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Mapping Geoheritage

Géraldine Regolini-Bissig
Emmanuel Reynard
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The new interest for the geomorphological heritage has induced the International Association of Geomorphologists (IAG) to create in September 2001, at the 5th International Conference on Geomorphology held in Tokyo, a specific working group aimed at working on issues concerning geoheritage, geotourism and geoconservation. It aims to improve knowledge and scientific research on the definition, assessment, cartography, promotion and conservation of geomorphosites. The group is chaired by Emmanuel Reynard (University of Lausanne, Switzerland) and Paola Coratza (University of Modena and Reggio Emilia, Italy).

Experiences are shared during workshops and international conferences. The workshop "Mapping Geoheritage" was organised by the Institute of Geography of Lausanne University in Sion and Lausanne, Switzerland, from 17 to 20 June 2008. 20 participants coming from six countries (Switzerland, France, Italy, Slovenia, Portugal and Poland) took part.

The objectives of the workshop were:

- to discuss experiences and needs in mapping issues in geoheritage and geotourism;
- to identify research perspectives in geoheritage mapping;
- to develop new methods and legends to be used for the cartography of geoheritage;
- to practice NTIC and GIS in mapping geoheritage.

This volume of "Travaux et Recherches de l'IGUL" presents eight contributions. In the first article, G. Regolini-Bissig (University of Lausanne) proposes recommendations for elaborating geotourist maps. The second paper, written by S. Martin (University of Lausanne) is a kind of application of Regolini-Bissig's proposals. It presents the different steps for the preparation of a geotourist map of the glacio-karstic area of Tsanfleuron (Swiss Alps). Four papers present case studies in various geomorphological contexts. P. Brandolini (University of Genova) and M. Pelfini (University of Milano) propose a method for mapping geomorphological hazards along hiking trails used for geotourism. B. Erhartič (Slovenian Academy of Sciences and Arts) discusses mapping issues at the scale of the country and of a geosite. A. Rovere and colleagues (University of Genova) discuss mapping issues of underwater geoheritage. Finally, M. Pelfini and colleagues (University of Milano) present investigations carried out on glacial geomorphosites in the Italian Alps. The last two papers have a more technical value. The first one, written by L. Ghiraldi and colleagues (Universities of Modena and Torino), concerns the use of GIS and geomatics tools in the assessment and exploitation of geomorphosites, whereas the second, written by M. Giardino and colleagues (University of Torino) presents a specific GIS mobile mapping tool useful for data collection and mapping in the field.

We hope that the papers collected in this volume will be useful for researchers working on geomorphosites and geotourism, and that they will help to fill a gap concerning mapping development in the domain of geoheritage management, conservation and promotion.

Lausanne, April 2010

Emmanuel Reynard and Geraldine Regolini-Bissig

Mapping geoheritage for interpretive purpose: definition and interdisciplinary approach

Géraldine Regolini-Bissig
Institute of Geography
University of Lausanne
Anthropole
CH - 1015 Lausanne

E-Mail: geraldine.regolini@unil.ch

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1. Introduction

Since the raise of awareness of the importance of Earth Heritage (European Manifesto on Earth Heritage and Geodiversity, 2004), geomorphosites have obtained increasing attention from the scientific community. Assessment methods, classification and conservation strategies have been developed to safeguard the geomorphological heritage for present and future generations (Reynard et al., 2009). On the other hand, Earth Heritage creates opportunities to develop educational and recreational programs as well as tourism projects. Various interpretive supports and local development projects have been engendered in the past few years to promote the geoheritage.

The promotion of Earth Heritage holds the challenging task to reveal to a public of non-specialists (Carton et al., 2005) not only its beauty but, above all, its value as testimony of Earth History. Today's promotion is manifold and concerns different popularisation products and services such as thematic walks, brochures and educational panels, guided visits, etc. Maps are often employed as part of the cited products to show itineraries or points of interest. They also exist as independent media, through which it is possible to visualise geoscientific information. In this case, maps become interpretive media that serve popularisation purposes. However, the efficiency of a map depends on how good the map is designed and how good the knowledge transfer between the parties (scientists, public) operates (MacEachren, 1995).

This paper proposes two definitions of maps used in Earth Heritage promotion (geotourist maps and interpretive maps). It focuses then on the implementation of interpretive maps by pointing out the advantages of using an interdisciplinary approach to improve map effectiveness.

2. Definition

A map that is produced in the field of Earth Heritage promotion is commonly called geotourist map. *"Geo"* stands for the provenience of the information from Earth sciences (geography, geology or geomorphology) and *"tourist"* specifies both the recreational circumstances in which the map is consulted and the users. In spite of the amount of geotourist maps and increasing investigation on this topic (Carton et al., 2005; Castaldini et al., 2005a, 2005b; Bertacchini et al., 2008; Coratza & Regolini-Bissig, 2009; Bissig, 2008), no definition has been proposed so far. By identifying the shared characteristics of a large sample of maps one observes some similarities. They all address a public of non-specialists, communicate geoscientific information and integrate information about tourist facilities and services. Accordingly to this lowest common denominator a geotourist map can, therefore, be defined as *"a map that is used to communicate with a public of non-specialists and that visualises geoscientific information as well as tourist information"*.

In practice, the respective proportion of tourist and geoscientific information as well as the system used for representing such information (visual language, level of simplification of the information, background choice, etc.) are very different from one geotourist map to another (Coratza & Regolini-Bissig, 2009). The term *"geotourist map"* has, therefore, to be thought of as an umbrella term, in which different types of maps can be distinguished. A classification based on a statistical analysis of more than fifty geotourist maps (Bissig, 2008) differentiates between five groups with different levels of scientific content and tourist information:

1) Index maps: They contain low tourist information and low geoscientific information. Their principal goal is to localise itineraries or points of interest.

2) Tourist maps: In this type of map, major attention is given to the representation of tourist information such as picnic areas, car parks, accommodation, etc. Scientific information is, on the contrary, unsubstantial.

3&4) Geoscientific maps for amateurs of Earth sciences: The scientific content is high and the tourist component is medium. It is necessary to distinguish between two types of geoscientific maps for amateurs of Earth sciences because of their different representation system.

5) Interpretive maps: They present a good balance between scientific and tourist information. Furthermore, they try to interpret the represented landscape by revealing its particularities.

Because of the diversity of geotourist maps it is necessary to give a more precise definition of *interpretive maps*: they are clearly designed for the purpose of knowledge transfer between specialists and a public not or poorly familiar with geosciences. Used as an illustration instead of a simple orientation device, the map communicates spatially relevant information that helps to understand complex geoscientific phenomena. For instance, the map can picture past and present processes, which contributed to the formation and evolution of a given landscape. As the following definition clearly states, the essence of interpretive maps is to reveal meaning. Tourist information is not essential but may be added to provide the user with practical visit information.

> *An interpretive map is used to communicate with a public of non-specialists. It focuses on the communication of geoscientific themes in order to provide the opportunity for the user to understand geomorphological or geological phenomena, formation or evolution. Tourist information is of secondary importance.*
>
> *Definition of interpretive maps*

3. Challenges of mapmaking for interpretive purpose

3.1 Information exchanges

The most important difference between interpretive maps and other geotourist maps is the way geoscientific information is presented to the public. The methodological approach, which leads to geotourist maps – especially geoscientific maps for amateurs of Earth sciences (Castaldini et al., 2005a, 2005b; Bertacchini et al., 2007) – is characterised by the principle of simplification. Starting with a geological or geomorphological map for specialists, the simplification is achieved through the reduction of the initial legend, and some specific figures being combined (e.g. active and relict landslides = landslides) or abandoned. In a second stage, basic tourist information (services and facilities) is added. In spite of the simplification process applied in the implementation phase, the derived maps are often rather complex. Furthermore, they are based on a mere reproduction of geoscientific facts from the specialists' representation and legend system, that the public may have difficulty in understanding (Kruhl, 2006).

For the implementation of an interpretive map, the approach with regards to two key processing stages – defined by Coratza & Regolini-Bissig (2009) as codification and decodification phases – should be reconsidered (Fig. 1). In the first phase, the map-maker chooses the information that is to be communicated and designs the map. The modalities according to which the elements to be presented on an interpretive map are selected differ significantly from the ones followed in other geotourist maps implementation: it concentrates on the communication of specific themes and is directed to a well-defined target group (see example below). In the second phase, the users extract the codified information. For an interpretation to be effective, the bridgework (map) has to be correctly understood by the recipient (user). Communication and design issues are, therefore, the focus of interest.

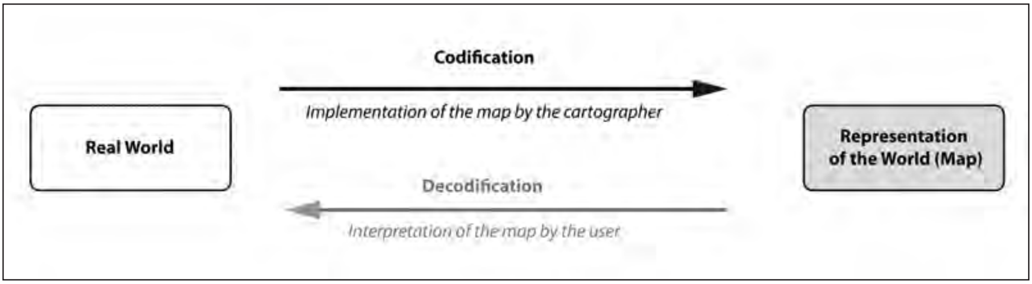

Fig. 1 Information exchange between cartographer and map user (Coratza & Regolini-Bissig, 2009).

3.2 Defining a new approach

The codification process determines what is going to be the content of the map. Rather than providing a simplified version of a map for specialists (see Carton et al., 2005), the proposed approach leads to the interpretation of the geoscientific reality of the mapped area. By interpretation we refer to the definition given by Tilden (1957) in the field of heritage interpretation: *"Heritage interpretation is an educational activity which aims to reveal meanings and relationships through the use of original objects, by firsthand experience, and by illustrative media, rather than simply to communicate factual information".* Thus, the interpretive approach in mapping Earth Heritage means to assemble the information in order to communicate a specific meaning instead of pointing out the single geoscientific elements, as it is often the case in conventional geotourist maps. Providing explanations regarding the distribution or interaction of the various elements will lead to a higher understanding of landscape formation by the user.

Coratza & Regolini-Bissig (2009) proposed guidelines for Earth Heritage mapping that integrate a series of interpretation principles. They have been adapted (Table 1) to fit the specific field of mapping Earth Heritage for tourist purpose. Some of the principles are illustrated here by using the example of an exercise conducted during a mapping workshop in Switzerland.

Being confronted with the task of designing an interpretive map for the site of Derborence (Valais, Switzerland) (Regolini-Bissig et al., 2009), the participants (several geographers and geologists) first identified its main geomorphological features. This was made in order to choose one or a few *themes* that were going to be revealed with a map. In general, landscape interpretation can pick up nearly every topic as long as the field is appropriate. However, the principal theme is often suggested by the field itself. Secondary themes or less evident features should not be shown on the same map, but would be better placed in subsequent illustrations, as they would unnecessarily increase the visual load of the map and somehow hide the principle information. The creation of Lake Derborence offers an interesting story to tell. Its origin is due to large historical rockslides and the lake currently tends to be filled by alluvial sediments (Bekker, 1883; Mariétan, 1960). Other geomorphological features and processes not related to the formation of the lake were deliberately ignored thereafter.

Secondly, the participants identified the potential *users* of the map. Choosing a specific target group is important in order to adapt the content to their previous knowledge and conceptions of geoscientific processes (Megerle, 2008) and to their map reading skills (Kealy, 1998). As the visitors of the area are mainly composed of families that come to stay around the lake for a daytrip, it was decided to create a map for this target group.

Map components	Guiding questions	Guiding principles
User	Who is the intended audience?	Maps should not be designed the same way whether they are produced for amateurs of Earth sciences, seniors, families, teenagers or children. Different map user groups have different requirements and map reading skills. Choosing one of these groups or defining the intended audience by analysing the composition of visitors of a given site helps to focus the mapping efforts and to produce tangible maps.
Purpose	What is the purpose of the map?	Maps are produced and serve different purposes such as localising geosites and giving tourist information (index and geotourist maps), interpret geomorphological and geological features (interpretive maps) and providing simplified geological or geomorphological information (maps for amateurs of Earth sciences). Each application requires specific mapping principles in order to fulfil the specific needs.
Theme	What is going to be revealed with the map?	In order to limit the features to be shown on a map, only a small number of elements should be presented at one time. Especially for interpretive maps one should focus on one or two principal themes. Secondary themes are better left for subsequent illustrations. It is also recommended to portray information sequentially (series of maps) or operate with zooms, instead of overloading a document.
The components above define the general framework of a map. They influence the decisions about the following elements, which have to be coherent with this framework.		
Level	Wich complexity of information is desired / required?	The “Level” refers to the complexity of the data. It depends on both the purpose of the map and on the user. In any case do not burden the reader with unnecessary details.
Scale	Which level of detail for the representation of the surroundings and the geomorphosites is desired / required?	One element to consider is the ratio between the area to be covered and the size of the map. The visualisation of the surroundings (map background) and of the geomorphosites (point symbols, pictorial symbols, adapted geosciences mapping symbols) also influences the scale.
Dimensionality	How to show the morphology of the mapped area?	Whether to work with topographic backgrounds, digital terrain models, satellite imagery, air photographs or drawings depends on the purpose of the map and on the intended audience. It may be useful to produce several alternatives and test with the user which one works best.
Design	How to produce maps that look good and are easy to understand?	It is important to adapt the design to the defined target group and to follow cartographic conventions and basic graphic and map design rules. In order to furnish a well-designed map, it can be useful to entrust the final design of the document to a graphic designer.
Form and size	For what purpose and in which context is the map going to be used?	The choice of the map form (paper or digital maps, material and size of the paper map) is crucial as it will affect the production and up-date costs. It should also be considered that the map study ought to be as comfortable as possible in a given situation. For example, a large fold up map may not be the best option for a windy trail along the coast, as it would flap in the wind.
Costs	What are the costs involved in preparing and publishing the map?	How much of the budget can be employed to acquire data? To carry out field research or to process data? To eventually produce the map? The cost is an important aspect for every mapping project as it determines a series of the characteristics of the map such as mapping techniques (software, data processing) and print options (material, size, colour).

Table 1 Guiding principles for geotourism mapping (modified after Coratza & Regolini-Bissig, 2009).

The *purpose* of the map arose out of the principal theme and the intention to produce an interpretive map rather than an index or geotourist map. The idea was, therefore, to explain the creation of Lake Derborence. Consequently, the group created a map with the title “How was Lake Derborence formed?” (Regolini-Bissig et al., 2009). Stating clearly the purpose of a map with a title helps to communicate the intent of the map and to draw attention. The formulation as a question is generally more effective as a plain description of what is presented (e.g. Geotourist map of Lake Derborence).

The level of a map is defined according to several parameters. It depends on the purpose and the potential users of the map. It varies also if the map has to be self-explanatory or if it is accompanied by written information, a brochure, for example. Being confronted to a public with presumed basic geoscientific knowledge, the complexity of the data *(Level)* was kept as low as possible. It was further reduced by presenting the data on a series of maps. At the same time, the interpretive aspect could be enhanced as each map represents a step in the succession of the events that lead to the formation of the lake. There was no need for additional written information.

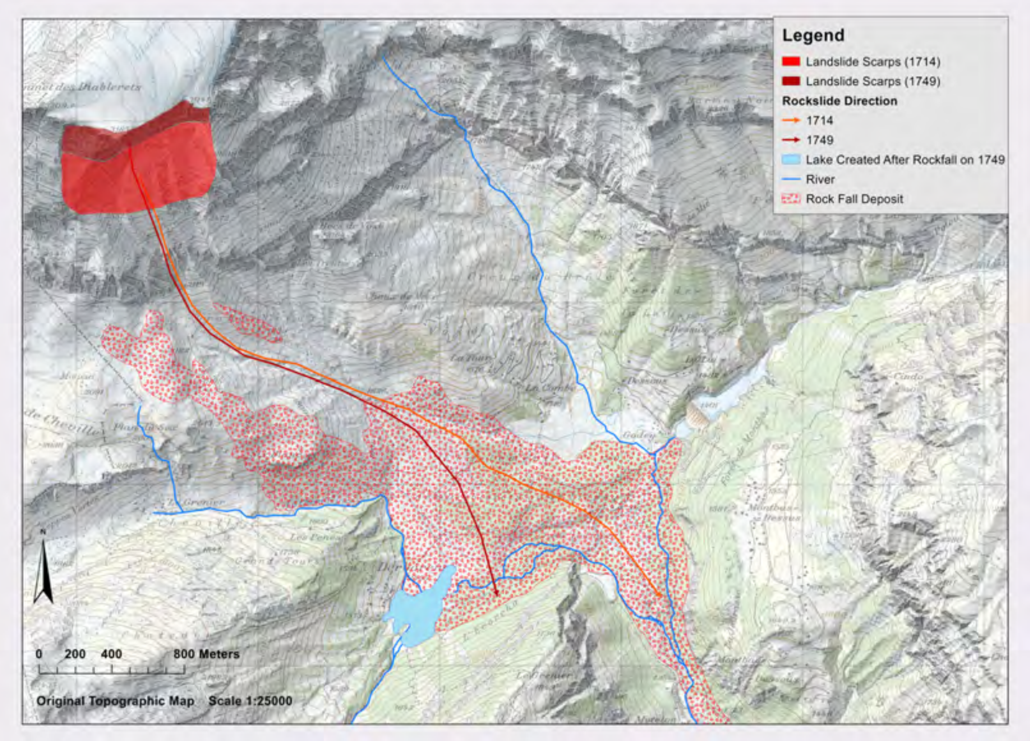

Fig. 2 First of a series of three maps explaining the formation of Lake Derborence. In this map two landslides and their deposits are represented (map designed by L. Ghiraldi and V. Garavaglia).

