity, due to contact between differently competent rocks, has allowed the development of typical landforms like mesas (i.e. G - *Pietra di Bismantova*) or monadnocks (i.e. K – *Pietra Parcellara*), rocky spurs, that in some cases were chosen for human settlements and especially castles (i.e. H – *Radicofani*, I – *Bardi Castle*). Locally, lithology may favour the increase of the ecological value of geomorphosites as in Trebbia and Orcia valleys where endemic flora corresponds to peculiar morphologies and substrates (i.e. H – *Radicofani*; K – *Pietra Parcellara*).

The focus of this *landscapes collection* has been actually put towards geomorphodiversity as support to different types of tourism (i.e. cultural, naturalistic, linked with sport and educational activities) which may provide a socio-economic return for local communities deriving from geoheritage management. Cultural tourism is linked for example with the cited castles (i.e. F – *Radicofani*, I – *Bardi Castle*), while sport tourism is more linked with rock-walls, rivers and slopes features as we have described above:

- climbing routes difficulty is linked with cliffs morphologies depending on structures or minerals weathering (i.e. A, B, C, D, E, L study cases),
- canyoning is linked with riverbed characteristics and water discharge (i.e. F study case),
- speleology is related to the morphology of hypogenic karst once again to be put in relation with water discharge or glacial exharation (i.e. D study case).

Each one of these outdoor activities, linked with geological-geomorphological features, is considered of great importance both for Geosciences and Physical education favouring multidisciplinary educational approaches (Bollati et al. 2018), as described in the case of the *Gekologia Project* (e.g. Pelfini et al. 2016, Bollati et al. 2018). Potential for use and educational exemplarity of proposed sites, related to outdoor educational activities is hence high.

Moreover, where ecological support role and cultural values are high, multidisciplinary educational projects addressed to schools of different level may be successful too. Nevertheless, geological characteristics as well as geomorphological processes are responsible also for potential hazard, generating risk for users (Motta et al. 2009 for climbing sites) and also for geosites themselves (Pelfini, Bollati 2014). However, at the same time, outdoor activities may become key situations for risk education, carried out in safety conditions, as mentioned for the Sardinia and Emilia-Romagna study cases (Coratza, De Waele 2012, Bollati et al. 2017b).

In conclusion, the hot spots of the Italian relief geomorphodiversity presented here underline the importance of structural and lithological diversity in combination with climate influence. The resulting landscapes are representative of the Italian geoheritage (Soldati, Marchetti 2017) characterized by specific values: scientific (e.g. geomorphological, educational, ecological), aesthetic, cultural, socio-economic. Moreover, their potential for use in term of sports, leisure, tourism and school activities is very high. All discussed sites, analogously to innumerable others in Italy and worldwide, are generally characterized by different kinds of fruition (cultural, sport activities, naturalistic). All the landscape features, as a whole, allow us to better understand concepts like time and space in relation with landscape evolution and human presence helping in overcoming the concept of the immutability of the geological landscape and to get in touch with its dynamicity. Moreover, this has a great importance for developing Geosciences education strategies as it allows to get in touch with Geosciences in an appealing way, to know and understand the control role of lithology in the modelling of the landscape and to get awareness about the active geomorphic processes, including Man-triggered ones.

Finally, the selected examples are representative of the possibility of enhancing of such environments under different perspectives, not disregarding the involvement of local communities and, for this reason, favouring the socio-economic return deriving from mountain geoheritage management.

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