Mem. Descr. Carta Geol. d'It.
LXXXVII (2009), pp. 109-122
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Geomorphological hazard assessment on natural rock wall for free climbing practice

Valutazione del rischio geomorfologico su pareti naturali in roccia per la pratica dell'arrampicata sportiva

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ABSTRACT – A new operative hazard and capability assessment methodology for free climbing sites is presented. The activity is based on specific surveys of geomorphological hazard, rock quality, and tourist capability and vulnerability, using a specific data collecting sheet. The *in situ* surveys provided data collection of tourist-sport quality indexes (site "appeal" capability), of geological-technical parameters of the studied rock wall and on the overhanging slope. Geomorphological survey aimed at the definition of hazardous processes.
The practical operability of the method has successfully been experimented on the crag *Vecchie Gare* of the *Pietra di Bimantova* (Northern Apennines) which resulted "very good" from the tourist-sport point of view, "fair" from the stability one and with high "appeal" (frequentation). The rock wall is affected by rock falls, coming from the upper slope, but with such a long return time which guarantees a sufficient safety level. This is in good agreement with the local authorities' decision, which allows the climbing on this wall, excluding the sector directly above some buildings (shrine and alpine hut), but forbidding it on the overhanging slope.

KEY WORDS: geomorphological hazard, slope stability, tourism, geological-technical survey, geomorphological risk, free climbing.

RIASSUNTO – Questo lavoro presenta una nuova metodologia operativa di valutazione del rischio e delle potenzialità dei siti per l'arrampicata sportiva. La procedura prende spunto dai dati ottenuti dal rilevamento sul terreno di pericolosità geomorfologica, di qualità della roccia, di potenzialità e vulnerabilità turistica, utilizzando una scheda di raccolta dei dati, adattata al caso specifico a partire da un documento in via di elaborazione nell'ambito delle attività dell'AIGEO (Associazione Italiana di Geografia Fisica e Geomorfologia). La raccolta dati *in situ* è finalizzata, in particolare, a ottenere l'indice di qualità turistico-sportivo (potenziale di attrattività del sito), i parametri geologico-tecnici della parete studiata e del versante soprastante e, infine, alla definizione dei processi geomorfologici potenzialmente pericolosi.
Le informazioni e i dati, normalmente rappresentati su una cartografia geomorfologico-turistica, sono stati raccolti e gestiti in un *database* dedicato. L'applicabilità del metodo è stata sperimentata con successo sulle pareti della Pietra di Bismantova (Appennino Settentrionale, Reggio Emilia), nel settore denominato "Vecchie Gare"; le pareti sono risultate di buona potenzialità turistico-sportiva, con alta frequentazione e di qualità media dal punto di vista della stabilità. L'ammasso roccioso della Pietra di Bismantova è ben conosciuto in Letteratura ed è stato approfonditamente studiato dal punto di vista geologico-strutturale e geomorfologico-applicativo (ROVERI, 1968; GSUEG, 1978; CANCELLI *et alii*, 1987; CONTI & TOSATTI, 1994). L'aspetto tabulare della "Pietra", pur simulando una semplice struttura monoclinalica immergente verso ovest, è il risultato, in realtà, di una notevole complessità sia geologico-strutturale, sia geomorfologico-applicativa. Infatti i principali blocchi rocciosi che la costituiscono (calcari organogeni arenacei della Formazione di Bismantova) sono stati interessati da meccanismi antitetici di fagliazione; questi ultimi hanno generato strutture cuneiformi impostate su un substrato deformabile (Formazione delle Argille Varicolori *Auct.* sul versante orientale e unità marnose epiliguri *Auct.* su quello occidentale) che hanno predisposto l'intero rilievo a marcate (e generalizzate nel caso del versante orientale) condizioni di instabilità. Nella valutazione della qualità e delle condizioni di sicurezza, ai fini della pratica dell'arrampicata sportiva, non si può prescindere dal quadro geomorfodinamico e strutturale, anche se, alla scala dei tempi umani, l'evoluzione del versante sembra caratterizzata da crolli di soli grossi blocchi, provenienti dalla parte alta del

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versante in roccia. I tempi di ritorno sembrano risultare sufficientemente lunghi e le cause innescanti indipendenti dalla scalata stessa, se limitata al settore in uso e non estesa alla parete soprastante, e legate a condizioni meteorologiche sfavorevoli alla scalata (e quindi a bassa vulnerabilità). La frequentazione delle pareti che ne risulta è in accordo con la decisione delle autorità locali, che permettono l'arrampicata sulle pareti basse, ad eccezione di una limitazione per un settore posto al di sopra di alcuni fabbricati, vietandola sulla parte alta del versante.

PAROLE CHIAVE: pericolosità geomorfologica, stabilità dei versanti, turismo, rilievi geologico-tecnici, rischio geomorfologico, arrampicata sportiva.