Having an approach based on interpretation principles determines what is to be shown on a map. The question of how it is to be represented leads to investigations concerning the communication process between the mapmaker and the public and design issues. Visual representation of geoscientific information (codification) must, therefore, fit the users' level of geoscientific knowledge and map reading skills (decoding). As seen above, geoscientists tend to represent data using the same representation and legend system used for communication among themselves. This may be misunderstood and can lead to misinterpretation of the data presented. Just as texts written with too many technical expressions, in a too small font or without relation to the readers' experience are unsuccessful from an interpretive point of view (Lehnes & Glawion, 2006), poorly designed maps will not keep the readers' attention and may be regarded as useless. Geoscientists involved in mapping projects should, therefore, have basic knowledge concerning visual information transmission and hold the necessary communication know-how with the chosen media.

Due to their prevalent training in natural sciences, geoscientists have often little experience in other branches such as human sciences. In many cases, map implementation could be enhanced using an interdisciplinary approach. Ideally, a project should be carried out in a collaborative effort (Patterson, n.d) by a team composed of scientists from different fields related to knowledge acquisition (psychologists), mapping issues (cartographers) and visual communication (graphic designers). As time and monetary resources are likely to be limited, a step up to an interdisciplinary approach could also be to incorporate major findings of related fields. Of course, this implies investing time but has the advantage of avoiding conceptual and fundamental design mistakes.

3.3 How to meet the mapping challenges?

It is not our ambition to give practical mapping advice in this paper, but to point out research fields that can help manage map codification and decoding. A short summary of different research fields and a few practical examples show their contribution for mapping enterprises.

Heritage interpretation

The already cited heritage interpretation deals with the mediation of scientific knowledge. Interpretation strategies and communication techniques were developed by different authors (Tilden, 1957; Ham, 1992; Beck & Cable, 1998) and were successfully applied in various settings of natural and cultural heritage interpretation: parks, zoos, museums, nature centres, and historical sites. In some countries (USA), *interpreters* are professionals that follow a specific training to acquire skills and knowledge allowing them to perform effective interpretation. In other cases, geointerpretation is often in the hands of scientists and needs yet to be professionalised (Kruhl, 2006; Megerle, 2008).

Different examples show that general interpretation principles can be blended with traditional cartographic principles (Bailey et al., 2007; Patterson, n.d.). But heritage interpretation also pays attention to maps as independent communication tools. Specific studies on how and in which context this medium best serves interpretation were carried out. One example is the case of *living maps* (Bremen et al., 1992). This giant canvas map, on which the visitors can place names, boundaries and symbolic projects, was developed to support the visualisation of large landscapes. Other studies focused on the topics of orientation and way finding. Interesting results concern, for example, the effectiveness of 2D versus 3D maps (Schoesberger, 2007).

Cognitive sciences

The cognitive sciences is another research field that studies the functionality of spatial and map knowledge acquisition. Including results about place recognition and way finding mechanisms as well as visual-cognitive processes of human-map interaction will help to design more accessible maps (MacEachren, 1995).

Graphic design

A very important point in map implementation is the design or how a map not properly designed "will be a cartographic failure" (Robinson, 1985). Before starting a project, it is, therefore, useful to get familiar with the elementary mapmaking principles. The presented guiding principles for geotourism mapping (Table 1) can help to ask essential design questions (user, level, dimensionality) that will affect many of the successive design choices. However, applying these principles cannot fully compensate expert mapping knowledge. It is, therefore, recommended to consult cartographic manuals (MacEachren, 1995; Slocum et al., 2009) and design handbooks. At the end of the mapping process, Martin & Reynard (2009) rightly propose to entrust the final design to a graphic designer. A professional, thus, that assembles together images according to visual communication principles in a way that is both accessible and aesthetic.

Social investigations

Even if in some cases the mapmaker can benefit from already acquired knowledge as described above, there may still be a need for investigations concerning the map users, either because the information is bound to the location or because generalised information is not available yet.

The determination of the target group is typical location-bound information. Currently, a lot of geotourist destinations do not dispose of statistical information about their visitors (Megerle, 2008). Often the most basic information such as gender, age profile, final educational attainment, work status, party size or level of geological studies are missing and mapping projects are carried out without defining a clear target group beforehand. This and other questions concerning the visitor's motivation and focus of interest (Hose, 1996; Pralong, 2006), conceptions of geoscientific processes or landform recognition (Kramar & Pralong, 2005; Bissig & Kozlik, 2008) can be answered by means of empirical investigation methods provided by Social Sciences (Reynard & Berrebi, 2008). They need only to be adapted for our purposes. For a higher adequacy of the products that are to be proposed, standardised questionnaires can be distributed on the spot or surveys using scenarios and pictures can be conducted with different target groups.

4. Conclusion and perspectives

The amount of different geotourist map types and the manifold and individual way they are implemented show that geotourist mapping is a quite recent topic. In order to better apprehend map purpose and map creation, a general definition of the *geotourist map* as well as a classification of the different sub-types was given. The paper focused then on *interpretive maps*, which in our opinion have the greatest potential for knowledge transfer between geoscientists and the public.

The elementary guiding principles that lead to the implementation of this kind of maps were presented and illustrated by the means of an example (map of Lake Derborence). It was clearly pointed out that map production cannot deal exclusively with the codification phase, but must also include the phase of decodification. Importance was also given to design questions, which have to be considered in order to offer intelligible communication. Finally, an interdisciplinary approach inviting the integration of findings from related sciences was suggested to further improve map implementation.

For the future, it would be desirable to harmonise map implementation for the different map types on a national and respectively international level in order to facilitate information reception for the user. A shared mapping philosophy as proposed in this paper with the described approach for the implementation of interpretive maps is only the beginning. It needs to be discussed to find a large consensus before the next step – the development of a standardised map design – can be undertaken.

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Geoheritage popularisation and cartographic visualisation in the Tsanfleuron-Sanetsch area (Valais, Switzerland)

Simon Martin
Institute of Geography
University of Lausanne
Anthropole
CH - 1015 Lausanne

E-Mail: simon.martin@unil.ch

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1. Introduction

This paper presents the underlying concepts developed by the Institute of Geography of the University of Lausanne (Switzerland) for a popularisation project of the geoheritage in the Tsanfleuron-Sanetsch area (Valais, Switzerland). Due to its wide scientific interest, the local geoheritage is of great value (Reynard, 2008). The article details the complementary links existing between the different parts of a geotourist project – databases, educational panels, educational material and geotourist map – developed for popularising the geoheritage value of the area. Each element of the project is briefly presented. Special focus is set on mapping questions: how cartographic design and information structure can be set in order to facilitate map's use and comprehension. In this way, the Tsanfleuron-Sanetsch map is presented as an applied example of the guiding principles proposed by Coratza and Regolini-Bissig (2009).

2. Geoheritage in the Tsanfleuron-Sanetsch area

2.1 Access and location

The area of Tsanfleuron is part of Les Diablerets mountain massif (Fig. 1). There are two main entrance points linked by hiking trails. In the west, the cable car Glacier 3000 leads from Pillon pass to an alpine restaurant (Fig. 3, point 2) and to the ski fields on Tsanfleuron Glacier. In the east, the Sanetsch pass (Fig. 3, point 5) is accessible by car from Sion. From the pass, tourists mainly go for a walk on the *lapiés* of Tsanfleuron (karstic area, Fig. 2) situated in front of the glacier. On this part, tourist facilities can also be found: hut and hotel. Many other hiking trails link the Tsanfleuron area to its surroundings: Derborence, Savièse, Gsteig, Pillon (Fig. 3). The tourist area covers more than 50 km^2 between the Sanetsch pass in the east and the glacier in the west.

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Fig. 1 Situation map.

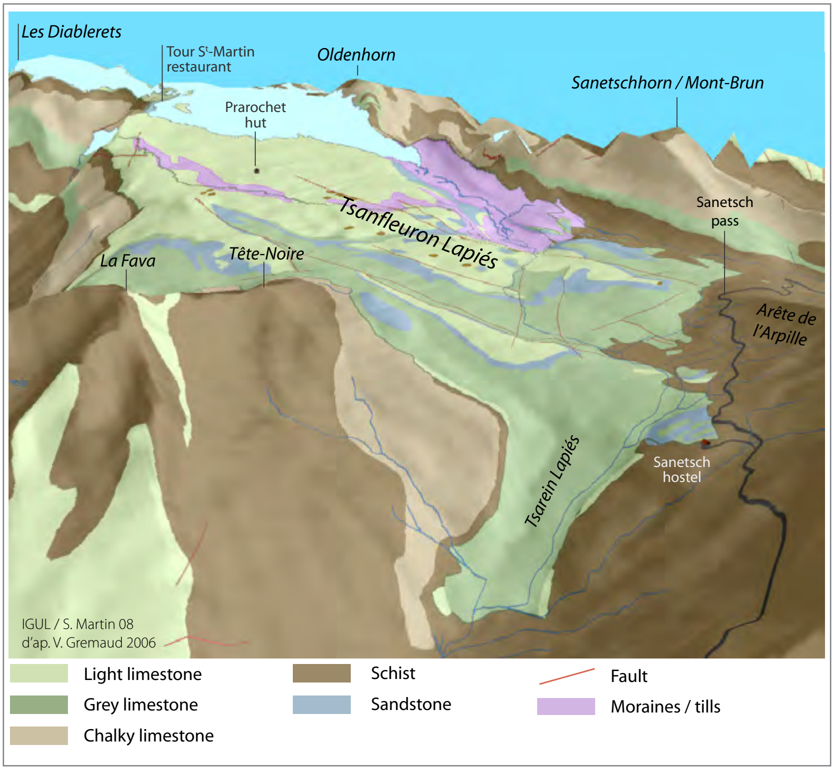

Fig. 2 Geological 3D map of Tsanfleuron-Sanetsch area (simplified from Gremaud and Nessi, 2006).

2.2 Geoheritage

With 9 km^2, the karstic area is one of the largest in Switzerland (Reynard, 2008). It covers a wide plateau pending to the northeast and belonging to the Diablerets and Mont-Gond nappes, part of the Helvetic domain. The Tsanfleuron lapiés are mainly formed in Eocene and Cretaceous (Urgonian) limestones (Fig. 2). The limits between the two nappes and other structural fractures could influence the karstic erosion and the groundwater flows (Gremaud, 2008). Although the main part of water flows eastward to the Glarey source (Morge river valley), the Tsanfleuron karstic area also supplies several surrounding springs (Savoy et al., 2008).

The karstic area was also extensively studied (Corbel, 1957; Maire, 1976; Tóth, 2006, 2008). Apart from carbonate crusts, many other karstic forms can be observed: wide range of karren forms, dolines and other glacio-karstic landforms like *Schichttreppenkarst* or *roches moutonnées* karren. Morphological differences between the upper and lower part of the *lapiés* were identified by Maire (1976): downhill the Little Ice Age (LIA) moraines, the karstic landforms are various and sharp, whereas above this limit, the landscape is mostly affected by glacial processes (Fig. 3, 4).

Tsanfleuron Glacier is a rather thin plateau glacier. Therefore, it has retreated fast during the last century. At its LIA maximum, around 1850, the glacier left large moraines crossing the present *lapiés.* A small tongue extends the glacier on its eastern part. The glacier has been widely studied: e.g. basal ice layers formation (Tison & Lorrain, 1987; Hubbard & Sharp, 1995; Hubbard et al., 2000) and relation between glacier and limestone bedrock with precipitation of carbonate crusts (Hallet et al., 1978; Souchez and Lemmens, 1985). Moreover, from October to May, the glacier is used for skiing from Glacier 3000 cable car station (Fig. 3, point 2).

The historical rockfalls of Derborence, in the near surroundings of Tsanfleuron, were also taken into account in the popularisation project. Indeed, rockfall deposits are visible from the Tour St-Martin (Fig. 3, point 3). As this event is linked with local legends on Les Diablerets mountain (*diable* means devil) and also became the subject of a novel (C.-F. Ramuz, *Derborence*, 1934), it contributes to the cultural value (Reynard, 2005) of the area. Furthermore, the Sanetsch pass has some importance as a language frontier and watershed limit (Rhone and Rhine river catchment areas).

3. The geotourist project

A first attempt was made a few years ago to popularise the rich natural features of the Tsanfleuron area (Collectif, 1995; Reynard, 2004). A geotourist trail was proposed on the karstic area with a leaflet describing natural features and processes (including glacier) and some tourist information. However, this popularisation project was not well communicated to a large public (Reynard, 2008).

In 2008, on the request of the municipality of Savièse (Valais, Switzerland), the University of Lausanne developed additional geotourist products on the whole area (Tsanfleuron lapiés and glacier, Fig. 1): educational panels, material for school children and a geotourist map. This project partly meets the popularisation plan proposed by Reynard (2006).

3.1 Databases

The first step was to collect existing information on the area. Separate databases were created for each type of data: bibliography (EndNote), pictures (MS Access) and geodata (ESRI ArcGIS). The three databases should be able to interact one with another and allow wider interactivity in data handling.

3.2 Educational panels

The main part of the project was to develop material for education panels. They had to present the whole diversity of the geoheritage. As the panels were put only near buildings, their number – five – and location were limited. Visitors' specificities added some constraints. Firstly, the text was written in three languages (French, English and German). This leads to a considerable use of schemes, pictures and maps to communicate. Secondly, as the majority of tourists stay in only one part of the area – glacier or *lapiés* – information had to be sorted and sometimes repeated (Table 1).

Location	Tourist facilities	Theme 1	Theme 2
1. Sanetsch pass	car park, bus stop	Introduction (context)	Karst
2. Sanetsch hostel	catering, lodging bus stop	Same as panel 1	Same as panel 1
3. Prarochet hut	catering, lodging	Karst	Glacier
4. Tour St-Martin	catering Snow Bus stop	Geology	Derborence rock falls
5. Scex Rouge	catering, ski lifts Snow Bus stop, cable car station	Introduction (context)	Glacier

Table 1 Description of the educational panels (Tsanfleuron-Sanetsch area; for location, see Fig. 3).

3.3 Material for school children

According to the municipality of Savièse, the geotourist project should also be aimed at the local population. Thus, it was a way to inform the population on the value of the landscape and natural features and raise environmental awareness. With the same intention, many illustrations created for the panels were adapted to school use. They became the base material of a slide show presenting in a simple way the main geomorphologic processes (karstic and glacial). A new chapter was added, presenting the danger of human misuse of the natural area: soil destruction and water pollution. Both the slide show and individual pictures were set on a CD distributed to the teachers in the commune.

3.4 Geotourist map

In addition to the educational panels, a map was designed to inform tourists on hiking trails and other facilities: restaurants, hostels, transportation. Moreover, additional educational information was developed for the back of the map. We chose to focus on the glacial and karstic processes, with more detailed information than on the panels. The links between the map (front side) and educational information (back side) were preserved by the use of a colour code and pictograms for each theme (Fig. 3 and 4). These links also allow the interaction on the field with educational panels.

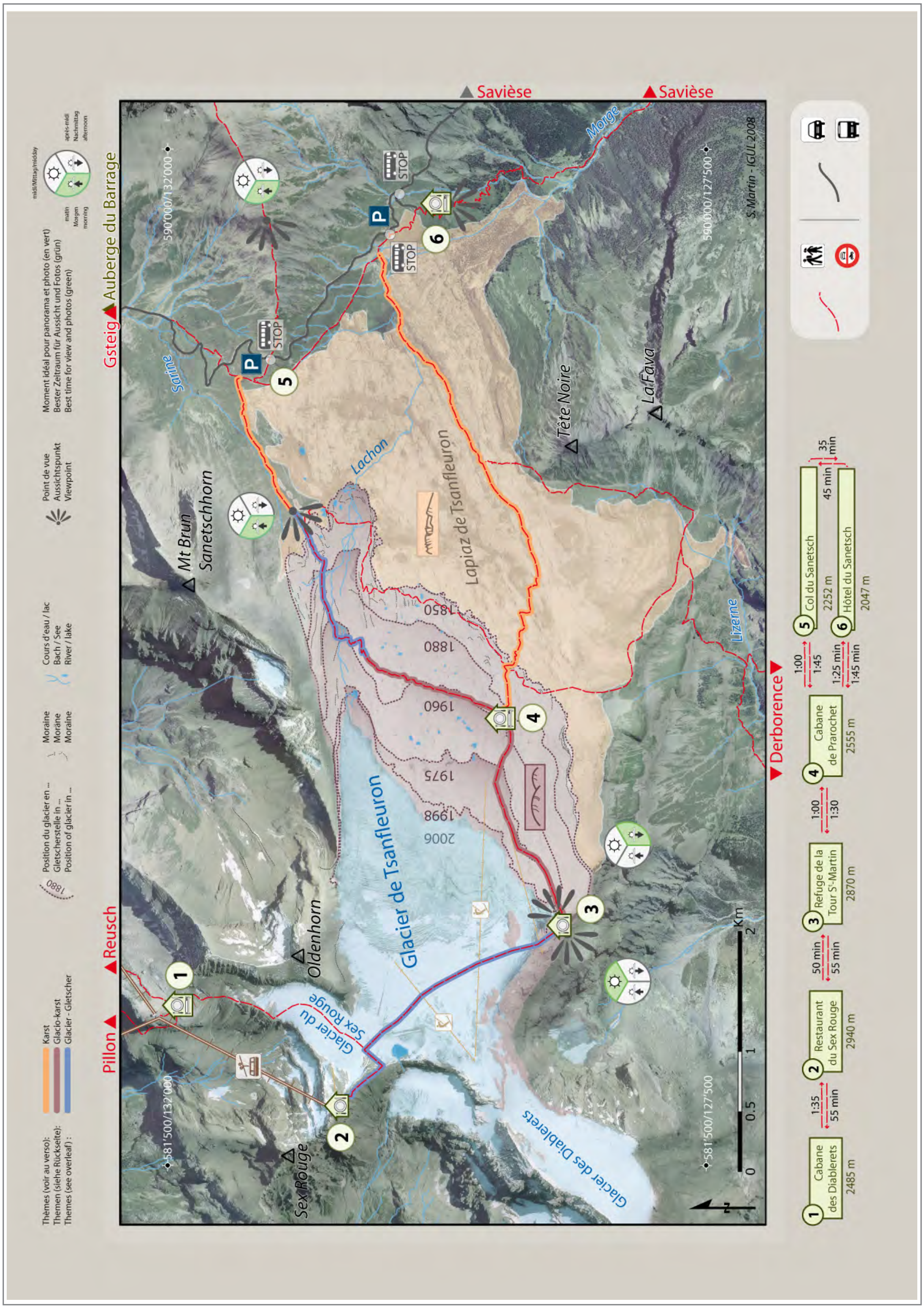

Fig. 3 Geotourist map of Tsanfleuron-Sanetsch area (front side).

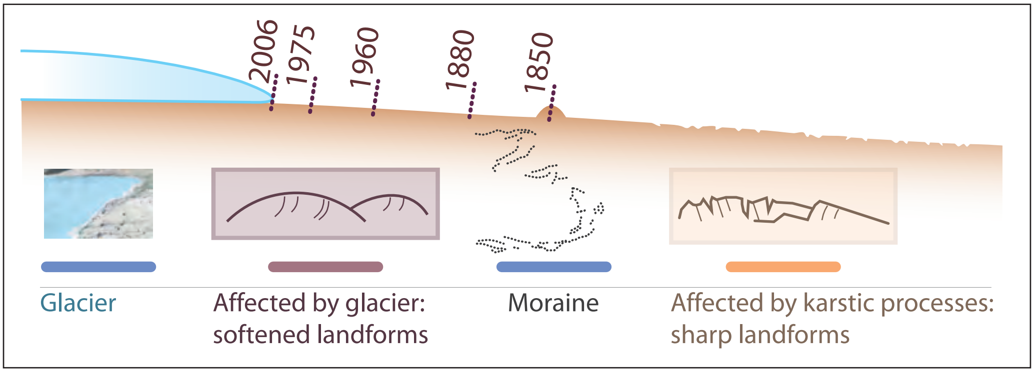

Fig. 4 Scheme of the three morphologic areas linking both sides of the map.

4. Mapping the geoheritage

4.1 Methodology

The Tsanfleuron-Sanetsch map is addressed to non-specialists, according to the categories of Carton et al. (2005). Its main purpose is to orientate people, but the map should also give information on local geoheritage (landforms and processes). The mapping process raised several questions, particularly on the map's design and sorting of content. The guiding principles for mapping geomorphosites proposed by Coratza & Regolini-Bissig (2009) were used as methodological basis (Table 2), in addition to more general cartographic methods (MacEachren, 1994; Bailey et al., 2007; Slocum et al., 2009).

Identifying the future users of the map and its main purposes are essential steps of the process, as they influence all other aspects of the map. Furthermore, the choices made during the mapping process must be coherent with the defined framework (Martin & Reynard, 2009).

Map components	Guiding questions	Guiding principles for the map of Sanetsch-Tsanfleuron
1. Users	Who is the intended audience?	a. upper part (glacier): tourists (mainly foreigners) come for a one-day trip, but generally remain on the glacier. b. lower part (Sanetsch pass, karstic area): local people, hikers and families coming for a one-day trip. c. whole area: hikers going through the *lapiés* of Tsanfleuron.
2. Purpose	What is the purpose of the map?	Category of "promotion maps" (Bissig, 2008) with particular aims: orientation, basic tourist information and educational elements. It should help the users to understand the main geomorphological components of the landscape (see Theme).
3. Theme	What is going to be revealed with the map?	Focus on the interaction of glacial and karstic processes that have shaped the landscape.
4. Level	Which complexity of information is desired / required?	According to the diversity of users, the map should allow two levels of complexity: general information (visual) and more detailed, but still popularised, information (textual).
5. Scale	What is the area to be covered?	The area covers the trails between main access points (Sanetsch pass and Glacier 3'000 station) and the places of interest (whole *lapiés* and glacier of Tsanfleuron).
6. Dimensionality	How to show the morphology of the mapped area?	Orthophoto whose relief is shown by a superimposed hillshaded layer (based on a 25m DEM).
7. Design	How to produce maps that look good and are easy to understand?	Adapted to users and purpose; information sorted by themes and complexity levels; links between levels and media (see also Martin & Reynard, 2009).
8. Form and size	For what purpose and in which context is the map going to be used?	Available on the spot, the map should be used as a guide, to consult on the way, in complement to a topographic map but also in interaction with educational boards visible in the field.

Table 2 Guiding principles (according to Coratza and Regolini-Bissig, 2009) adopted for the geotourist map of Tsanfleuron-Sanetsch.

4.2 Educational content

Educational content should not overload the map (Coratza & Regolini-Bissig, 2009), as this must firstly orientate the users. We chose to focus on three themes: (1) glacial dynamics and landforms, (2) karstic processes and landforms and (3) the relation between both processes and associated landforms. The map shows the areas where each theme prevails, above and below Little Ice Age moraines (Fig. 3, 4; according to Maire (1976). The only other educational elements displayed on the map are the historical extensions of the glacier from 1850 until today, based on topographical maps analysis.

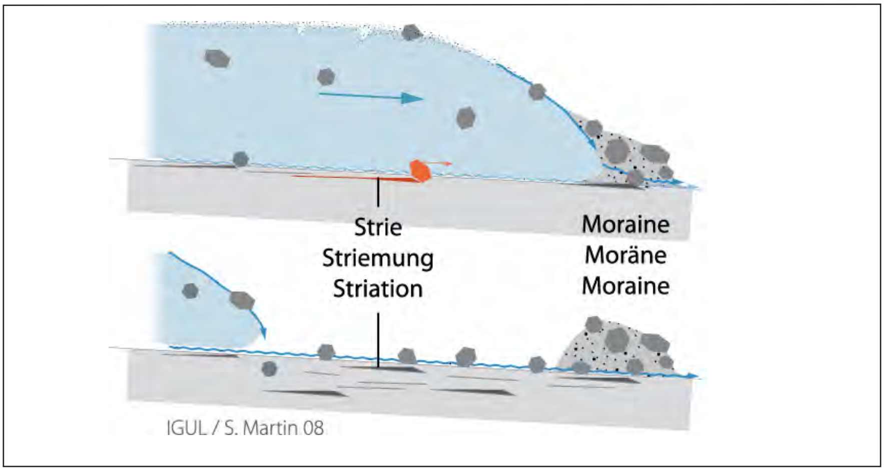

Fig. 5 Example of scheme (glacial striation).

On the back, information is organised according to the three themes (Fig. 4). Texts, explanatory schemes (Fig. 5) and annotated pictures (Fig. 6) help the user to understand the landforms he sees on the field (with help of the map) and complete the information displayed by educational panels. The use of various media (map, schemes, text), multiple scales (general context, processes and forms) and strong links between them (colour, pictograms, text) allow multi-level reading. This is the key point when being aimed at non-specialist and heterogeneous users.

Fig. 6 Example of annotated picture (moraines).

4.3 Background layer

In order to facilitate orientation, the background layer represents the terrain. It is also a means to increase the attractiveness of the map. To keep the map readable, background with a heavy visual load – such as topographical maps or aerial photographs – should be avoided. Patterson (2002) recommends using a background representing the terrain as "real" as possible: remove lines, rasterize all vector items, modulate tones and texturize areas (forests, rocks…). For the Tsanfleuron-Sanetsch map, we first chose to use a hillshaded layer with hypsometric tinting (Fig. 7, left). However, the last version uses a hillshaded orthophoto (Fig. 7, right). Relief is harder to understand, but – according to the majority – the map looks better in this way. To bring out important information and pictograms, the thematic areas cover partly the underlying orthophoto (Fig. 3).

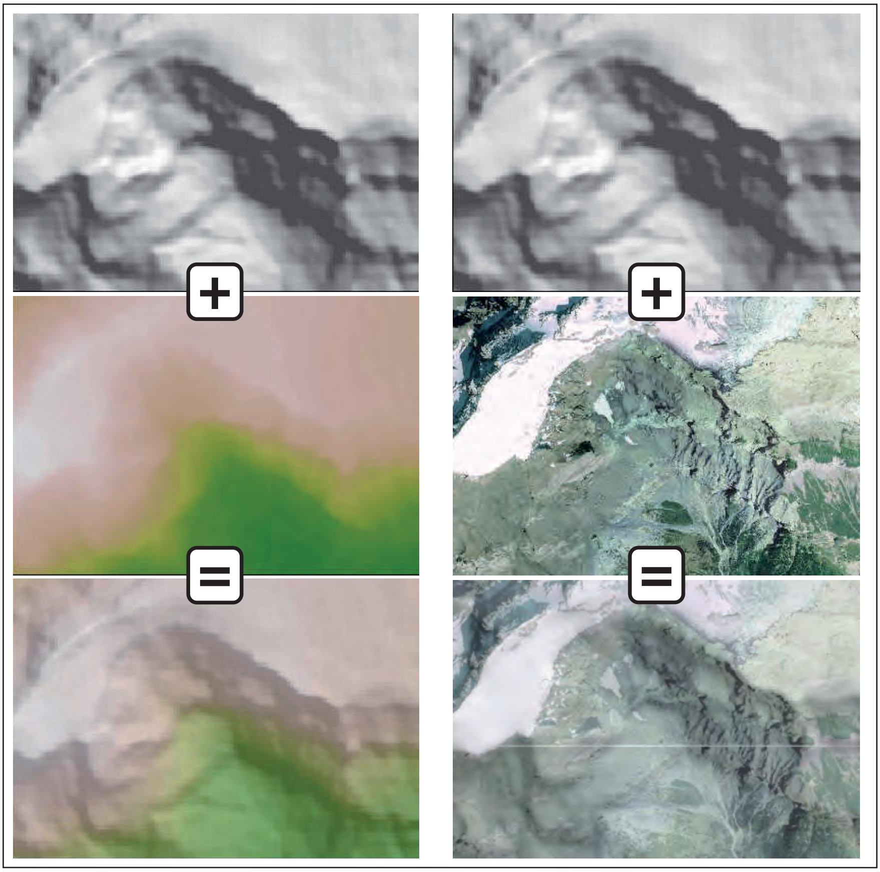

Fig. 7 Hillshaded background layer with hypsometric tinting (left) and orthophoto (right).

4.4 Information layers

As the geotourist map meets several purposes, numerous types of information are to be displayed (Table 3). However, only useful information must first be selected in order to keep the map simple and attractive. Both questions "what to put on the map" and "what to omit" should be resolved by keeping in mind the chosen purposes and the user needs (Martin & Reynard, 2009). It is also essential to differentiate the categories of information by the use of visual variables (Bertin, 1967; MacEachren, 1994). In this way, the map allows the user to find easily what he is looking for.

Purpose	Information	Geometry	Representation
Orientation	location	point	pictogram; coordinates, names
	routes and direction	line	linear sign (3 types)
	landscape	surface	hillshaded orthophoto (Fig. 7)
View	viewpoint	point	oriented pictogram, (Fig. 8b)
	view direction	line/angle	
	best time for view (photo)	---	pictogram (3 types) (Fig. 8a)
Geoheritage	(geo)site	point/line/surf	linear sign (moraines)
	thematic trail	line	3 colours
	thematic area	surface	3 colours
Basic tourist information	transportation	point/line	pictogram (4 types), linear sign
	catering, lodging	point	pictogram (2 types)
	time of walk	---	text (arrow)

Table 3 Categories of information displayed on the Tsanfleuron-Sanetsch map and their representation.

Orientation

The map should inform the user on his current position, on his destination(s) and on the general aspects of the surrounding landscape. In fact, it is a tool for building an indirect experience of space (Golledge & Stimson, 1997; Bailey et al., 2007). Orientation is also important for understanding spatial interactions and phenomena such as glacier retreat.

There are two main categories of tourists visiting the Tsanfleuron-Sanetsch area (Table 2): people staying in one part of the area (on the glacier around the cable car station or on the *lapiés* between Sanetsch pass and Prarochet Hut) and hikers crossing the area. These normally already have a topographic map. The geotourist map is, therefore, used as a complement. To allow interaction between both kinds of maps, we chose to keep a few similar place names (glaciers, summits), northward orientation and coordinate points. Tourists staying in one part do not need a precise map, as the path network is well indicated in the field. For them, we kept only visible or useful items: ski lifts, hydrographical network, pathways and tourist facilities (Fig. 3).

View

Viewpoints on aesthetic panoramas are tourist attractions. But looking on the landscape can also be a way to understand natural processes and landforms. Several views are displayed on the educational panels and on the back of the map with annotations and schemes. Each viewpoint selected for the map refers to these pictures and offers a look on a specific theme (glacier, rockfalls, *lapiés,* all parts of the area).

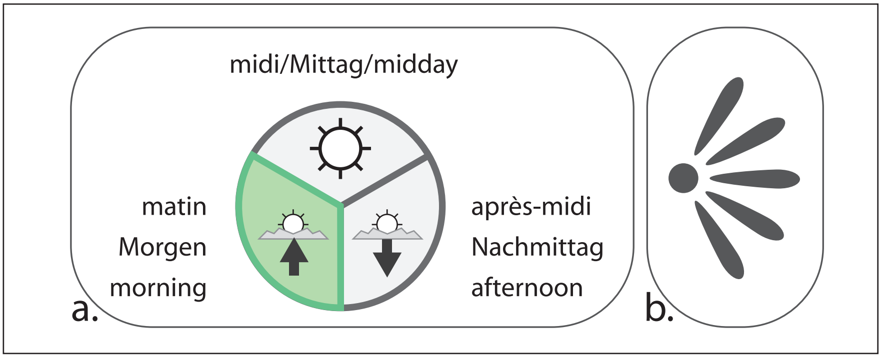

Fig. 8 a) Best time for view pictogram; b) Viewpoint pictogram.

Along with directional viewpoints, a pictogram informs the user on the best time to see the landscape or to take a picture from this point (Fig. 8a). This idea was proposed at a regional scale by Carton et al. (2005).

Geoheritage

Although the geotourist map of Tsanfleuron-Sanetsch area deals with geomorpholgical features, it is not a geomorphosite map. Apart from moraines, no landform is represented on the map. Only morphologically similar areas are displayed (Fig. 3). The map is, therefore, used as an interface to access and organise the educational information on the back and give a general view of the landscape and spatial distribution of phenomena.

The two main types of morphology are symbolised on the map with pictograms. One represents striated (or a little karstified) *roches moutonnées* whereas the other shows sharp karren with sinkholes (Fig. 4). Along with the explanation on the back, the user can, therefore, recognise the interesting landforms on the field, whatever the way he follows.

Basic tourist information

As it is a mountain area, there are only a few tourist facilities. There was, therefore, no need to select them. All what could be useful to plan a short trip while being already on the spot was kept on the map: time of the walk between two points, destinations outside of the map's boundaries, transportation (bus stops, cable cars, car parks), hostels, restaurants (Fig. 3). However, as the map will not be reprinted each year, changeable information (timetables, price lists) was rejected. Pictograms were made explicit in order to reduce textual information and legend. It is all the more important since the map's users speak different languages.

On the back side, additional information is given on two themes. Firstly, people interested in learning more about local geoheritage are given information about the educational panels and the educational brochure (Reynard, 2004). Secondly, hikers are made aware of the dangers in mountain area and the importance of preserving the environment (rubbish, dogs, use of vehicles). Therefore, the map participates in both of the geoheritage popularisation's main goals: protection and tourist promotion (Reynard, 2008).

5. Conclusion and perspectives

Considering a geotourist project as a whole permits us to increase communication effectiveness. However, it implies clearly sorting the information between the different media and keeping strong visual and thematic links between them.

Furthermore, project design – especially the map – should be coherent with a predefined framework. In this way, the guiding principles proposed by Coratza & Regolini-Bissig (2009) help taking each element into account. The first questions should, therefore, be: who are the users, what are the purpose(s) and, then, what is the theme? This basic framework influences information complexity and sorting (different levels) and general design of panels, figures and map.

A geotourist map (and other complementary media) can be considered as a user interface, linking to thematic information. But the map should also be a simplified representation of landscape that allows links between observed reality and scientific explanation to be made. Special effort should, therefore, be made to visualise more effectively natural landscape and features.

Spatial and informational interaction may be a key to manage complex information content and increase map effectiveness. Moreover, this could solve the recurrent problem of users heterogeneity by widening the multi-level reading possibilities. Thus, people who do not like reading maps could also comprehend "their" geoheritage.

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Mapping geomorphological hazards in relation to geotourism and hiking trails

Pierluigi Brandolini
Department of Antiquity, Medieval and
Geographical-Environmental Sciences
University of Genova
via Balbi 2
I - 16126 Genova

E-Mail: brando@unige.it

Manuela Pelfini
Department of Earth Sciences
"Ardito Desio"
University of Milano
via Mangiagalli 34
I - 20133 Milano

E-Mail: manuela.pelfini@unimi.it

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1. Introduction

The activity of geotourism necessarily involves the interaction with the natural environment, and the degree of contact will vary depending on the geotourists' cultural background and physical ability (Swarbrooke et al., 2003; Dowling & Newsome, 2006). In this sense, there are increasing requests to exploit a territory by creating suitable networks of trails (Gray, 2004; Brandolini et al., 2007; Reynard et al., 2009). It is, therefore, necessary to survey the potential hazards and the geomorphological features that could impede progress along tourist itineraries in order to allow tourists to enjoy the landscape and avoid potential harm (Bell, 1999; Piccazzo et al., 2007; Reynard, 2008, Pelfini et al., 2009). The knowledge of the natural environment represents the first step in the risk mitigation.

Climate and meteorological variability play an important role in the increase of both the geomorphological and environmental hazard levels, for example debris flows and avalanche triggering. These factors also increase the vulnerability of human visitors, due to the presence of slippery paths, wet rocks, and high temperature and humidity in low altitude and coastal environments, or due to loss of orientation or a worsened physical condition in the case of bad weather at high altitudes.

The high-altitude mountain environment, for example, appears to be significantly modified in recent decades because of the rapid and intense reduction in glacier masses, the degradation of permafrost, and the ever-increasing diffusion of tourist settlements and infrastructures. Today, alpine skiing, alpinism, and other extreme sports practised beyond walking routes or on paths with limited accessibility are of great popularity. In areas recently uncovered by glaciers, numerous unsettling phenomena are occurring: slopes and valley bottoms are covered with abundant unstable debris, glacial deposits only partially consolidated and often with an ice core are easily removed by running water, glacier fronts are sometimes suspended over valley bottoms with the possibility of discharging masses of ice or boulders and glacier lakes are susceptible to rapid emptying. These progressive climatic variations have led to environmental changes that are rendering some alpine trails impossible to pass, glacier-covered areas, used for summer skiing, unpracticable and stretches of excursion trails inaccessible.