1. – INTRODUCTION

Several quantitative and semi-quantitative methods have been already proposed in the last thirty years to be applied in classifying and characterising the rock mass, from the geo-technical and geo-mechanical point of view, both in tunnel and slope construction (see, principally, BARTON *et alii,* 1974; BIENIAWSKI, 1974; ROMANA, 1991). In the last ten years specific themes concerning sport activities on mountain slopes (namely hiking and climbing) have been separately developed in Italy within PRIN project (BRANDOLINI *et alii*, 2004a and b; MOTTA & MOTTA, 2005) and Italian Geological Survey activity (AMANTI *et alii*, 1996 and 1998); they respectively analysed geomorphological risk assessment of tourist paths and both landslide hazard mapping and decommissioned quarry rock wall stability in re-using as climbing sites. This work wants to contribute, more generally, to the studies concerning the interconnection between the geomorphology (variety and the specificity of morphologic conditions) and the tourist dynamic (DEBARBIEUX, 1995; LEONARD & MAO, 2003). Being often the mountain, and in particular the Mediterranean mountains, with the "plurality of the physical supports" and the many geographic fair conditions, a key element in the process of tourism attraction and economic growth (LEONARD & MAO, 2003).

The aim of this research activity is to present a new way of classifying climbing areas in relation to: their tourist-sportive appeal (expressed through quality indexes), risk rating (based on hazard assessment, mostly due to the rock mass behaviour) and, in perspective, the realization of a related geo-database, allowing easy updating and free access. Preliminary results have been already published (MOTTA *et alii*, 2005 a; MOTTA *et alii*, 2005 b) with the specific target to promote a cultural and technical-scientific debate about the climbing activity on natural walls and its capability (as "natural" economic activity) in contributing to mountain sustainable development.

Finally, the authors aim at defining more precisely the natural risk for the climbing frequentation, in terms of geomorphological features and geotechnical conditions, generalised to the used wall and the overhanging slope; defining risk as the consequences of a particular phenomenon of geomorphological instability on a particular human, social, economic condition of vulnerability, (PANIZZA, 1988).

2. – METHODS AND TOOLS

The proposed methodology has been developed starting from *in situ* surveys and data collection, with a specific form, in a significant and representative test area, concerning: the user's presence and satisfaction, the site's features, the equipped crag, the entire rock slope stability and geomorphological processes (including active, dormant and stabilised landforms).

Specific sheets, regarding specific surveyed geomorphological hazards, related to the probability of geomorphological instability phenomenon (PANIZZA, 1988), have been separately filled with data concerning processes, landforms, deposits involved, time evolution and occurrence interval. The resulting three collecting forms provided the attribution of values related to:

- sport and tourist quality, including number and types of potential users and vulnerability/economic values in the case of rock climbing;
- stability of the crag/rock wall, aimed at the assessment directly linked to climbing practice;
- stability of the whole rock mass, including the overhanging slope, aimed at the assessment of the geomorphological hazard of the site;
- they are respectively displayed in table 1, table 2 – 3 and table 4, fulfilled in the chosen and presented case study of the *Pietra di Bismantova*.

Such a data set has been analysed according to the methodologies previously developed and tested singularly by the Authors, respectively MOTTA & MOTTA (2005) for the tourist use, AMANTI & PECCI (1995) for the rock wall classification and characterization and PANIZZA V. (2005) for the geomorphological hazard assessment.

It is important to highlight that all the field data can be (and actually have been) simply collected and subsequently analysed with the usual tool-kit of the geologist, that is a geologist hammer and a compass, according to the methods suggested in AMANTI *et alii*, 1992 and AMANTI & PECCI, 1995. Geo-mechanical data have also been collected with a Rock Schmidt Hammer (Uniaxial Compressive Strength in terms of Schmidt Hammer Test) and a Barton Profiler (roughness and the related shear strength, both calculated according to the Barton's Q-System, 1988) just to have a quantitative control of the calculated indexes.

2.1. – Assessment of the site use capability

Many thousands crags are spread over the Italian mountain ranges and cliffs. They present both high values in terms of geoconservation, as a geosite, and of tourism, as landscape resource.

Only few outcrops can be specifically used for climbing practice: in fact most of them are in weak rock or far from roads or exposed to high altitude hazard. The quality of a rock wall depends on several features, easily identifiable and quantifiable as, for example, the presence of modern and good equipment.

The frequentation of a climbing site, during working days, often strictly depends on the proximity of large cities, due to the limited availability of free time (Biancotti *et alii*, 2001; Leonard & Mao, 2003)

On the other hand, during the week end and the holidays most of the climbers travel, often coupling sport and tourism. In this case the principal factors, reported in table 1, play a significant role in the choice of a destination, also including the time availability vs city distance (Biancotti *et alii*, 2001). Most of the numerical factors in this table are attributed following subjective criteria, or better, following the well known preferences of the climber community, in terms of rock type, climate, vicinity of roads and parking availability. They have been tested in many climbing sites, in Italy and also in some European sites; the relative rating has been determined (Biancotti *et alii*, 2001) as in the following: a sample of 10 climbers received a list of 100 more than well known crags of the western Alps and surrounding areas to be ordered on the basis of the personal frequentation.

A rating of frequentation was attributed taking into account the average of the answers.

Considering two crags for time and analysing the differences among them, the method proposed in Biancotti *et alii* (2001) assigns a rating reflecting the classification based on frequentation.

The final rating is obtained by the product of the values attributed to each feature.

Given the empirical and subjective nature of this kind of evaluation, the numerical factors could slightly vary from site to site, in particular in the case of the feature 2.1 (rock type). In fact the rock climbers of the western Alps, for example, where the form has been tested for the first time, usually classify the sandstone as a "weak" rock (as sandy, fragile and easily artificially excavatable for the progression), whereas it is well appreciated in other parts of Italy (e.g. Northern Apennines) or of the World (North America and eastern Europe), where it is more massive or crystalline.

2.2. – Semi-quantitative assessment of geo-technical features of the rock mass and wall

Taking into account the available literature and the summarizing previous works, the assessment of the rock mass quality in a semi-quantitative way aimed at the collection of survey data concerning namely tunnels and engineering works on natural slopes (Barton *et alii*, 1974; Bieniawski, 1974; Romana, 1991).

Furthermore, survey data, especially oriented to the geological knowledge of the technical behaviour of the slope, have been proposed to be organized and rationalised in a special form (Amanti & Pecci, 1995), with the original aim of landslide hazard mapping (Amanti *et alii*, 1992), new methods and tools of survey and study (Amanti *et alii*, 1994) and the rehabilitation of decommissioned rock quarries for climbing use in Italy (Amanti *et alii*, 1996; 1998).

The original data collecting form (Amanti & Pecci, 1995) was modified in the new form presented in table 2 and 3, eliminating data not referable to rock or not useful for the calculation of the Modified (after Amanti & Pecci, 1995) Bieniawski RMR (Rock Mass Rating), i.e. earth and soil, as well as general or "descriptive" indications (already previously provided). Particular care has to be devoted to the survey of weathering conditions. For what concerns the presence and the spatial distribution of discontinuities and joints, two new pieces of information have to be collected: the first one concerning the persistence of discontinuities and the second one the total number of joints per m^3.

It is important to highlight that the preliminary survey of the persistence of a single discontinuity or of a set of joints is needed in order to characterise the behaviour of the rock mass and to proceed in further analysis. In the present context and perspective of study we suggest to use the Piton Infixion Test (Amanti *et alii*, 1994), an experimental, easy and useful test, capable to determine, in a qualitative way, the persistence of a discontinuity (at the scale of the outcrop) on the basis of different sound of the rock piton during the infixion (metallic into a persistent joint or plonk into a blind joint).

Tab. 1 – *Form for the assessment of the capability of rock crags for climbing practice; data surveyed in the Pietra di Bismantova site. The final rating is obtained by the product of the values attributed to each feature.*
– Scheda per la valutazione dell'idoneità delle pareti rocciose per l'arrampicata, dati rilevati alla Pietra di Bismantova. Il valore finale è ottenuto dal prodotto dei valori attribuiti ad ogni singolo fattore.

1. Crag height

0.2 H<10m **1** 10m<H<20m **2** 20m<H<30m **1.5** 30m<H<50m **1** > 50m

2. Rock features

2.1. Rock type
2 Limestone
1.7 Others sedimentary carbonatic rocks
1.8 Siliceous eruptive rocks (granites, acid lava)
1.8 Gneiss
1.3 Metamorphic massive rocks (amphibolites, marbles...)
0.6 Metamorphic schistose rocks
1 Quartzite
0.8 Sandstone
1.2 Conglomerate
0.2 Volcanic rocks (basalts, basic lavas)

2.2. Rock quality (for climbing)
0 Deep weathering
0.2 Shallow weathering, it is necessary to be careful
0.8 The rock is sometimes doubious, it is necessary to be careful
1 The rock is cracked, they are not dangerous blocks
1 Slabs with narrow steps, because cross of several joints systems
2 Surface with weathering and case-hardening
0.3 No cracking, smooth surface
0.9 Surface smoothed by climbers (potential rock slides)

3. Climate features

3.1. Local climate

Altitudine/aspect	N	W / E	S
0 - 500	**1.2**	**1.0**	**0.8**
500 - 1000	**1.0**	**1.2**	**1.0**
1000 - 1500	**0.8**	**1.0**	**1.2**
1500 - 2000	**0.4**	**0.8**	**1.0**
> 2000	**0.1**	**0.4**	**0.8**

3.2. Dampness and rain exposition
1.2 "Xerothermic oasis"
1 Normal, rain exposed
0.8 Very wet
2 Possibility of climbing with rain

3.3. Wind exposition
0.8 Wall providing a shelter
0.6 Windy
1 Normal

4. Frequentation capability

4.1. Car park access
1 Paved road
0.9 Paved road, then dirt-road < 1km
0.5 Dirt-road more then 1km in length
0.1 Dirt-road in bad condition

4.2. Parking capacity
1.2 > 20 cars
1 5 – 20 car
0.5 < 5 cars

4.3. Average approach time from the car park to the wall
1.5 <10' **1** 10'<t<20' **0.5** 20'<t<30' **0.3** 30'<t<60'
0.1 1h<t<2h **0.01** >2h

4.4. Climbing troubles (absence: coefficient 1)
0.1 Vicinity of active quarry
0.01 Crag near to main road
0.5 Crag near to secondary road
0.5 Urban position
0.7 Wall close to tourist beach
0.2 Poor social security (theft)

5. Landscape troubles *(absence: coefficient 1)*

5.1. Landowners troubles
0 Access prohibition (enclosures, restricted areas…)
0.8 Access across private lands (fields, vineyards)
0.1 Rockwall hazards on buildings

5.2. Human heritage
0 Rock carving surfaces on the whole of the wall
1.2 Some rock carving surfaces
1.1 Historical site (caves used by pursued peoples...)
1.1 Historical climbing routes

5.3. Wildlife problems
0.8 Protected area
0 Area with climbing limitation
0.1 Nests of protected birds (hawks, owls...)
0.5 Habitat or winter refuge of wildlife (wild bees, snakes...)
0.1 Endemic species of plants
0.2 Protected flowers
0.6 Minerals or fossils interesting for collectors