Along the coasts, the intense expansion of tourism facilities such as residences, docks, bathing and sporting areas, and an increase in the number of visitors over the last few decades, have caused significant changes in the original morphological balance and the natural dynamics of the coastline and the coastal slopes. The growing dispersion of coastal trails, mainly steep seaside access routes at the foot of slopes or cliffs, has necessarily led to an increase in the risk of accident, heightened by the fact that people using these paths are often inadequately equipped.

This is particularly important when new itineraries are proposed for environmental valorisation and for geomorphosite use. Moreover, temporary situations due to meteorological and climate influences can modify hazard and risk scenarios.

In the framework of the national research project "Geomorphological heritage as a resource for a sustainable tourism" and of the Italian Association of Physical Geography and Geomorphology (AIGEO) Working Group "Geomorphological hazard in relation to tourist activities", a method to establish a census, in a standardised way, of all the elements that can contribute to the risk assessment in tourism applications was proposed and tested. It was successively applied to different morphoclimatic and morphogenetic situations, in different environments, coastal and mountain areas, mainly in the western Ligurian rocky coast and in the central Alps (Lombardy and Trentino Alto Adige).

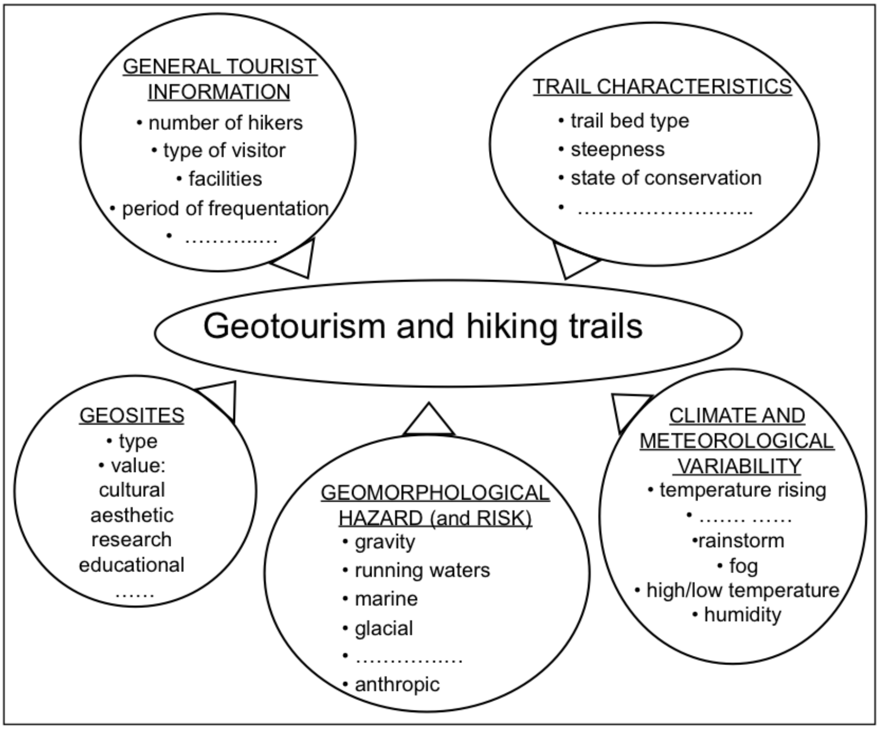

Fig. 1 Main topics to be considered in geotourist promotion, planning and management of hiking trails.

Some main topics were considered with the aim of realising specific thematic maps (geotourist maps), which should be readable by a large number of users and not only by specialists. The maps will include general tourist information (number of hikers, type of visitors, facilities, period of frequentation, etc.); geosites (type, value, cultural, aesthetic, research, educational, etc.); trail characteristics (trail bed type, steepness, state of conservation, etc.); geomorphological hazard and risk (running water, marine, glacial, anthropogenic hazards, etc.); climate and meteorological variability (rainstorm, fog, high/low temperature, humidity etc.) (Fig. 1).

The goal of this article is to point out typical situations of geomorphological hazard and tourist vulnerability along hiking trails, in order to highlight the importance of an easily readable geotourist map following the guidelines proposed by Coratza & Regolini-Bissig (2009). Two examples are presented, using different scales in order to show maps and detailed situations.

2. Methods

2.1 Hazard survey

The first step is the census of geomorphological hazards through traditional geomorphological surveys and the mapping of them at different scales, by using a scientifically accepted legend (e.g. Gruppo Nazionale Geografia Fisica e Geomorfologia, 1986; 1993)

In the frame of the national project "Climate and geomorphological risks in relation to tourism development" (Piccazzo et al., 2007), we proposed a standardised analysis methodology (data collection model) for risk assessment in tourist areas (Brandolini et al., 2004; 2007). A survey protocol was defined to quantify the geomorphological hazard levels, to undertake a census of elements of vulnerability of a given area including the morphological elements and the geographical-physical processes that may highlight the vulnerability, to approach risk scenarios.

The method consists of the compilation of five sheets during the survey phase related to the description of the area or tourist itinerary, the mapping and describing of the geomorphological hazard, the mapping and describing of the geomorphological elements that can increase vulnerability, the analysis of tourism vulnerability (tourist influx and infrastructures) and the estimation of geomorphological risk (Aringoli et al., 2007).

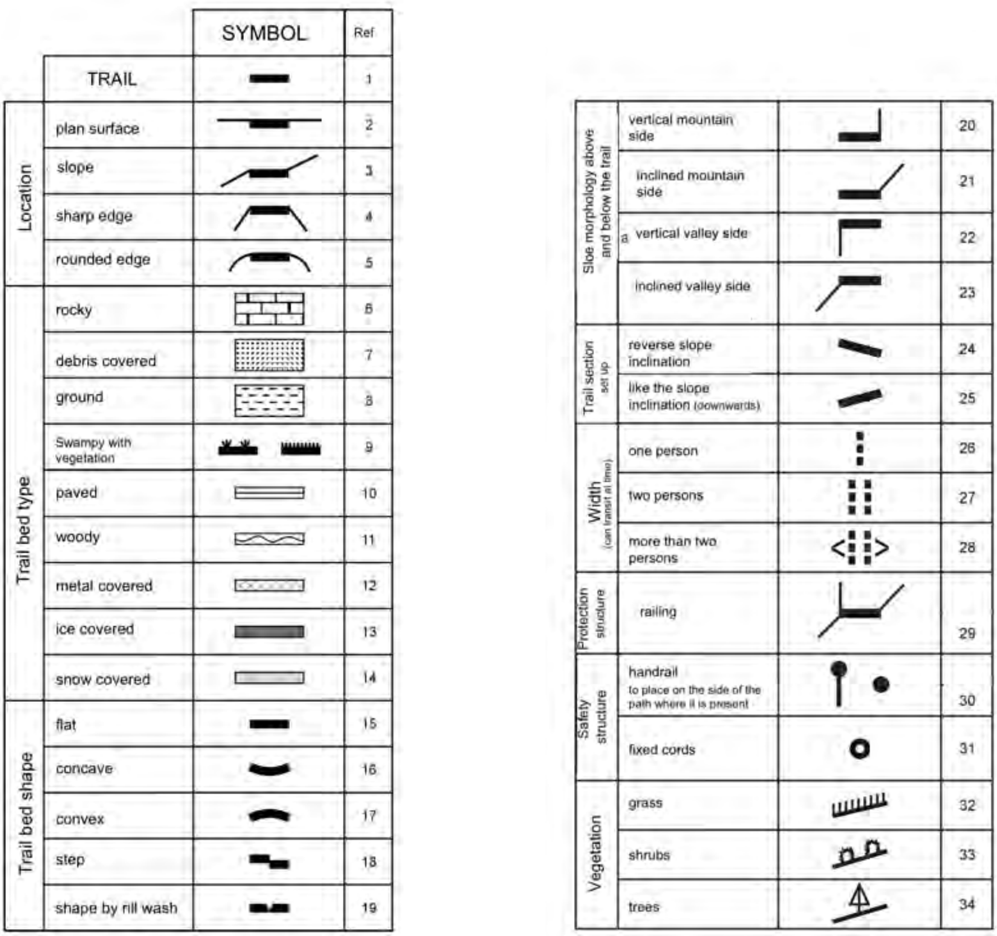

Fig. 2 A proposal of symbols to represent trail features in geotourist maps (modified after Pelfini et al., 2007).

2.2 Trail network analysis

The second step is a census of natural aspects, including the morphological elements of the route, which are not hazardous in the strictest sense, but which may impede or render passage difficult. The physical and morphological characteristics of trails make their use more or less suitable for different users. Additional elements change according to the stability of the substrate or due to the dynamic processes in progress or to the weather conditions. Several of these aspects may increase the difficulty of passage. On most occasions, tourist vulnerability varies in relation to knowledge of the territory, physical and psychological preparation, and equipment. These are important aspects but that cannot be generalised or coded with certainty. The trails are analysed and subdivided into segments with homogenous characteristics, synthesising more information concerning the path in a unique, easily understandable, symbol. The symbol represents a combination of simple signs representative of the geometric characteristics of the trail and of the slope on which the trail passes. For the whole description, see Pelfini et al., 2007 (Fig. 2).

2.3 Vulnerability analysis

The successive analysis considers the main characteristics of visitors that mainly frequent a trail. Detailed trail information is particularly important and useful to mitigate vulnerability of inexpert tourists that have little environmental knowledge about natural hazards. A typical example is represented by trails used for accessing beaches along rocky coasts (Brandolini et al., 2006). Here the equipment is generally not adequate because the aims are sun bathing and swimming. Acclivity and rock exposure can represent risk for users. Analogous environmental characteristics are generally better approached in a mountain environment where excursionists are, in general, more conscious of mountain characteristics and undertake trails with better equipment. Nevertheless, reports on accidents reveal both changing environmental situations and increasing vulnerability. In fact, access facilities (e.g. cableways) allow people to reach high altitudes (especially glacier environments) easily; in these cases, the ignorance of processes and morphological elements inducing risks (e.g. crevasses) can be very dangerous.

2.4 Meteorological related information

Meteorological information is particularly important where geomorphosites are frequented by people not accustomed to natural hazards. High temperatures could increase human vulnerability in summer along coastal trails as well as the cold and rain can in high mountain environments. Clouds at low altitudes can lead to a loss of positioning. Moreover, in any morphoclimatic environment rainstorms can increase both trail walking and slope instability phenomena. A census of morphological situations susceptible to modifications in relation to meteorological events is, therefore, very useful.

2.5 Data computerisation

All the data are collected into computer supports, inserted in a Geographical Information System environment, also using a pocket PC with Global Positioning System (GPS) tools.

3. Case studies

3.1 An example from the Ligurian coast (Northwestern Italy)

* (with the contribution of F. Faccini)

A typical case representative of a tourist area in a coastal environment is Palmaria Island in the Liguria region (Northwestern Italy). With a land area of 1.65 km^2 and a maximum elevation of about 190 m a.s.l., it is a very small island, which is inscribed in the UNESCO World heritage list. It is a site of great geomorphological and cultural value, characterised in particular by the presence of historic quarrying traces of Portoro marble – a grey-black limestone with yellow veins – dated back to Roman times (Brandolini et al., 2005, 2009).

High rocky cliffs on the western and southern slopes characterise the island, whereas small promontories and pocket beaches feature along the remaining coastline. The geomorphological setting of the coastline and of the drainage pattern appears to be conditioned by NW-SE and NE-SW tectonic lineations: the processes in progress are mainly related to marine, gravity and running water activities, subordinately to karst phenomena. Man-made landforms related to quarrying and mining, agricultural terracing and military structures are also important.

The climate of the islands is characterised by an annual mean rainfall of about 900 mm, with a maximum in October (120 mm) and a minimum in July with values below 30 mm, and an annual mean temperature of about 15°C. Mean air temperature data shows a minimum in the winter months (8-9°C) and a maximum in July and August (23°C).

It is possible to visit the whole island in half a day, walking along a ring trail of approximately 4 km, ranging from sea level to 190 m a.s.l. The path is articulated in some sections to detour to peculiar geo-panoramic points of interest and geosites related, in particular, to significant outcrops of "Portoro marble" both in open-cast and underground quarries, to exemplary cliffs, wave-cut in dolomite and limestone bedrocks and sometimes bordered by pocket beaches, and to sea and karst caves, which indicate traces of sea level changes and human presence in the Prehistoric Age (Brandolini et al., in press).

The geotourist map (Fig. 3) shows the location of the main geosites, geo-panoramic points, and historical sites related to hiking trail features and presence of geomorphological hazards.

Several rock fall phenomena have been detected along some parts of the trail network. Among these, we note potential rock falls, especially near the vertical fronts of the numerous abandoned quarries and the beaches frequented for sun tanning and bathing. Along the littoral, hazards are connected to strong sea storms, particularly those from the SW and SE (Fig. 5).

Types of geosites	Tourist vulnerability (hiking path features)
1. Geomine	8. Slippery or rambling track
2. Karst	9. Narrow trail
3. Geomorphological	10. Exposed path
4. Geological	11. Track steepness – a. low; b. medium; c. high
Geomorphological hazards	**Other geotourist emergences**
5. Rock fall	12. Beach
6. Debris flow (associated with heavy rainfall)	13. Geo-panoramic point
7. Sea storm	14. Military structures

Fig. 3 Geotourist map of Palmaria Island and legend (after Brandolini et al., 2009).

Fig. 4 Trail sectors in the western side of Palmaria Island affected by geomorphological hazards due to running water and rock fall processes.

Fig. 5 Eastern sector of Palmaria Island. Cala del Pozzale (a) and Cala dello Schenello (b) beaches, affected by rock fall and debris slide phenomena.

Following the criteria, mentioned in the previous paragraphs, for subdividing the trails into segments with homogeneous characteristics, the pathway in southeastern and southwestern sectors of Palmaria Island is distinguished by a location along steep slopes, by frequent narrow stretches, mainly dirty or debris covered. The state of conservation of the trails is, in general, quite good, with the exception of the steeper sectors, where the trail bed is affected by erosional phenomena due to running water. In the case of sudden and heavy rainfall, the path can become uneven and very slippery, and can be affected also by debris flows (Fig. 4).

In the northern sector of the island, the trail – dirty or asphalted – is located in a plain zone, just along the coast, a few meters above the beach, or along the embankment in the berthing area, and it presents, in general, a good state of conservation, with the exception of one segment affected by wave erosion attack.

3.2 An example from the Ortles-Cevedale Group, Italian Alps*

*(with the collaboration of M. Bozzoni and V. Garavaglia)

A typical situation from the Alpine environment is represented by trails in the Solda Valley (Province of Bolzano), at the boundary between Lombardy and Trentino Alto Adige, in the Stelvio National Park (Central Italian Alps). This is a glacial valley deeply worked by glacier fluctuations and clear signals of their activity are conserved in the moraine systems bordering the glaciers; these are now strongly shrinking or already extinguished. One of the trails crosses the western side of the valley where three glaciers, considered glacial geomorphosites, are located: Vedrette "Alta" and "Bassa del Marlet" and Vedretta del Finimondo. Along the path, examples of hazard and risk are present.

The trail connects three mountain huts: Coston, K2 and Tabaretta. It is highly frequented especially in the middle part (K2-Tabaretta) where a chairlift allows visitors to reach the K2 refuge easily; a gentle walk through the forest makes it possible to reach and then to cross the glaciers. It is possible to observe glacial geomorphosites interesting, also, from an educational point of view (Pelfini 2007; Garavaglia and Pelfini submitted). The Finimondo Glacier is located in a short, narrow valley on the eastern side of the Ortles; snow accumulation is due mainly to avalanches and the tongue is covered by debris; the glacier is used for winter skiing. The Alto del Marlet Glacier is situated at the bottom of a steep valley; it is fed mainly by avalanches from the Ortles peak and shows a very steep topography, uneven and covered by debris. It is now catalogued as a *debris covered glacier*. The Basso del Marlet Glacier moves down valley from the northern crest of Mount Ortles, in an easterly direction; it occupies a steep narrow valley, the tongue is very crevassed and in the upper part, avalanche deposits accumulate, whereas the lower part is half debris covered. The two Marlet glaciers deposited a huge moraine system formed by lateral ridges built during the Little Ice Age fluctuations.

The trail system located on the western side of the Solda valley, consisting of nine paths, was carefully analysed paying particular attention to morphological characteristics and geomorphological hazards that can affect trails. Morphological evidences possibly representing difficulties for passage and causing an increase in vulnerability were marked along the trail, and numerical values related to slope and exposure were deduced by automatic functions from the digital elevation model (DEM). Finally, seasonal geomorphological hazards and situations along the trails were outlined (avalanches, residual snow cover, etc.).

Fig. 6 Panoramic view of the western side of the Solda valley. Coston and K2 huts are indicated by triangles drawn on the limit of the trail. The trail is characterised by hazard sites and/or sites where vulnerability could increase because of local morphology or temporary situations (residual snow). Some of these situations are shown in figures 7, 8 and 9.

Fig. 7 A portion of the trail Coston-K2. Here the trail is cut into a steep rocky slope. The trail bottom can maintain its track thanks to a wooden support. Only one person at time can walk on it, with a steel rope for assistance. The symbol evidences the flat bottom of the trail and the material that characterises the trail (rectangular form), the slope inclination, the passage of only one person at time; the small circle indicates the presence of the safety support (steel rope).