6. Development capability

6.1. Crag length
0.7 Pillar **1** 20m<L<50m **1.3** 50m<L<100m
1.4 >100m

6.2. Number of well-protected routes (modern equipment)
1 >10 **0.7** <10

6.3. Climbing style
1.8 Sustained vertical or overhanging walls
2 Variety of slabs, roofs or overhangs, sustained difficulties
1 Long walls, difficulties concentrated in short distance (boulders)
1.2 Slabs
0.9 Short routes, hard difficulties (boulders)
0.6 Short and easy routes
0.8 Smooth walls with carved pockets or pasted stones

6.4. Crag seclusion
1 Distance of other climbing spots < 30 km
1.5 Distance of other climbing spots > 30 km

6.5. Panorama quality
1.5 Dominant position
1.2 Ample panorama
1 View limited (by vegetation…)
0.8 Low position (deep valley…)

7. Fame

2 The description of the crag is in a guide
1.5 The description of the crag is in climbing magazine
1 It is possible to find the description of the crag in shops or bar near to parking
1 The description of the routes is in a bill at the foot of the crag
1.2 The description is only on web sites
0.8 No description

2.3. – Geomorphological assessment of the active processes on the rock wall and on the overhanging slope

As the safety of rock climbers depends both on the specific rock mass mechanic features and on the general environmental and geomorphological outline of the slope surrounding the climbing wall, it is of primary importance to be able to evaluate the stability of a rock face via a preliminary and in-depth investigation of the geomorphological characteristics and active processes throughout the site and of the zones above.

In rock walls the structural factors which can produce instability are principally represented by its vertical orientation and preferential detachment determined by the discontinuity net.

The weakening of the rock wall, in particular along the micro landforms used by the climbers for the vertical progression, can induce risk conditions. Each discontinuity, in fact, can be used by the climber as a way of progression both for self safety/protection equipment and for the vertical progression. At the same time the position, orientation, persistence, features and density of the joint systems influence the rock mass quality and induce the development of erosional processes (Panizza V., 2005).

Tectonic movement, present or recent, insistent erosive processes on the wall-face or the overhanging slope and other causes of weakening the rock mass (Panizza M., 2005; Bollettinari & Piacentini, 2005) can induce instability and produce more or less large and unpredictable rock falls. As the gravitational phenomena occurring on vertical rock walls are characterised by extremely high velocities, both in the case of collapse and toppling, the danger caused by these processes is naturally very high, independently of the amount of material involved (Bollettinari & Piacentini, 2005).

It therefore seems clear that a geomorphological survey of the area should always precede or support the geotechnical and semi-quantitative measurements of the rock wall.

Signs of instability are evident, at first sight, on the rock-face and in the zone below. For example, the presence of lighter areas can indicate recent detachment, whereas blocks and debris at the base show evidence of a recent rock fall ("fresh" surfaces still not weathered or not yet colonized by lichens) while the most weathered surfaces, characterised by a darker colour, can show low geotechnical qualities; therefore, they are not safe for climbers.

For what directly concerns the geomorphological hazard survey the proposed protocol (modified and simplified after Brandolini *et alii*, 2004 a and b) needs the filling of four forms. They namely collect the evidence of geomorphological hazards and tourist risk. The first form is aimed at the general description and localization of the area, whereas the three others analyze the geomorphological hazards and the potential risk of the climbers. More in detail the forms classify and quantify the active processes and the related landforms and deposits, with the description of morphometric features and temporal frequency of the phenomenon. The description of hazards is divided in two parts: the first one concerning all the geomorphological phenomenon surveyed in the studied area and the second one concerning a deeper description of each active geomorphological phenomenon affecting the slope or the close surroundings. Finally, in the last form the actual geomorphological risks are described.

3. – THE CLIMBING CASE STUDY OF THE *PIETRA DI BISMANTOVA* ROCK WALL: AN APPLICATION OF THE PROPOSED METHOD

After a review on the available methods and tools and the discussion on the best draft, a general control of the form has been performed in the test site of the *Pietra di Bismantova* (indicated more briefly "*Pietra*" in the following, figure 1).

The choice was suggested by the well known scientific outline of the area and the high frequentation of both climbers and hikers.

Moreover, the particular climbing sector and wall, chosen for the test of the form, has been used for one of the first climbing competitions in Italy, guaranteeing an actual presence, continuity and activity in the last twenty years.

3.1. – The climbing area and selected site *Pietra di Bismantova* (Northern Apennines): geographical, geological and geomorphological outline

The characteristic relief of the *Pietra*, close to the village of Castelnovo ne' Monti (Reggio Emilia, Italy), is the product of structural landform in arenaceous limestone.

The general structural pattern of the *Pietra*, originally interpreted by Roveri (1968) as a monocline gently westward dipping, is further complicated by the superimposition of gravitational processes and landforms, leading to a complex evolution. An exhaustive geological and structural study (Conti & Tosatti, 1994) highlighted as the tabular NE-SW monolithic attitude of the *Pietra*

Tab. 2, 3 – *Form for the semi-quantitative assessment of geo-technical features of the rock mass and wall. For detailed information see* A*MANTI* & *P*ECCI*, 1994. In bold data surveyed are the Pietra di Bismantova.*
– Scheda per la valutazione semi quantitativa delle caratteristiche geotecniche della massa rocciosa e della parete. Per ulteriori dettagli si veda AMANTI & PECCI, 1994. In grassetto i parametri rilevati alla Pietra di Bismantova.

TABLE 2		1	2	3	4
ORIENTATION OF THE ROCK WALL		Strike: **N 220°**		Dip: **vertical (85° - 90°)**	
Ia	NATURE OF WEATHERING	Absent	**Sand/granular**	Silt	
Ib	DEGREE OF WEATHERING	**Unweathered or slightly weathered**	Poorly – very weathered	Completely weathered	
II	DEEP/THICKNESS OF WEATHERING	**< 1m**	1-3 m	3-5 m	
III (**R3**)	HARDNESS (DISCONTINUITIES SPACING)	**>100cm**	30-100cm	5-30 cm	
IVa	PERSISTANCE OF DISCONTINUITIES	**Yes on sight Yes on piton test (persistent)**	Yes on sight No on piton test (semi-blind)	No on sight Yes on piton test (semi-persistent)	
IVb (**R4**)	ATTITUDE OF DISCONTINUITIES	**Yes** see AMANTI & PECCI, 1994	No		
IVc (**R2**)	TOTAL NUMBER OF JOINTS PER m^2	**21**			
V	STRENGHTENING LAYER ON WEAK LAYERS	**Yes**	**No**		
VI	PERMEABLE LAYERS ON NON-PERMEABLE	**Yes**	**No**		
VII	NATURAL FRICTION ANGLE (Φ RES)	**>25°**	20°-25°	15°-20°	<15°
VIII	GEOTECHNICAL COMPLEXITY	**Non complex**	Shale	Alternances with clay	Chaotic with clayey matrix
Ixb (**R1**)	CHARACTERISTIC OF COMPRESSION STRENGHT	Number of geologist hammer hits (Rock): **5**			
X	DEFORMABILITY	**Layered and massive rock**	Shale and alternances	Granular and compact or over consolidated ùand cohesive hearth	Granular and cohesive disturbed hearth
XI	PROGRESSIVE BREAKING HAZARD	**Overconsolidated clay and unweathered rock**	Overconsolidated clay, weathered and poorly cemented rock	Poorly cemented and weathered rock	Overconsolidated weathered and weak clay
XII (**R6**)	PERMEABILITY	Very permeable	**Permeable on average**	Poorly permeable	Non permeable
XIII	DEGREE OF COHESION OR CEMENTATION	**Cemented**	Overconsolidated	Normal consolidated	Underconsolidated
XIV	PRESENCE OF WEAKNESS ZONES	**Very few failure surfaces without clay**	Few failure surfaces also with clay	Many failure surfaces	Very abundant failure surfaces

TABLE 3							IXa FRICTIONAL CARACTERISTIC OF STRENGHT	
(R5)	Attitude (strike/dip)		Opening (mm)	Filling see Amanti & Pecci, 1994	Persistence (yes/no)	Percolation	Average spacing (cm)	Barton profile see Amanti & Pecci, 1994
STRATIFICA-TION OR SCHISTOSITY	N 150°	Horizontal	0	0	Yes	No	5 cm	High roughness (class 10)
FAULT								
JOINT FAMILY 1	N 330° - 85°E	Transverse to the slope	10/50	No	Yes	No	1000	High roughness
JOINT FAMILY 2								
JOINT FAMILY 3								
SCHMIDT HAMMER (rocks)	An average (on 10 measures) of 34.2 of the Schmidt rebound number, corresponding to about 70 MPa							
BARTON PROFILE - TO BE DRAWN (rocks)	Profile n. 10, corresponding to 18 – 29 interval of values for JRC							

Fig. 1 – Location and general view of *Pietra di Bismantova*.
– *Ubicazione e veduta generale della Pietra di Bismantova.*

can be actually divided in two blocks: the major roughly rectangular and the minor with an arched-shape. The structure (CONTI & TOSATTI, 1994) is deepened along two antithetic fractures and outcrops above ductile-deformable units, respectively clays of the *Argille Varicolori* (*Unità liguri Auct.*) in eastern margin and flinty marl of the *Formazione dell'Antognola* (*Unità epiliguri Auct.*) in the SW sector. Here, more or less in correspondence of the shrine and the morphological trench (*sensu* CONTI & TOSATTI, 1994 and CANCELLI *et alii*, 1987), the survey site has been chosen in correspondence of the climbing sector *Vecchie gare*. From the geological point of view (GSUEG, 1978; CONTI & TOSATTI, 1994), the principal body of the *Pietra* is composed by well cemented bioclastic limestone with a gros-grain texture, belonging to the *Formazione di Bismantova – Membro della Pietra di Bismantova* (upper Burdigalian). The stratification shows frequent layers with sub-horizontal strike and slip. The contact between the large walls of the plateau and the topographic surface is marked by a large *glacis,* partly broken up or eroded and actually reduced into weakly tilted strips.

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*; subsequently, between the 1940s and the '60s, most part of the easier paths were climbed, soon becoming "classic" and well equipped. In the same years the first artificial lines were climbed, often attracting the most important italian mountaineers. Since the end of the '70s free climbing development started together with the equipment of a great number of paths, characterising also today the southern and equipped face (fig. 2).