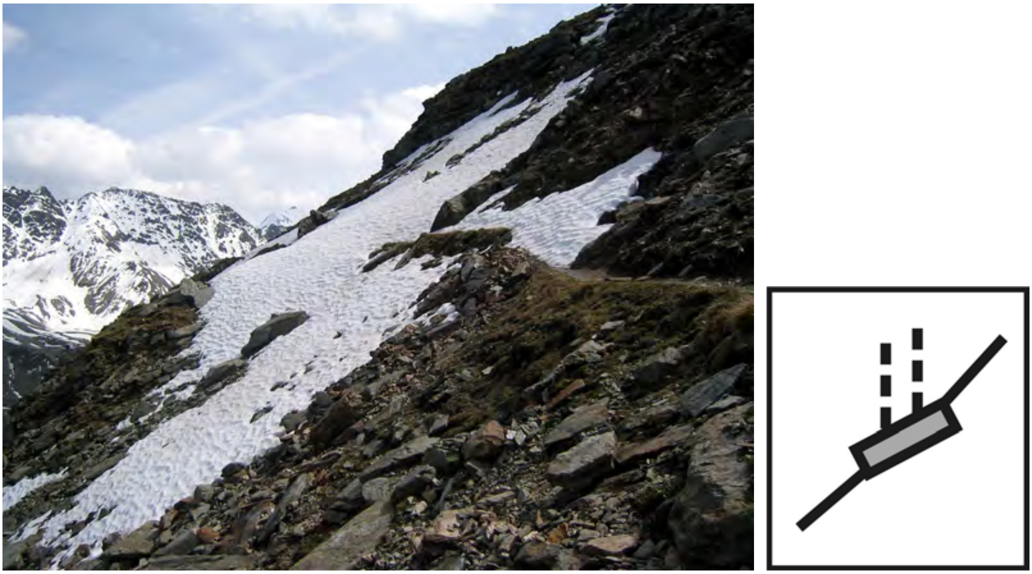

Fig. 8 A portion of the trail Coston-K2. The trail is hidden by residual snow. The picture was taken in June 2005. Snow patches are very frequent at the beginning of the summer season above 2500 m a.s.l. The symbol shows a grey rectangle corresponding to the snow cover; the inclination of the rectangle indicates the trail bottom height on the slope; the two segments, above and below the trail, represent approximately the inclination of the slope. The two dotted lines evidence the possibility of the passage of two people at time.

Fig. 9 Another portion of the same trail (represented in Fig. 6) partially buried under a deposit of debris and blocks. This is an example of a typical situation occurring at high altitudes at the beginning of the summer season. Due to the frequency of these instability phenomena, annual maintenance is required and, sometimes, new works after heavy rainstorms. This kind of hazard, if evidenced on geotourist maps, allows walkers to frequent trails with more safety. Moreover, public managers can use the same information to decide on modifications of the itinerary, temporary interruptions or in taking other decisions.

A portion of the trail connecting the Coston and K2 huts is analysed here (Fig. 6). Many of the situations correspond not only to geomorphological hazards but also to morphological situations inducing an increase of the tourist vulnerability, (Fig. 7-9).

4. Conclusions

In the framework of planning and management of existing or new itineraries, the examples reported in this paper are not exhaustive of the whole range of possible cases correlated to geomorphological hazard and risk. They are just representative of an emerging necessity to provide hikers with objective information for the evaluation of their own vulnerability, using suitable and objective symbols on maps, which should help the hikers to evaluate the path difficulties in relation to their own skills.

In fact, information such as "difficult or easy trail" should be avoided because perception of trail difficulties (trail bed type, steepness, width, etc.) are subjective and depend on training, equipment, as well as the environmental knowledge of the hikers.

The selection and simplification of information and the symbols placed on a map must be adequately related to the scale of the map. It is also appropriate not to insert too many symbols in order to simplify the comprehension of the geotourist map.

Nevertheless, hiking trails demarked as hazardous or difficult to access should not be understood as a means of causing alarm, but rather as a useful instrument for risk mitigation, with the aim of developing and promoting sustainable tourism initiatives such as geotourism. Finally, we firmly hope that local authorities would exploit such knowledge in order to implement suitable prevention measures where necessary.

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Conserving geoheritage in Slovenia through geomorphosite mapping

Bojan Erhartič
Anton Melik Geographical Institute
Scientific Research Centre of the Slovenian
Academy of Sciences and Arts
Gosposka ulica 13
Sl - 1000 Ljubljana

E-Mail: bojaner@zrc-sazu.si

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1. Introduction

That difference should not only be tolerated but also celebrated is now commonly accepted. The trend towards valuing diversity has nowhere been more evident than in biology. In recent decades, growing concern about species extinction and habitat loss has led to some important international environmental agreements. The protection of abiotic natural heritage in Slovenia has never been given sufficient attention, and it is considered that it should be protected adequately within the context of other components of the environment.

Slovenia has an extremely complex territory as well as a rich environmental heritage. Therefore, specific instruments and models are indispensable for proper management and appraisal. Maps of abiotic and biotic natural heritage can be very useful tools, allowing the most diverse topics to be represented with simple graphics. A map can, therefore, be defined as a basic introductory instrument for providing information concerning both the complexity and the individual components of a territory (Carton et al., 2005). The study of geomorphosites (Panizza, 2001) and, more generally, of geosites and geoheritage, is a very recent development. To date, investigations carried out on geomorphosites in Slovenia have been limited and have mostly focused on identification, classification, and protection (Agencija Republike Slovenije za okolje, 2009). The problem of cartographic representation has been engaged with but not yet resolved. This article presents the first attempt to map geoheritage in Slovenia.

The introduction presents some main characteristics of Slovenia and recent developments in nature conservation in Slovenia. Special attention is given to the abiotic components of nature. The second part deals with mapping abiotic natural heritage and geomorphosites on the basis of an experimental study carried out in Slovenia by the author. Bled, a world-renowned tourist centre in northwest Slovenia and an area with a large number of natural attractions, was chosen as a case study. Although tourism in Bled is highlighted by its cultural components (a thousand-year-old castle and a church on a small island), natural (in particular, geomorphological) features provide the basis and attractiveness for studying the site.

Geoheritage mapping is seen as an important tool for strengthening the knowledge of geomorphological values; this agrees with the statement by Carton et al. (2005) that "geomorphological maps are useful tools for identification, selection, and assessment of geomorphosites".

2. Main characteristics of Slovenia

The Republic of Slovenia covers 20'273 km^2 with a population of 2'025'000 inhabitants (2007) (Statistical Yearbook of the Republic of Slovenia, 2008). It is situated in the southeastern part of the Alps and on the northernmost part of the Balkan Peninsula. It encompasses four geographical regions: the Alps, Dinaric Alps, Mediterranean and Pannonian basins (Orožen Adamič, 2004). A significant landscape and biological diversity within a relatively small territory is one of the main characteristics of Slovenia. It is greatly supported by different types of climate, geological structure, varied relief and great differences in altitude (from 0 to 2864 m, 600 m being the average). From west to east, the climate changes from (Sub)mediterranean to continental, which is demonstrated by the annual amount of precipitation (2000 to 3000 mm in the Alps in the west, 800 mm in the east of the country).

Fig. 1 Valvasor's map of an intermittent karst lake. One of the first geomorphosite maps (Valvasor, 1689)?

Forests cover almost 1.2 million hectares or about 60% of the territory, which makes Slovenia the third most forested country in Europe. Although forests are without doubt Slovenia's great wealth, they also represent a problem in field research on geomorphological heritage and abiotic nature. Observations are difficult, especially in young forests, and aerial images usually do not penetrate through dense tree crowns.

Due to prevailing carbonate bedrock (42%), appropriate climate and amount of precipitation, karst phenomena are especially well developed in Slovenia. The Sežana-Komen karst region attracted attention of researchers early in history since it was located close to important railway route (Vienna-Trieste).

One of the first and most famous researchers of karst geomorphology and hydrology was J. V. Valvasor (1641-1693). He was the first to professionally describe and present the "functioning" of an intermittent karst lake on a map. He interpreted karst phenomena inaccurately from today's perspective but professionally enough for his times so that his renowned study of intermittent Cerknica Lake (Fig. 1 + 2) earned him membership in the eminent British Royal Society.

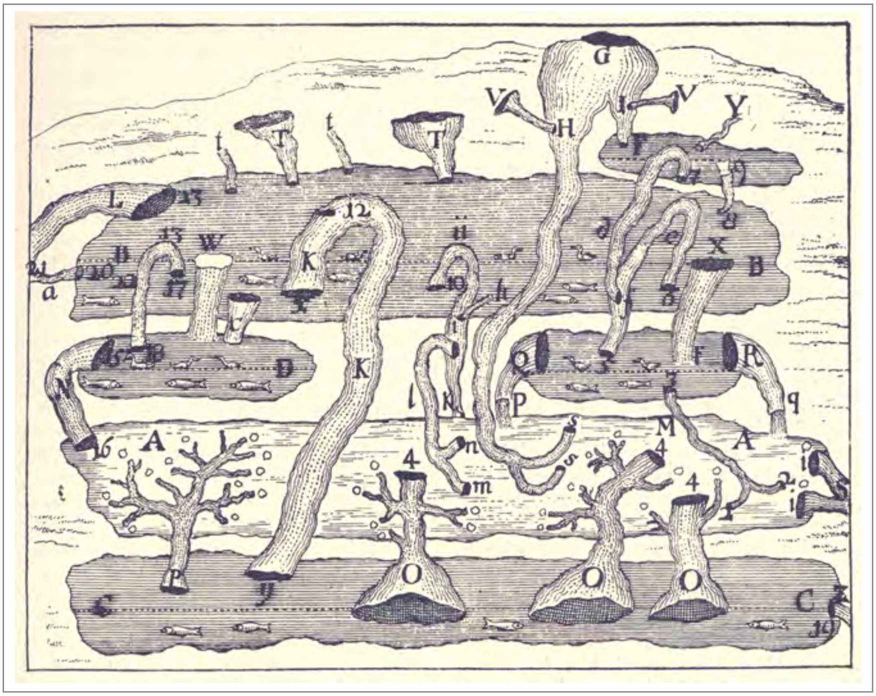

Fig. 2 Valvasor's sketch of the "functioning" of an intermittent karst lake (Valvasor, 1689).

3. Protected areas in Slovenia

3.1 Natural heritage

Due to EU requirements, Slovenia introduced Natura 2000 as a mechanism for the conservation of natural habitats, wild fauna (especially wild birds), and flora. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. It comprises Special Areas of Conservation (SAC) designated by member states under the Habitats Directive, and also incorporates Special Protection Areas (SPAs), which are designated under the Birds Directive (Natura 2000). The average percentage of Natura 2000 areas in EU countries is 15%, whereas in Slovenia it is much higher, over 36% of Slovenian territory (Natura 2000).

This very high percentage is a consequence of the relatively well-preserved natural environment in Slovenia (70% of Natura 2000 are forests).

Natura 2000 is based primarily on biological criteria, which tell little about the diversity of abiotic nature in Slovenia. Although Natura 2000 is primarily designed to maintain certain aspects of biodiversity, protected areas also conserve abiotic nature.

Category	**Centres Number**	**Centres Area (km^2)**	**% of State territory**
Wider protected areas			
National park	1	838	4.1
Regional park	3	434	2.1
Landscape park	42	1015	5.0
Smaller protected areas			
Strict nature reserve/wilderness area	1	0.02	0.0
Nature reserve	52	69.8	0.3
Natural monument	1217	155.5	0.8
Total	**1316**	**2320**	**11.4**

Table 1 Types, numbers, and size of protected areas in Slovenia according to IUCN categories (Agencija Republike Slovenije za okolje, 2009, Lampič & Mrak, 2007, Statistical Yearbook of the Republic of Slovenia 2008). Note: the total area is smaller than the sum of partial numbers, because some smaller protected areas are part of wider protected areas.

Nature protection in Slovenia is defined through the Nature Conservation Act of 1999 (Zakon o ohranjanju narave, 2004). According to the act, the wider protected areas (national parks, regional parks, landscape parks) cover approximately 2300 km² or around 11% of Slovenia (Agencija Republike Slovenije za okolje, 2009). The percentage of protected areas in comparison to other European countries ranks Slovenia near the bottom of the international scale (Berginc, 2007).

3.2 Abiotic natural heritage

The Slovenian Nature Conservation Act defines 10 different kinds of valuable natural features (Erhartič, 2009): geomorphological, subsurface geomorphological, geological, hydrological, botanical, dendrological, zoological, ecosystem, landscape, and designed nature. At least four of them correspond to the term "geodiversity" (diversity of abiotic nature) (Gray, 2004): surface geomorphological, underground geomorphological, geological and hydrological valuable natural features. However, other types of valuable natural features may also contain abiotic nature.

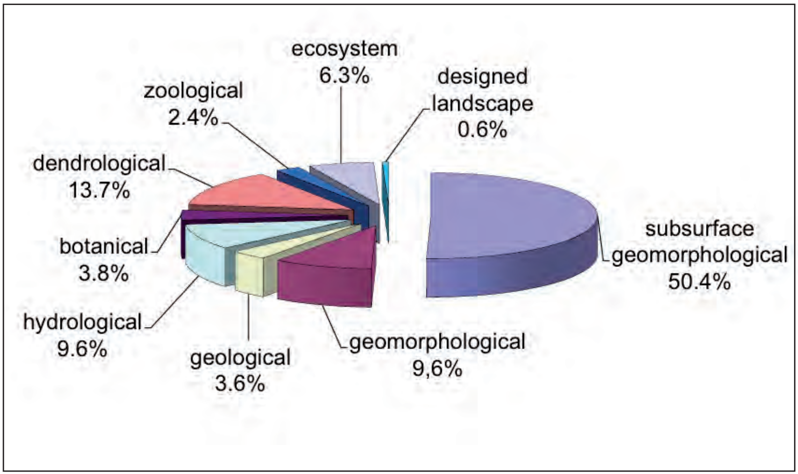

Fig. 3 Valuable natural features in Slovenia in 2008 (Agencija Republike Slovenije za okolje, 2009).

There are about 19’000 valuable natural features in Slovenia (Agencija Republike Slovenije za okolje, 2009). Figure 3 shows that half of them are underground geomorphological valuable features because all karst caves are declared as (subsurface) valuable natural features of national importance. The large number of trees as a natural value is also not difficult to explain. Surface geomorphological and hydrological natural features follow, in third and fourth place. Abiotic natural values as defined above represent 73% of Slovenia’s valuable natural features.

Around 85% of valuable natural features can be shown as points (caves, erratic boulders, trees), and the rest of them are indicated as areas, mostly very small. There are only 338 areas larger than 1 km² (Agencija Republike Slovenije za okolje, 2009). Table 2 shows the ten largest valuable natural features.

Slovenia has a good on-line register of valuable natural features, designed and maintained by the Environmental Agency of the Republic of Slovenia and the Institute of the Republic of Slovenia for Nature Conservation. Unfortunately, the list does not indicate why a specific feature was declared as a natural value. However, the expert evaluation criteria are exceptionality, representativeness, complexity, conservation status, rarity and ecosystem, and scientific or evidential importance; aesthetic and cultural values are not among them. This is the main problem of the Slovenian Nature Conservation Act and has consequences on the nature conservation system as a whole, as well as on geomorphosite assessment and mapping. According to the act, specific landforms or sites cannot be declared valuable natural features due to their outstanding beauty (aesthetic aspect) or cultural significance.

Name	Type	Feature (form)	Area (km^2)
Pokljuka	geomorphological	karst mountain plateau	136.64
Jelovica	geomorphological	karst mountain plateau	109.63
Nanos	geomorphological, geological	thrust structure	91.01
Kraški rob	geomorphological, botanical, zoological	thrust structure	65.05
Menina planina	geomorphological	karst mountain plateau	52.34
Krakovski gozd	zoological, botanical	flooded forest	46.36
Mura	hydrological, zoological	river	43.97
Vrata	geomorphological	glacier valley	43.87
Cerkniško polje	geomorphological, hydrological	karst polje (with intermittent lake)	35.44
Trnovski gozd	geomorphological, botanical	thrust	32.49

Table 2 The ten largest valuable natural features by surface. Their total area is 656.8 km², which is 3.24% of the national territory. The large majority of them are geomorphological features (Agencija Republike Slovenije za okolje, 2009).

3.3 Holistic approach

Although nature conservation in Slovenia is still largely the domain of biologists, the situation is slowly changing. Conservation is moving from the protection of species, to the protection of biodiversity, and towards a holistic approach to nature conservation (Serrano & Ruiz-Flano, 2007), which takes into account bio-, geo-, and landscape diversity. Some non-governmental organisations and the Scientific Research Centre of the Slovenian Academy of Sciences and Arts have undertaken the initiative with regard to a holistic concept.

The changes in conservation concepts, both in Europe and in Slovenia, and the incorporation of biodiversity have led to a greater understanding of the role that the abiotic components of a landscape play in determining value, an aspect without which it is not possible to conserve nature. Indeed, protected areas and places of maximum interest are often defined as such because of the abiotic elements that make up these outstanding landscapes (Serrano & Ruiz-Flano, 2007). Abiotic elements and dynamics are considered important, not only for sustaining life, but also for supporting the smooth functionality of terrestrial and marine systems and the conservation of habitats and landscapes.

Following these concepts, a systematic study of abiotic nature was also recently initiated in Slovenia. The assessment should be conducted following various steps indicated by a number of authors (Panizza, 2001, 2003; Pereira et al., 2007; Rodriguez, 2008):

1. Identification, inventory of heritage;
2. Classification, evaluation (qualitative and quantitative assessment);

3. Mapping (cartography);
4. Protection, conservation, preservation;
5. Presentation, interpretation, promotion.

The manner of accomplishing all these steps is quite an important issue because it involves the communication of a message from a scientific source (the first four phases) to the general public, who are the potential "users" of geoheritage (the fifth phase). In its practical (case study) part, this article focuses in particular on the third step of analysis: mapping geoheritage.

4. Mapping geoheritage

Compared with the research carried out in geomorphosite assessment and promotion, geomorphosite mapping has not received the same consideration. Today, scientists from various European countries are engaged in geomorphosite mapping (Coratza & Regolini-Bissig, 2009). It is important to have detailed geomorphological maps that provide fundamental data for meticulous description of sites. Large-scale geomorphosite mapping should, therefore, be considered an elementary part of the assessment process when carrying out inventories (Serrano & Gonzales-Trueba, 2005; Perreira et al., 2007; Coratza & Regolini-Bissig, 2009). *General overview maps* (Fig. 4) can be used in various areas, such as hazard assessment, spatial planning, tourism purposes (planning of interpretative trails), and so on. At the end of the inventory process, it may also be useful to create *thematic overview maps* to synthesize the distribution of various parameters that were assessed (e.g. glacial geomorphosites, punctiform geomorphosites) (Coratza & Regolini-Bissig, 2009).