The name of *Pietra* derives from the particular shape of the rock outcrop, extended along NE-SW direction and overlooking the landscape of the area. The outcrop is bordered by steep walls high more than one hundred metres in the southern slope, where the tabular summit reaches the maximum elevation of 1047 m (fig. 3), decreasing in thickness towards the northern slope. All the surrounding slopes are widely interested by landslide body of accumulation, but undoubtedly more frequent on the eastern margin, in correspondence of the outcrops of the *Argille Varicolori*, with the failures still well detectable along the principal discontinuities.

3.2. – THE FULL-FILLED FORM

Given the "test site" perspective of the work on the *Pietra*, all the potential interesting parameters (from the tourist, geological-technical and geomorphological point of view) have been surveyed and collected on the preliminary form. As specified in the previous paragraphs, the form, after the test in the *Pietra*, has been modified in the presented definitive draft.

3.2.1. – *The site use capability (tab. 1)*

The final rating obtained after the step to step table 1 elaboration for the sector Vecchie Gare is:

$$2 \cdot 1.3 \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1.2 \cdot 1 \cdot 1 \cdot 1 \cdot 1.4 \cdot 1 \cdot 1.2 \cdot 1.5 \cdot 1 \cdot 2 = 15.7$$

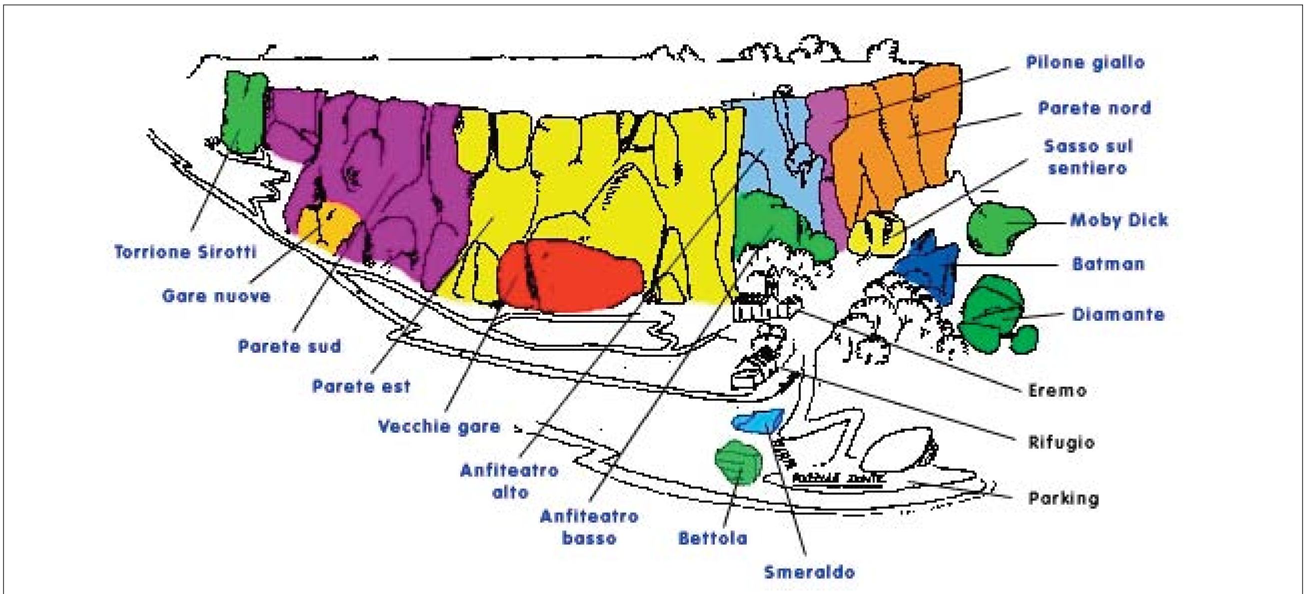

Fig. 2 – Sketch of the equipped walls of the *Pietra di Bismantova (www.sincretech.it/bismantova/html/arrampicata).*
– *Schema delle vie attrezzate per il freeclimbing della Pietra di Bismantova (www.sincretech.it/bismantova/html/arrampicata).*

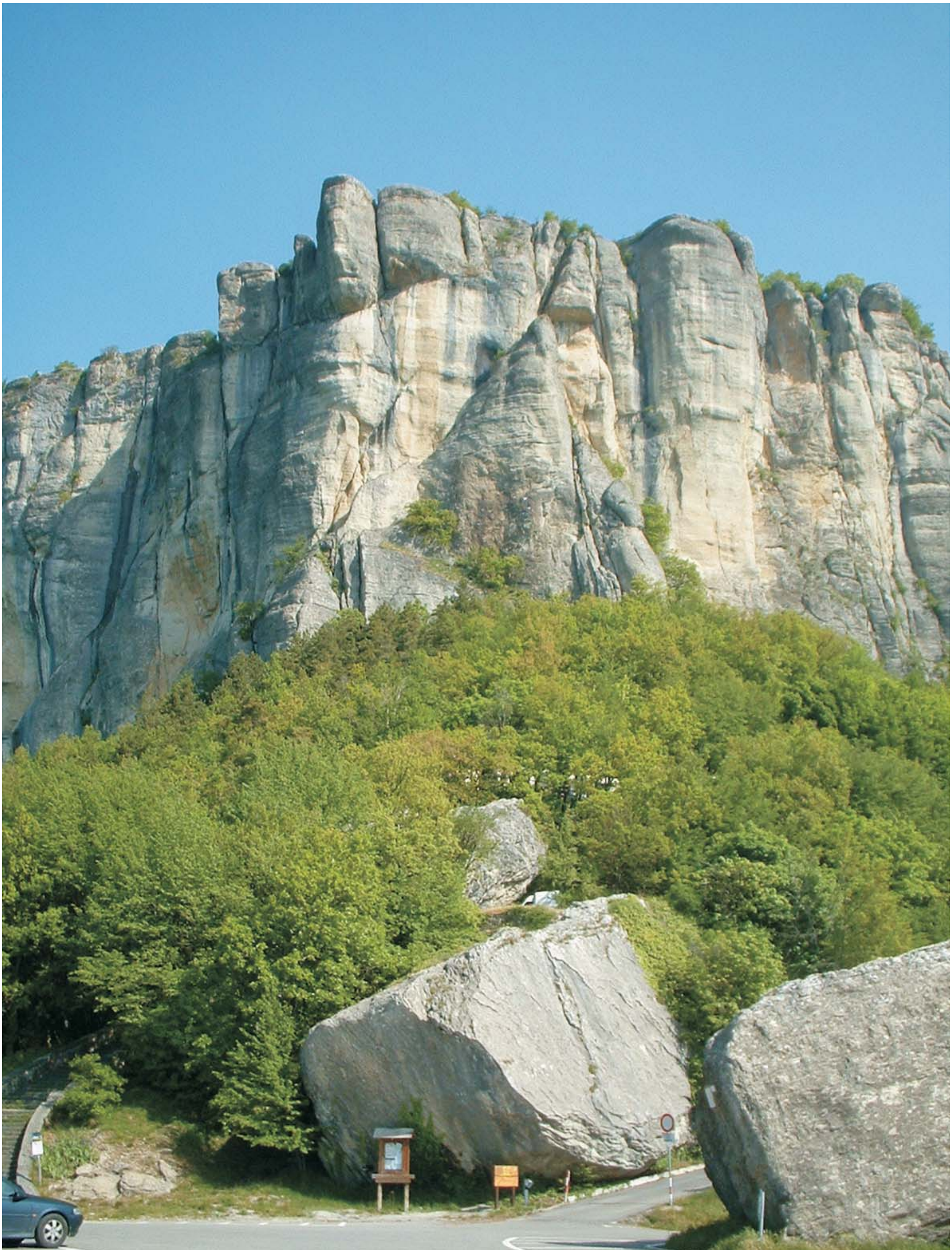

Fig. 3 – The high walls of the southern slope.
– *Le alte pareti del versante meridionale.*

The rock of the *Pietra*, rich in calcareous matrix and cement and equipped with case hardening, is highly appreciated, as confirmed by the organization of climbing competitions. The rating of feature 2.1 is practically comparable, for example, to the massive alpine metamorphic rocks. In fact, even if with different genesis, the crag surface on the sandstone of the *Pietra* (and related climbing styles) are quite similar to the one characterizing the alpine prasinites.

The obtained result is comparable to the one of the famous climbing areas of Finale region (Western Liguria, where rock climbing is actually promoting a well detectable tourist flow) and of the Briançonnais. A particular factor plays a role in increasing the site use capability: in highly frequented crags the rock quality usually seems to show a time-dependent decay because of the smoothing of the rock and the lowering of the grip (values of "rock quality" from 1-2 to 0.9, in table 1). Particularly on limestone the frequentation of a crag describes the following cycle: discovery → notoriety → smoothing → quality loss → abandonment. On the contrary, the *Pietra* shows an inverse trend, in fact the handholds of the local sandstone seem to become deepened with use and in the meantime the frequentation increases.

3.2.2. – *Assessment of the rock mass and wall quality (tab. 2 - tab. 3)*

The form has been completely fulfilled in the test site of *Pietra*, including mechanical data surveyed both by experimental methods and instruments (Schmidt hammer and Barton profiler). The resulting Modified Bieniawski (after AMANTI & PECCI, 1995) Rock Mass Rating (BMRMR) = 58 corresponds to fair rock condition (uniaxial compressive strength of the rock between 50 and 100 MPa – BIENIAWSKI, 1974) and also well matches the value of the uniaxial compressive strength, calculated on the basis of the Schmidt hammer test, in fact, imputing a value of Schmidt hammer rebound number equal to 34.2 (from an average of ten hits) and considering an estimated sandstone bulk unit weight 2.45 kN/m^3 (IPPOLITO *et alii*, 1983) a value of about 60-70 MPa has been calculated.

The obtained value and BMRMR are in agreement with the stability condition of the rock mass, controlled at meso and macro scale respectively by stratification and sub-vertical tensile discontinuities. They produce, respectively, little "brick pattern" at the toe of the wall (fig. 4) and mega-boulders at the toe of the whole slope (fig. 3).

3.2.3. – *Geomorphological hazard and active processes (tab. 4)*

In the form fulfilled for the *Pietra*, we describe in details the main geomorphological hazard affecting the rock wall examined. Some characteristics of the phenomenon are briefly described: like spatial and morphometric characters, frequency in time, valued on the base of geomorphological evidences, rock characters and other. In other fields of the form some more details are given, concerning the description of the geomorphological hazard and the meteorological conditions increasing the phenomenon.