The first map presented here (Fig. 4) shows the general distribution of geomorphological heritage in Slovenia. Simple symbols are used to indicate the location of geomorphosites on a simple digital elevation model (DEM) map. The variety of symbol shapes and colours produces extra information for immediate comprehension. Each geomorphosite on the map has a number in the corresponding table (not shown in figure 4) with additional information such as name, ID number, type, and a short description (similar to those shown in table 2).

There is no space for any other information on such a map. Therefore, small-scale maps are in most cases just *index maps.* However, more advanced maps have reference symbols that are specific ideograms with a precisely coded meaning, similar to those used in nature guides or on notices (Carton et al., 2005). These symbols allow an initial subdivision of geosites into various categories (e.g. a large or small symbol for a site of national or local importance, a wave to show a hydrological feature, an ammonite to show a geological-paleontological site or feature, etc.) that may interest the user.

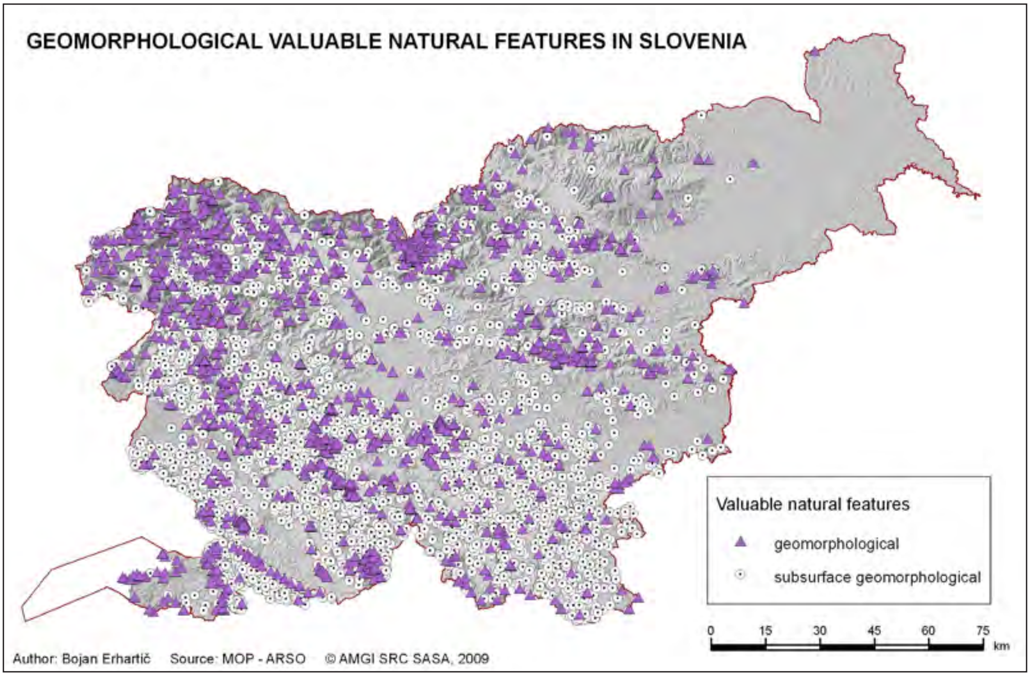

Fig. 4 Map showing geomorphological valuable natural features. Because of the small map scale, geomorphosites are presented only with punctual symbols. The largest concentration occurs in mountain and karst regions.

Map scale is an extremely important aspect of mapping. With regard to geomorphosites, a map can be at either a small or a large scale, but it is appropriate to have a limit between the two extremes. Carton et al. (2005) propose that maps at a 1:200’000 scale or less can be used as geomorphosite indexes (distribution of geomorphosites in a country or region), whereas those at larger scales can be used for showing geomorphosites in detail.

5. Case study of Bled

5.1 Bled: short overview

The lakeside settlement of Bled (500 m a. s. l.) is one of the oldest tourist centres in Slovenia. It lies in a basin at the eastern foot of the Julian Alps, where the Bohinj glacier cut several hills, created the lake hollow and several moraine deposits. These Ice Age gravel mounds also constitute the terraced region south and east of Bled. Lake Bled was created only about 14,000 years ago when water flooded the depression left by a receding glacier. It was once much larger and twice as deep as it is today, with an effluent at its eastern end. The current effluent stream, the Jezernica, etched its way south and since then the lake started decreasing in size. Today, it is 2100 m long and 30 m deep. Its surface temperature in summer is 24°C and it remains warm enough for swimming until the autumn. On the geological fault-line near the lake there is a thermal spring which has been tapped to supply the indoor swimming pool (Gosar & Jeršič, 1999).

The first visitors to Bled were pilgrims visiting the Church of St Mary on the island. Bled was also frequented by the nobility due to its outstanding beauty and the presence of thermal springs. Tourism in Bled would never have developed if Ignac Novak, an administrator of Bled Castle, had had his way. On several occasions in the late eighteenth century, he suggested that the lake should be drained for farmland and the clay from the lakebed used for making bricks. Luckily, his ideas were rejected by the Carniolan Assembly (Janša-Zorn, 1984).

It was the Swiss-born physician Arnold Rikli that helped Bled attain worldwide acclaim by building and developing a spa, and introducing a special treatment regime. Rikli worked at Bled more than fifty years (1854-1916), and the number of visitors increased dramatically when nearby rail lines were opened (Janša-Zorn, 1984).

Although Bled has been settled for more than one thousand years, it was established as a town in 1960, when five villages, which spread around the lake and are separated by several geomorphosites (moraines and hills, Castle Hill (599 m) among them), were united. Due to the fast growth of the city, many interesting abiotic and biotic natural features were covered or lost (e.g. wetlands, moraines and terraces).

Fig. 5 Bled, a world-renowned tourist centre with a unique mixture of natural and cultural elements and a large number of geomorphosites (photo: Bojan Erhartič).

5.2 Methodology

To date, investigations carried out on geomorphosites in Slovenia have been limited and have mostly focused on identification and classification. This article presents some first attempts to map geoheritage. The use of Geographical Information Systems (GIS) is acquiring ever-increasing importance because they allow useful elaborations, continuous updating of data, and easy interaction with the final user (Carton et al., 2005). This study uses geomorphologic mapping to analyse abiotic natural values in a small but diverse and interesting tourist area in the foothills of the Alps. The abiotic components of nature are essential to identify the qualities of a space in terms of tourism resources.

The method used is somewhat different from those recommended by Italian geomorphologists (Castaldini et al., 2005) because the first step was not performed: the creation of a "classical" geomorphological map. The database of the Environmental Agency of the Republic of Slovenia was used as a basis. All biotic features were excluded, and only the abiotic valuable features were analysed. The *map of abiotic natural features* can be seen in figure 6. We focused mainly on the accuracy and reliability of the data from the institute's database. Therefore, spatial information was gathered from orthophoto images and fieldwork in order to accurately locate and assess geomorphosites. After making a database (compilation and evaluation of an inventory), a *map of geomorphosites* (Fig. 7) was created and compared to the map of abiotic natural features.

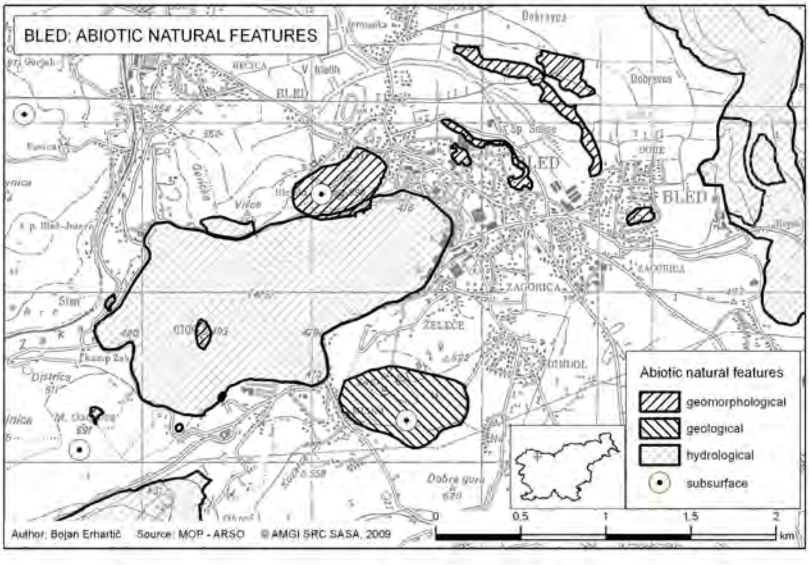

Fig. 6 Map of abiotic valuable natural features.

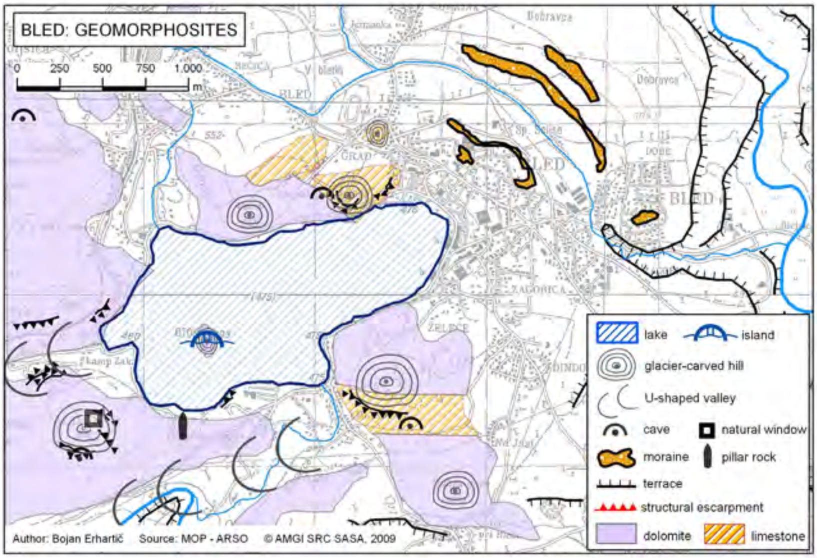

Fig. 7 Map of geomorphosites.

5.3 Discussion

On large-scale maps, geomorphosites are best shown by means of the more or less traditional symbols used in detailed geomorphological maps (Fig. 7). Only the symbols showing the form or set of forms making up a geomorphosite are depicted, whereas all the other elements of the landscape are omitted. The topographic basis and its scale were selected on the basis of the goals of the documents and the dimensions of landforms that are represented (Carton et al., 2005). Furthermore, on this large-scale geomorphosite map (Fig. 7) each geomorphosite has been numbered progressively and referenced in the corresponding table (not shown in figure 7).

Aim of the map

Although Carton et al. (2005) proposed a distinction between two categories of maps depending on the user (maps for specialists and maps for non-specialists), it was decided to create a *general overview map* (Fig. 7) without further interpretation purposes. The aim was only to synthesize the distribution of different parameters that were assessed. This map does not have specifically-defined final users, but is in fact a strong visual communication tool because it reveals distribution patterns that are much more difficult to identify from the written text of an inventory card (Coratza & Regolini-Bissig, 2009).

The geomorphosite map gives a general overview of the abiotic components of the most important tourist destination in the Slovenian Alps and may represent a basis for further work to local authorities. Users can also be other specialists or non-specialists, but this is not a (geo)tourist map in the strict sense because it does not contain tourist information. Some practical information (e.g. directions, parking, paths, and viewpoint) is an essential part of geotourist maps. However, as Bissig (2008) said, orientation and tourist information is the map's secondary function. Its primary function is the communication of spatially relevant themes and processes that contribute to the formation of a geomorphosite or a geomorphological landscape. An essential part of the morphogenesis explanation of the case study area is understanding the movement of the retreating Bohinj glacier at the end of Pleistocene era (Šifrer, 1969, 1992).

Content of the map

Quite obvious hills or arcs of terminal moraines can be seen in and around Bled. They consist of three successive stages of the retreating glacier. At the edges of the Sava River terraces, smaller and larger parts of older moraines occur on the surface in some places. Those parts have not been proclaimed valuable natural features (they are not shown in figure 6 as geomorphological heritage). Even so, they were evaluated very highly due to their outstanding scientific and educational value. Thus, they were recognised as geomorphosites (Fig. 7).

In contrast, the fossil site (a geological natural value) was excluded from the geomorphosite map for two reasons: because it is difficult to find the fossil site, and it would be problematic to promote paleontological heritage because uncontrolled exploitation could lead to devastation of the site. Some layers of rock types (limestone and dolomite) were put on the geomorphosite map instead, so the user could easily see and understand the difference between types of bedrock.

Design choices

Digital geomorphosite mapping has many advantages. The scale problem is less important because GIS allow the reduction or amplification ratio to be automatically obtained. The most important map components to be discussed are background maps, symbols, and a legend.

The geomorphosite map used some geomorphological *symbols,* although Carton et al. (2005) did not recommend them. Maps for non-specialists are designed to be easily understood while remaining an effective means of conveying scientific information.

In order to attain this goal, the 1:25'000 *topographic maps* were used as a *background* (1:50'000 is also useful) because they are known to and sometimes used by tourists, especially hikers. The topographical background also gives users precise locations, helping them orient themselves. Thus, most users can presumably interpret them. A simplified topographic map was not used as a base, but the transparency of the background was increased. A topographic basis was also used in order to emphasize the connection between geomorphological heritage and settlement. The impact of urbanisation on the natural heritage is clearly visible as well as the influence of geoheritage on the pattern of settlement. Thus, it can be useful for spatial planning and conservation needs.

Visual elements highlight features on a map. Colours can be used in two ways: according to the description of various types of landforms (Fridl, 1999) and processes (karst, glacial, hydrological, structural), or according to the importance of a specific element. The second approach was chosen in this case study. It enabled the use of more intense colours for the prominent landscape features (e.g. moraines and structural forms). The lake and the island are the most important distinctive features, and so their symbols were placed at the top of the *legend.*

Because Slovenia (part of Yugoslavia until 1991) has a quite long tradition of geomorphological mapping, some symbols proposed by Natek (1983) were used (e.g. terraces and structural escarpments). When a geomorphosite is punctiform or linear, it is easy to choose which forms will be represented and what their relative *symbols* will be. It is, however, more difficult to choose the landscape elements when it is an areal (polygon) type of geomorphosite (Carton et al., 2005). The most important question is how to present megaforms (e.g. U-shaped valleys or glacier-carved hills) as well as some mesoscale (e.g. erratic boulders) or even microscale forms on the same geomorphosite map. At the international level, at present there are a great variety of geomorphological legends, which differ from one another in their content, adopted symbolism, and scale representation because a single, universally recognised legend has not yet been implemented (Gustavsson et al., 2006, Coratza & Regolini-Bissig, 2009). International guidelines for establishing a common mapping standard are needed and should be discussed in the near future.

6. Conclusion

The mapping of geomorphosites is an important tool for territorial management as well as an effective means of communication and spreading knowledge, especially to raise awareness among the general public. A geomorphosite map can be used to prepare development plans at both the national and local levels. Managers of protected areas may use information from the map for establishing guidelines and a management plan, monitoring, directing tourism development, and promoting the ever-changing abiotic nature.

Growing sensitivity to numerous features of the environment has led geomorphologists to tackle the problem of in-depth study, preservation, and appraisal of geomorphological heritage. There is a growing awareness of the importance of geomorphological values concerning not only the scientific knowledge of a territory but also its environmental management and production activities. The scientific aspect has often added greater value to the appraisal of areas with a strong attraction for tourists.

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Bringing geoheritage underwater: methodological approaches to evaluation and mapping

Alessio Rovere, Matteo Vacchi, Valeriano Parravicini, Carla Morri, Carlo Nike Bianchi, Marco Firpo
Dipartimento per lo Studio del Territorio e delle sue Risorse
Università degli Studi di Genova
Corso Europa 26
I - Genova

E-Mail: alessio.rovere@unige.it

In Regolini-Bissig G., Reynard E. (Eds) (2010). *Mapping Geoheritage,* Lausanne, Institut de géographie, Géovisions n°35, pp. 65-80.

1. Introduction

The valorisation of the natural heritage (here intended as the complex of biotic and abiotic elements of nature worthy of conservation) assumed a growing importance in the last years, leading to place biodiversity and geodiversity concepts side by side (Brilha, 2002). This in turn channelled efforts to protect not only biotopes, but also the associated physical landscape or environment through the identification of geosites or geomorphosites (Panizza & Piacente, 1993; Panizza, 2001; Reynard, 2004, 2005). In the field of abiotic heritage evaluation, various methods have been proposed for the recognition of scientific and additional values of relevant geological and geomorphological sites (Panizza, 2001; Coratza & Giusti, 2005; Pereira et al., 2007; Reynard et al., 2007; Serrano & Ruiz Flaño, 2007; Zouros, 2007). Natural heritage studies cover most types of environments, from mountain and subterranean areas to plains and coasts. Nevertheless, while many approaches to valorisation of natural heritage are reported for emerged shorelines (e.g. Carobene & Firpo, 2005; Zouros, 2007), research on coastal submerged areas (Orrù & Ulzega, 1988; Orrù et al., 2005) still lacks common schemes and approaches when compared with studies dealing with marine ecological resources (Bianchi, 2007 and reference therein).

Inspired from a methodological approach developed in France for the evaluation of terrestrial natural spaces in the framework of the EU Habitat Directive (Bardat et al., 1997), the Regional Activity Centre for Specially Protected Areas RAC SPA (UNEP) (Relini, 2000) obtained evaluation indexes for 148 ecological units (biocenoses, associations or facies), which correspond to the main marine habitats of the Mediterranean Sea. The combination of these criteria led to the realisation, in the last decade, of marine territorial cartographies in some Italian protected areas (Bianchi, 2007, and references therein). From these experiences, Bianchi (2007) defined "marine natural emergences" as species, habitats or landforms of high conservation interest, achieving the result of a territorial cartography displaying these three typologies of marine natural emergences. Applying this approach, Rovere et al. (2007a) argued that "adding the abiotic values to the biotic ones appears of importance in the evaluation of the natural heritage", but pointed out the discrepancy between the definition of biological and ecological values and the abiotic ones, the former being codified, the latter lacking common evaluation schemes.

The development of underwater abiotic heritage assessment approaches demands for a greater effort with respect to the terrestrial environment (e.g. costs of boats and SCUBA equipment) and faces several limits, such as logistics of field activity (time and depth limitations for diving) and adverse environmental conditions (e.g. scarce visibility due to reduced water transparency). These limits are flanked by the conceptual difficulty, for administrators and policy managers, to conceive the marine environment as "territory" (Bianchi, 2007), as its perception is low with respect to the terrestrial environment and the tools for its management are not always defined. Due to these considerations, evaluation of scientific and additional values of abiotic heritage should be coupled with the evaluation of the inherent accessibility to users of the underwater natural heritage due to the aquatic medium itself (need of swimming skills or diving licenses to access sites).

Approaches to the valorisation of the underwater abiotic heritage should be developed using several distinct but interrelated kinds of inputs. Firstly, direct and indirect surveys, together with published information, provide the baseline maps to implement the conceptual framework for the evaluation of the abiotic heritage. Secondly, a conceptual framework, comprising of the categories and criteria to assign values to the landforms inside a given area, has to be developed and applied. Merging the baseline data and the conceptual framework into georeferenced databases will allow maps of the abiotic heritage to be obtained. Thirdly, accessibility values must be considered, as they represent the potential use of the heritage values, and accessibility maps need, therefore, to be produced. Finally, the abiotic heritage maps should be integrated with other information, such as ecological and socio-economical values or environmental degradation and risk assessment in order to obtain a complete territorial cartography, which is the base for the management of the natural heritage as a whole (Bianchi, 2007).

In this study, we propose a methodological approach that integrates the inputs mentioned above. In particular, the direct surveying techniques and the conceptual framework for the evaluation of the abiotic marine heritage together with its accessibility to use will be applied to a case study in the *Isola di Bergeggi*, a recently established Marine Protected Area (MPA) in Liguria (Italy).

2. Study area

The MPA *Isola di Bergeggi* (Fig. 1), located in the central part of the Ligurian Sea (NW Mediterranean), is characterised by the alternation of sandy and rocky coastlines, the latter being composed of Triassic dolomitic limestones of the "Brianzonese" domain ("Dolomie di S. Pietro dei Monti"). The presence of calcareous cliffs in the area allowed the formation of karst features, among which the best known is the *Grotta Marina*, a cave of karst origin whose shape has been subsequently modified by sea ingressions during the Late Quaternary period (Bianchi et al., 1988; Carobene & Firpo, 2004). According to the morphobathymetric and sedimentological map produced by Rovere et al. (2007b), the underwater coastal part of the study area is characterised by submerged cliffs cut by tidal notches and abrasion platforms, and of sand, pebble and rockfall deposits at their foot; the deeper part of the continental shelf (ranging from ca. 10 to more than 80 m depth) is mostly characterised by seagrass meadows, loose sediments and deep cliffs and rocky outcrops.

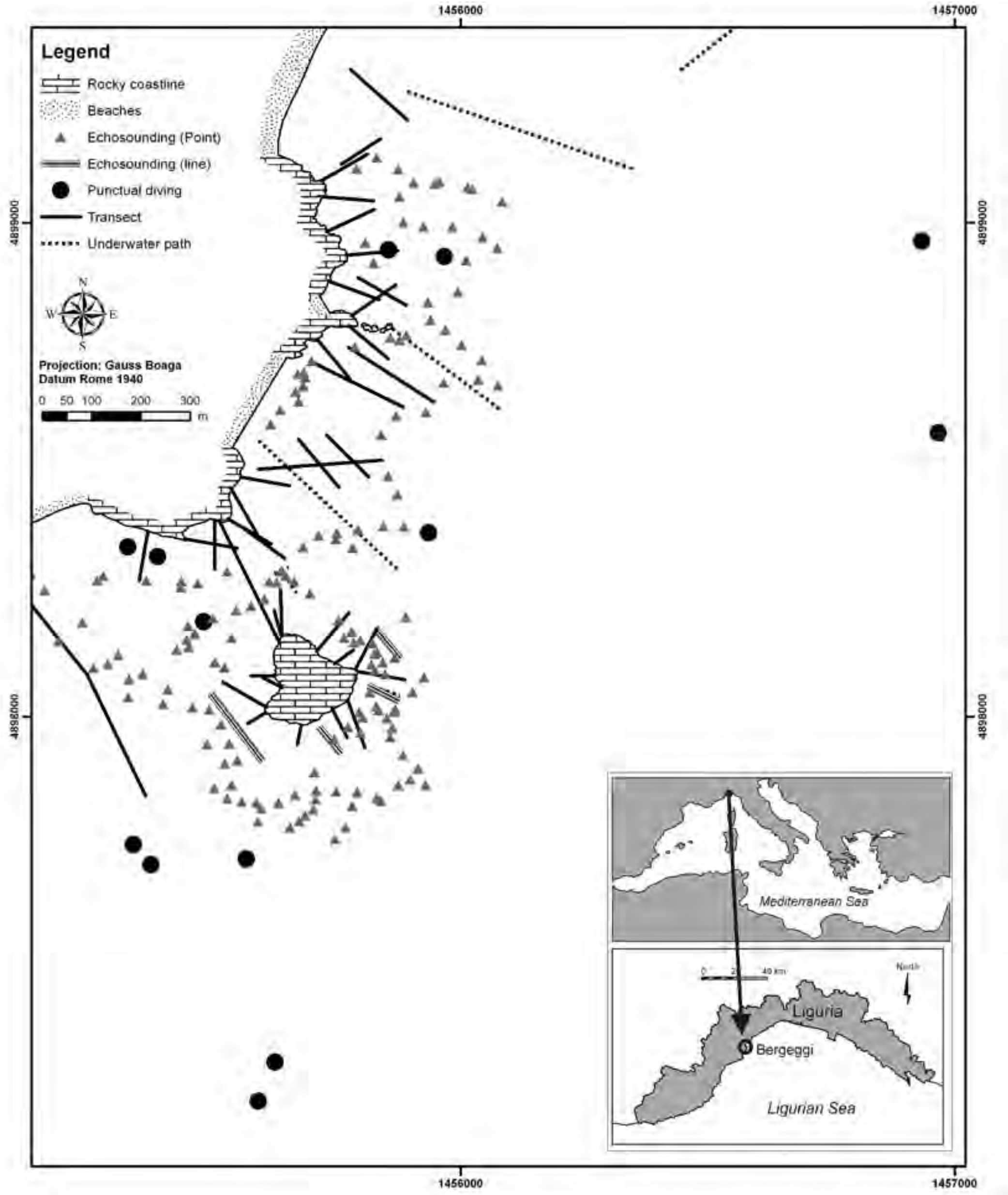


Fig. 1 Location of the study area with direct and indirect surveys.

3. Methods

Assessment of the underwater abiotic heritage was carried out using both indirect and direct surveys (Fig. 1). Indirect surveys consist in remote sensing techniques for mapping marine bottoms (aerial photography, satellite images and acoustic records from side scan, single or multi beam sonars). In general, these techniques have the advantage of mapping larger areas than direct surveys, allowing us to obtain georeferenced data at landscape scale useful for providing the cartographical basis for detailed mapping. Indirect surveys made in the study area included echo sounding (points or lines), as well as data from side scan sonar sonograms and aerial and photographs (Diviacco & Coppo, 2006). Nevertheless, in coastal marine environments, implementation of indirect surveys with direct ones is needed because of some critical issues dealing mainly with the interpretation and ground-truthing of aerial images and geophysical surveys and with the need for detail. Depth transects, underwater paths and punctual surveys were, therefore, carried out using scuba diving techniques (Bianchi et al., 2004). Depth transects consist of marked lines positioned on the bottom, along which the topography, relevant morphologies and types of sediments are measured. Underwater paths are similar to transects, except that they are done without reference lines and the distances are estimated with Personal Diving Sonar (PDS) and compass navigation. Underwater paths are the simplest type of polygonal survey, a method that proved to be efficient in mapping submerged shoals and caves (Colantoni, 2007).

In order to evaluate abiotic heritage and accessibility, the study area was divided into territorial units (hereafter called TU), defined as parts of the territory that: i) should give a sufficiently detailed territorial information; ii) can be compared from the point of view of the value and function that they have in the framework of environmental evaluation; iii) can be easily and uniformly represented in a GIS, allowing the building of relational databases to extract information for territorial management (Bianchi, 2007). These units are typically submultiples of the UTM grid, and can have various dimensions according to both the scale of baseline maps and the objectives of the study (in general, maps for environmental decisions require higher scales than those for environmental planning). In this study, the dimension of the TUs was set to 100 × 100 m due to the high detail (1:2000) of the baseline maps: the morphobathymetric and sedimentological map (Rovere et al., 2007b), the marine biocenose map (Parravicini et al., 2007a), and the marine emergence map (Parravicini et al., 2007b).

The Total Abiotic Heritage values (hereafter referred to as TAH) were divided into two categories: scientific and additional (Reynard et al., 2007). Scientific values are referred to as the sum of the geomorphological significances that a process or landform may assume in terms of four subcategories: integrity (INT), representativeness (REP), rarity (RAR) and paleogeographic value (PAL). Additional values refer to the aspects that have a link with a process or landform, but that cannot be directly ascribed to the field of geomorphological sciences. The subcategories identified for these values are: cultural (CULT), ecological (ECOL), economic (ECON) and aesthetical (AEST). These subcategories were described and adopted in terrestrial environments by Reynard et al. (2007).

The TAH values of each TU were assigned as follows (Tab. 1, 2):

- for each subcategory, a score was assigned to each landform, ranging from 1 to 5;
- additional and scientific values were obtained for each landform averaging the scores of the relative subcategories (Tab.1, 2);
- the TAH value of a landform was obtained averaging the scores of its additional and scientific values;
- the values at TU level were obtained by averaging the relative values of the landforms contained in the TU (Fig. 2);
- the TAH values at TU level were re-classified into five classes, which were represented into thematic maps as different colours of the TUs (Fig. 3);
- the accessibility of a TU was similarly scored in five classes (Tab. 3) ranging from 1 (high accessibility) to 5 (low accessibility). In the TUs where more than one value of accessibility was eligible, it was decided to retain the lower accessibility value allowing for the use of the higher abiotic heritage value (see Fig. 2 for an example).

Subcategory description / Criteria for the evaluation	1	2	3	4	5
SCIENTIFIC VALUES					
Integrity (INT): state of conservation of a given landform	Bad conservation due to both natural and human causes	Bad conservation due to human causes	Damage can occur in some parts of the landform but landscape integrity is preserved	Good conservation due to human intervention	Good conservation due to natural conditions
Representativeness (REP): exemplarity of a given landform	No exemplarity	Bad example of process or landform	Fair example of process or landform	Good example of process or landform	Reference site (in scientific literature) for the description of a process or landform
Rareness (RAR): rareness of a given landform at national, international or global level	Common or rare only at local scale	Rare at regional scale	Rare at national scale	Rare at international (e.g. continental) scale	Rare at global scale (e.g. few examples worldwide)
Paleogeographical (PAL): importance of a given landform in defining processes or environments that have characterised the Earth history	No paleogeographic value	Scarce paleogeographic significance	Good representation of a paleoprocess	Good representation of a paleoenvironment	Good representation of a paleoprocess and a paleoenvironment

Tab.1 Description of subcategories and criteria for the evaluation of scientific values.

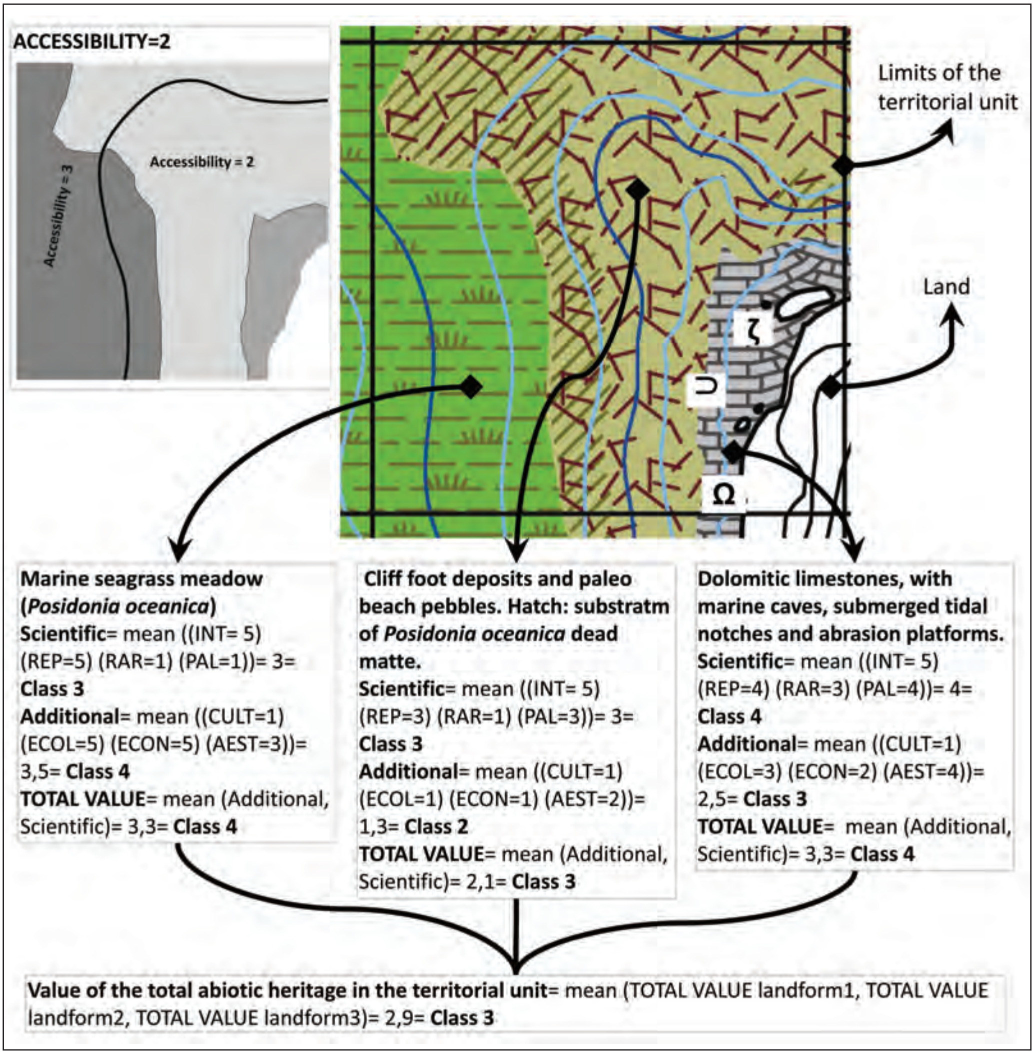
Subcategory description / Criteria for the evaluation	1	2	3	4	5
ADDITIONAL VALUES					
Cultural (CULT): cultural values in a site (according to Pereira et al., 2007)	Without cultural features	Cultural features with no connection to landforms	Immaterial cultural features related to landforms (e.g. legends)	Material cultural features related to landforms	Anthropic landform with high cultural relevance
Ecological (ECOL): importance of a habitat for the national or regional natural heritage, as defined by document UNEP (OCA)/MED WG 149/5 Rev.1 (Relini, 2000)	Scarce ecological value		Intermediate ecological value		High ecological value
Economical (ECON): assessment (e.g. number of visitors, benefits) of the products generated by the landform.	No economical value	Scarce economical value	Economical values related mainly to biological heritage	Economical values related mainly to abiotic heritage	Economical values related to natural (biotic and abiotic) heritage
Aesthetical (AEST): the value of the landform in terms of emotional impact on users, partially following and adapting the scheme proposed by Reynard et al., 2007	Where Ec is the aesthetic relevance of an habitat (as defined by document UNEP (OCA)/MED WG 149/5 Rev.1: Relini, 2000); Int the integrity derived from the INT subcategory; Ver the contribution of the landform to the verticality of the landscape; Str the presence of three-dimensional structures in the landform. Each value is assigned a score from 1 to 5, so the AEST subcategory can vary between 0 and 5. The AEST score was divided into 5 classes according to the results of the AEST index: 1: 0-1 2: 1-2 3: 2-3 4: 3-4 5: 4-5				

Tab. 2 Description of subcategories and criteria for the evaluation of additional values.

Description	Accessibility
Accessible from the coast, snorkelling	1
Accessible with snorkelling, need of a boat	2
Accessible with scuba diving I level	3
Accessible with scuba diving II level	4
Accessible with technical diving or speleo diving	5

Tab. 3 Description of the criteria for the evaluation of accessibility of territorial parcels.

The evaluation of the TAH was made not only on the data source derived from the baseline map (Rovere et al., 2007b), but also on the field notes taken during direct surveys, in order to obtain a greater detail. As an example, in some zones of the study area during field mapping, a strong human impact due to date mussel harvesting was recorded on both cliffs and deposits at the cliff foot (Parravicini et al., 2006; Rovere et al., 2009), but it was not included in baseline maps. The use of field notes during the evaluation led to a reduction of the integrity of these zones, and hence the TAH value of the related TUs.



Marine seagrass meadow (*Posidonia oceanica*)
Scientific= mean ((INT= 5) (REP=5) (RAR=1) (PAL=1))= 3= **Class 3**
Additional= mean ((CULT=1) (ECOL=5) (ECON=5) (AEST=3))= 3,5= **Class 4**
TOTAL VALUE= mean (Additional, Scientific)= 3,3= **Class 4**

Cliff foot deposits and paleo beach pebbles. Hatch: substratm of *Posidonia oceanica* dead matte.
Scientific= mean ((INT= 5) (REP=3) (RAR=1) (PAL=3))= 3= **Class 3**
Additional= mean ((CULT=1) (ECOL=1) (ECON=1) (AEST=2))= 1,3= **Class 2**
TOTAL VALUE= mean (Additional, Scientific)= 2,1= **Class 3**

Dolomitic limestones, with marine caves, submerged tidal notches and abrasion platforms.
Scientific= mean ((INT= 5) (REP=4) (RAR=3) (PAL=4))= 4= **Class 4**
Additional= mean ((CULT=1) (ECOL=3) (ECON=2) (AEST=4))= 2,5= **Class 3**
TOTAL VALUE= mean (Additional, Scientific)= 3,3= **Class 4**

Value of the total abiotic heritage in the territorial unit= mean (TOTAL VALUE landform1, TOTAL VALUE landform2, TOTAL VALUE landform3)= 2,9= **Class 3**

Fig. 2 Example of scoring procedure of a territorial unit.