The whole outcrop of the *Pietra* is affected by several joint systems: the more frequent surveyed in the studied crag outcrops with N330° (N150°) – subvertical dipping, in agreement with CONTI & TOSATTI (1994). The structural finger-print is evident and well-detectable along the wide and high bordering walls (fig. 4). The weathering processes, namely due to infiltration (seepage) of running water, concentrate along the joint system pattern; in fact on the tabular summit of the *Pietra* there are frequent landforms connectable to the karst dissolution; on the other hand gravitational phenomena, mainly linked to the frost wedging and related fall also of large dimension blocks, are active, still at present, at the toe of the slopes.

This activity, as highlighted in *Gruppo di Studio delle Università Emiliane per la Geomorfologia* - GSUEG (1978), has been witnessed by accumulation bodies of rock falls, expanded along the eastern borders. The published map (GSUEG, 1978) also highlights wide deposits of blocks due to rock falls, successively re-mobilised by creep processes affecting the underlying less massive units.

At present the most important hazard sources affecting the walls, equipped for free climbing, consist of sudden debris and blocks fall; the layering planes and the thick network of joint systems, affecting the whole outcrop of the *Pietra*, isolate blocks and pillars of several shapes and dimensions: the progressive widening of discontinuities, namely due to weathering, is able to promote instability processes. Previous studies (GSUEG, 1978; CONTI & TOSATTI, 19949 have already detected the toe of the southern-eastern slope of the *Pietra* attributable to a rock fall accumulation area. The frequency of the phenomena has been evaluated with an order of about ten-years return time by the authors of the present work. At the same time the triggering factors of rock block falls and topples have been evaluated in seismic activity, even if light, in cumulate rains during prolonged periods and in frost-thaw cycles, possibly coupled with precipitations.

Fig. 4 – One of the walls of the climbing sector *Vecchie Gare*.
– Una delle pareti del settore di arrampicata Vecchie Gare.

Tab. 4 – *Form part concerning the description of the geomorphological hazards, filled for the Pietra di Bismantova.*
– Parte della scheda relativa alla descrizione delle pericolosità geomorfologiche, riempita per la Pietra di Bismantova.

GEOMORPHOLOGICAL HAZARDS PART 3.1

Hazard typology: rock falls

Spatial characteristics:
☐ areal ☒ linear ☐ punctual

Cause
☒ Natural
☐ Man made

Specific description of the hazards:
Main preparing causes: dormant edge of monocline relief and presence of wide joints. Chemical and mechanic erosion induced by presence of water in the discontinuities. Frost wedging

Main triggering causes: Progressive widening of the discontinuities and related gravity falls of blocks and boulders. Seismic shock. Direct stress

Rock characteristics:
Lithotype: Arenaceous limestone

Weathering degree:
☐ hight ☐ average ☒ low

Joint rating: ☐ hight ☐ average ☒ low

Morphometric features of the phenomenon
Surface area: whole
Vertical difference height:: 75 m
Average pitch: vertical
Length of the interested section: whole

Potential frequency of the phenomenon:

Ten-year
yearly
seasonal
monthly
continuous

Hazard degree associated to the event: Low

Meteorological variation triggering or increasing geomorphologic hazard:
cumulate heavy rain; frost coupled with rain

4. - CONCLUSIONS AND PERSPECTIVE

The use of the data collection form has been tested in the *Vecchie gare* climbing sector of the *Pietra*, in order to apply the proposed methodology for the general assessment of a rock natural wall. The results in terms of quality and tourist-sport frequentation, rock wall stability and geomorphological hazard, well match the perception of a "suitable" site, in good safety conditions management, with localized geomorphological hazard and rock instability problems, where a climbing limitation or prohibition is already active.

The use of the data collecting form is, at the moment, experimental and needs further tests (for the evaluation of the methodology) in different lithological, geographic and tourist contexts. The definition of the same format of the form is still in progress, due to the relative high number of fields to be filled, and to the perspective to realize a digital "light" version to be used on a pocket pc directly *in situ*.

Therefore, with regards to climbing practice, the risk mitigation can be obtained with a reduction of vulnerability, depending on climber condition, and/or with a reduction of geomorphological hazard. In the first case information and awareness concerning the environment and its evolution are of paramount importance; from the hazard mitigation point of view prevention is carried out throughout the study and knowledge of the geological setting and active geomorphological processes and monitoring of the related quantitative parameters, to be collected in the proposed form.

The production of scientific-informative documents can represent the point of convergence of these two paths: to this goal several data can be collected from scientific observations and included in the informative document. Not all the scientific information can be presented but they must be selected and used by tourists, climbers or professionals.

The first operative indications concerning the results obtained in the test sites can be shared by the climbing community for a better management of the safety and environmental conditions of the rock walls. In a first and preliminary step the operative indications could be highlighted in traditional and digital climbing guides. In fact, although outdoor tourism is nowadays a consolidated truth and practice, many activities do not take into account the natural and climatic limitations to this such a tourism. Proposed sportive activity is often superficially chosen and therefore insufficient attention is paid to the geomorphological processes, sometimes causing accidents. Moreover, areas of great danger are often frequented for practicing the so-called the "extreme sports", namely impetuous torrents (rafting), ravines (canyoning), caves (speleology), crags (free climbing) and others.

In a wide and more general framework this kind of management would be, in the authors' opinion, a real occasion for sustainable tourism in mountain areas to be proposed to local administrations.

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