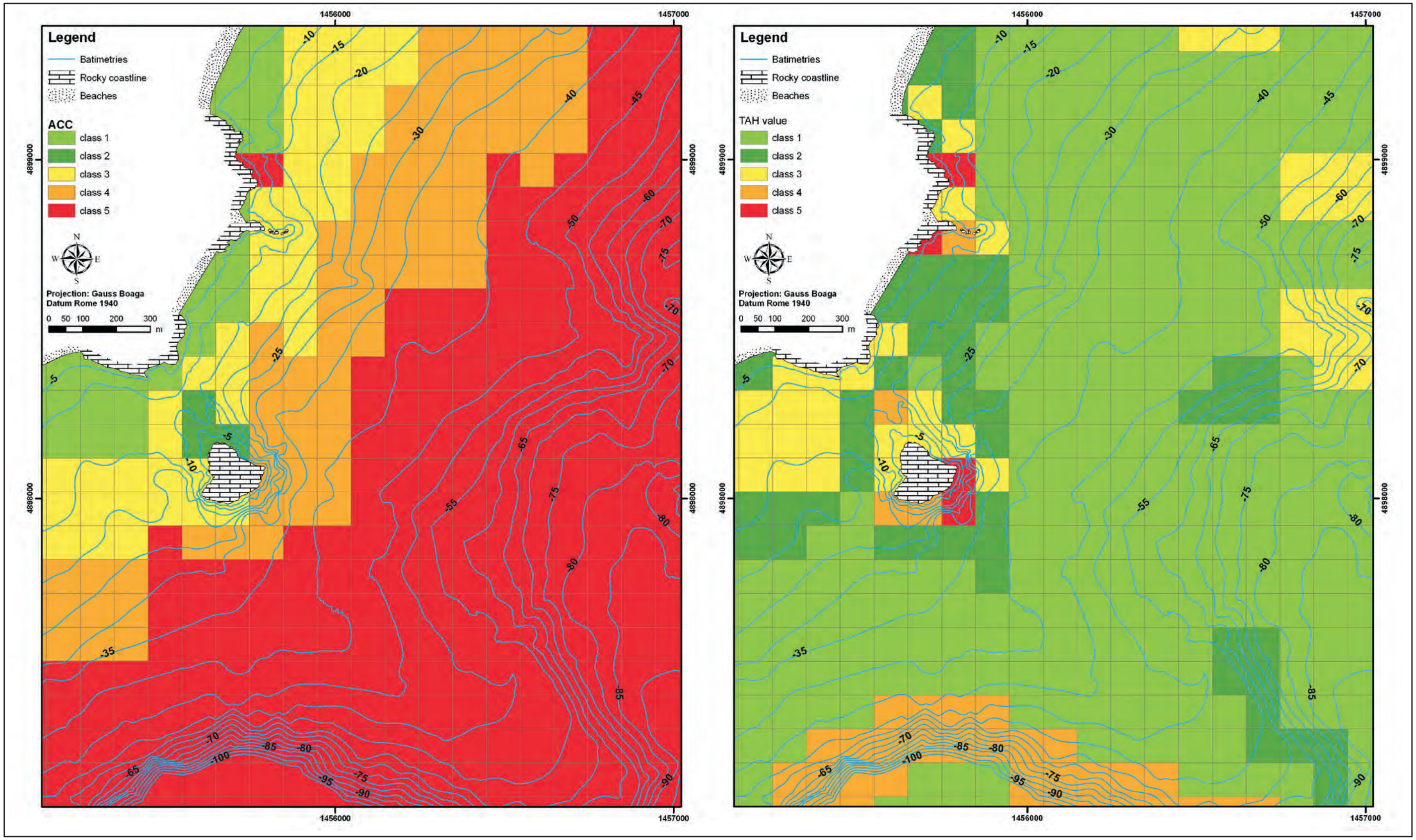


Fig. 3 Left: accessibility map; Right: total abiotic heritage values (mean of scientific and additional values).

4. Results and discussion

This study produced two main orders of results. The first one is represented by the refinement of the methodological approach, which was adapted in part from similar terrestrial studies dealing with the valorisation and conservation of geomorphosites, and in part from parallel approaches for the evaluation of ecological values. The second order is represented by the direct implications for the valorisation, conservation, and, finally, management of the MPA *Isola di Bergeggi.*

4.1 Methodological approach

Although indirect survey techniques were essential for the realisation of a cartographic basis (e.g. bathymetry, limits of *Posidonia oceanica* meadows), data from direct surveys proved invaluable to obtain the details for the comprehension and spatial representation of the morphologies. The availability, during the evaluation procedure, of the dataset obtained from direct surveys also helped in assigning values to each landform. In general, this consideration suggests that direct surveys must be planned not only with the typical aims of a geomorphological survey (e.g. description of landforms, processes) but also taking into account their successive use for the TAH evaluation, and should, therefore, include data, which usually are not surveyed (e.g. the integrity and the cultural values associated to a landform).

A major problem with the evaluation of TAH is subjectivity, which can also affect the choice of the number and typology of subcategories. In fact, while the distinction in categories that can be ascribed to the “scientific” and “additional” ones adopted here is well established in literature, different authors propose various supplementary subcategories to the ones adopted in this study (e.g. Zouros, 2007 and reference therein). This is a key point in the evaluation of TAH, and can be solved using three approaches. The first is a bottom-up approach, where an expert board is asked to determine subcategories and criteria, based on the comparison of many specific study cases. The second is a top-down approach, where an expert board is asked to determine, a priori, which are the subcategories and criteria to give to each landform in a hypothetical condition, independently from local contexts, and then test the definitions in study cases. The third is a no-uniformity approach, implying that it is simply impossible (or too difficult and time-consuming) to choose a common evaluation scheme for the evaluation of abiotic heritage in the marine environment and, even if the division into categories of “scientific” and “additional” values is maintained, the choice and evaluation of subcategories should be done following site-dependent considerations.

None of these approaches can be considered as the best, but they are intertwined and could represent three different steps in the evaluation of TAH. In fact, studies using no-uniformity approaches in different environments may provide the base for bottom-up choice of subcategories and criteria, which should necessarily be revised, implemented and generalised by expert boards, in a top-down perspective in order to enhance and improve further studies dealing with TAH and the comparison between different areas.

Another source of subjectivity resides in how the shift from landform-level to TU-level values is realised, as yet advanced by Bianchi (2007) during the compilation of ecological territorial cartography. Three main methods can be identified, each with their own pros and cons (Tab. 4): none can be considered as the best in absolute terms. In this study, the value of the TU was calculated by averaging the values of the landforms contained in it (third method in Tab. 4). The confrontation of the concordance/discordance of values obtained with these three methods would be particularly helpful in the choice of the correct methodology.

Method	Pros	Cons
The value of the parcel corresponds to the sum of the values of the landforms contained in it	It takes into account the value of geodiversity	Many low-value landforms are not equivalent to a single high-value one
The value of the parcel corresponds to the maximum value of the landforms contained in it	Landforms with high values are put in evidence	It does not take into account geodiversity
The value of the parcel corresponds to the mean of the values of the landforms contained in it	Many landforms of low value give a low value of the TU as a result	Averaging low values with high values produces mediocrity

Tab. 4 Three main methods, which can be used for the passage from landform-level values to those at TU level, with their respective pros and cons.

4.2 Management implications

In the study area, almost 80% of the TUs are located in the deeper continental shelf (Fig. 3) and have low values of TAH (classes 1 and 2) and accessibility (classes 4 and 5) (Fig. 4a, b); exceptions to this pattern occur in the SSW part, characterised by a wide submerged cliff and several rocky outcrops ranging from 50 to almost 90 m depth (Fig. 3). Coastal territorial units usually have high accessibility, exception made for the SE part of the Bergeggi Island and the Bergeggi Marine Cave (Fig. 3).

The comparison of TAH and accessibility values (Fig. 5) suggests three possible scenarios of tourist use of TUs having intermediate or high (class ≥ 3) TAH values: i) 7% of these TUs can be used for the development of snorkelling trails (Fig. 5, square A); ii) 5% is suitable to be used for the development of underwater trails for both experienced and first-level divers (Fig. 5, square B); iii) 11% of these TUs are suitable to be used as sites for technical diving (Fig. 5, square C).

The comparison between classes of values of scientific subcategories (Fig. 4c) shows that a significant percentage of the TUs have high (classes 4 and 5) values of INT, RAR, PAL and REP subcategories. For the additional values (Fig. 4d), 19% and 14% of the TUs have high values of respectively ECON and AEST subcategories. Scores of additional values show the absence of cultural features but point out the presence of TUs with high ecological importance, suggesting the opportunity of developing further multidisciplinary studies focusing on the links between abiotic and biotic values in this area.

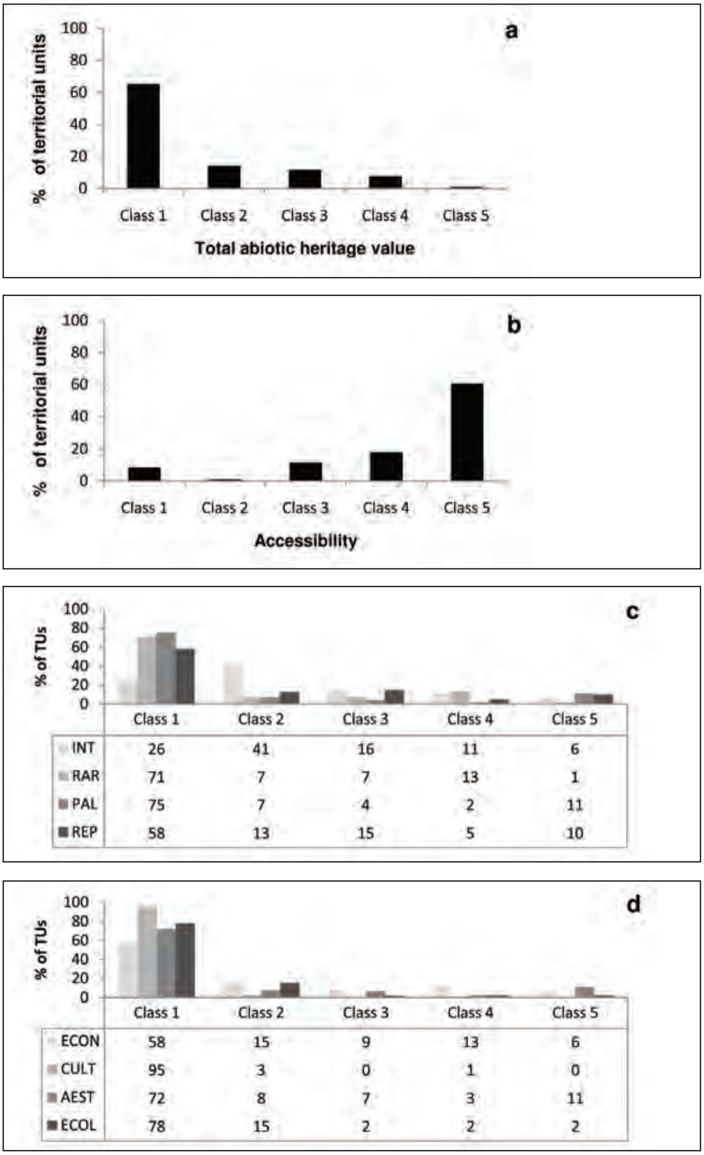


Fig. 4 Histograms representing the frequency distribution (%) of the scores of the territorial units according to: a) total abiotic heritage (TAH); b) accessibility; c) subcategories of scientific values; d) subcategories of additional values.

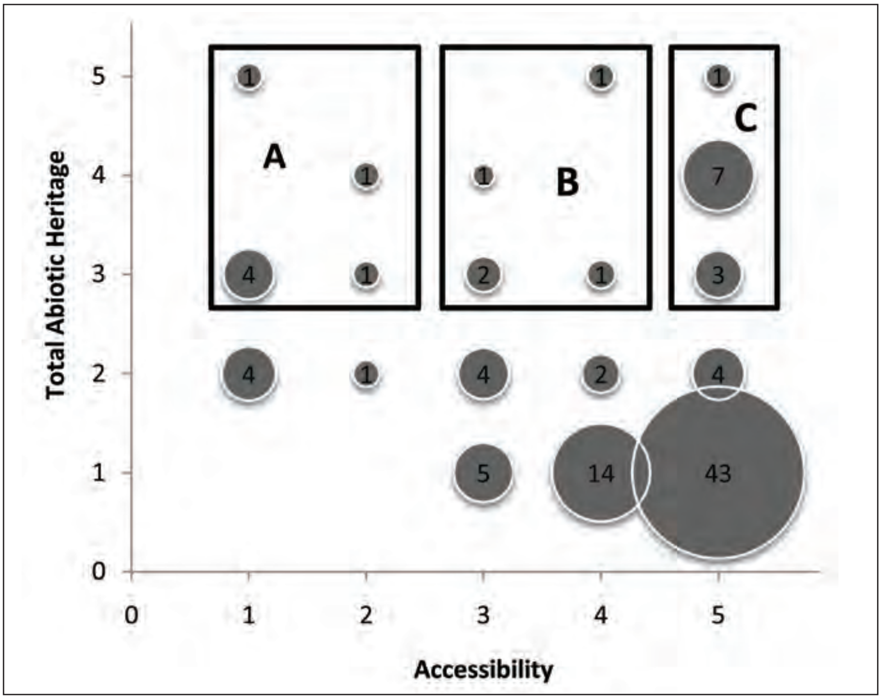


Fig. 5 Bubble diagram representing the values of Accessibility vs Total Abiotic Heritage (TAH). The diameter of the bubbles represents the percentage of territorial units with the associated values. The squares represent TUs, which can be used for: A) the development of snorkelling trails; B) the development of underwater trails for both experienced and first-level divers; C) site for technical diving.

The study area is characterised by a significant number of TUs with high scientific, additional, or both values located mainly in the coastal part, which is the most accessible for tourist use. In particular, the TUs characterised by high aesthetical values will allow for a use of the marine natural heritage based on the simple perception of the submerged seascape. Hence, aesthetical values may act as a "flag" for the scientific values of the area, shifting underwater tourism from an unaware and merely recreational use of the sea to the conscious use rooted in the knowledge of the marine natural heritage. This twofold possibility of valorising the natural heritage, together with the status of MPA, enhances the economical values of the TUs with high scientific and additional values inside the Bergeggi area.

5. Conclusion

What lessons can be learnt from this study for the future applications of methodological approaches to mapping and evaluation of the abiotic heritage underwater? The adoption of direct field techniques allowed us to include, in the planning of underwater geomorphological surveys, the assessment of values related to the submerged abiotic heritage. A common methodological approach is needed to define which are the subcategories and the criteria to adopt for the evaluation of abiotic heritage values. This is a critical point and each of the solutions discussed (top-down, bottom-up or no-uniformity) have their own pros and cons, but, in all cases, would be effective in reducing the subjectivity of the evaluation. At present, studies on different environments with different subcategories and criteria are being carried out, providing the "no-uniformity base", but an effort should be done in the near future to generalise the results of these studies and to adopt common schemes for the evaluation of TAH. Once a common evaluation scheme is chosen and adopted, common criteria will be necessary to shift from the assignment of values at landform level to that at TU level (sum, maximum, mean). The methodology developed and applied in this study represents the first attempt to face, and try to solve, these issues.

In perspective, the methodological approach proposed in this study proved to be efficient in providing indications for the assessment and evaluation of the marine abiotic heritage. Once integrated with input from other disciplines (such as biology and ecology), the proper valorisation of the abiotic components will concur to define a complete conceptual framework to be adopted for the management of underwater natural heritage as a whole.

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Dendrogeomorphological investigations for assessing ecological and educational value of glacial geomorphosites. Two examples from the Italian Alps

Manuela Pelfini, Valentina Garavaglia,
Irene Bollati
Dipartimento di Scienze della Terra
"A. Desio"
Università degli Studi di Milano
Via Mangiagalli 34
I - 20133 Milano

E-Mail: manuela.pelfini@unimi.it

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1. Introduction

One of the main goals of recent research carried out on geomorphosites is their valorisation in the frame of sustainable tourism and educational applications. Nowadays, many alpine geomorphosites are becoming the object of educational trips thanks to their educational values related to spectacular landscapes (Garavaglia & Pelfini, submitted). Among these, the glacial geomorphosites are becoming of great interest as representative of the mountain environment response to the global warming. Moreover, they highlight the interactions among the assessment values like rarity, representativeness and integrity (Grandgirard, 1999; Pelfini & Smiraglia, 2003; Reynard et al., 2007). Some glaciers are very meaningful as the most representative of the various typologies (e.g. valley glacier, debris covered glacier etc.) but others, without any integrity, are unique because they are the last glacial remains within a particular site. This is the case of the Calderone glacier in the Italian Apennines, the most southern European glacier and the only one still existing, even if debris covered and broken into two ice aprons (Pecci et al., 2008).

The glacier geomorphosites are highly representative for the study of climate history (Reynard & Panizza, 2005), responding in this way to educational goals. Moreover, their ecological value, represented among others by supraglacial and proglacial vegetation, is considered extremely useful for studies on glacier dynamics and reconstructions of glacial fluctuations, adding values for educational approaches once more.

Even if great attention is paid in assessing geomorphosite values, in order to promote and protect them, insufficient attention has been paid to “geomorphosite” topics in educational programs and only recently pedagogical trails for education in physical geography through geomorphosite observation have been proposed (Garavaglia & Pelfini, 2008).

This work tries to demonstrate the importance of the ecological value through the tree vegetation as a natural archive of data. Dendrochronology can be considered a very precious method not only to reconstruct geomorphological events, and so to increase the value of the scientific attribute (Grandgirard, 1999), but also to highlight the ecological valence of particular and sensible geomorphosites like glaciers. In fact living trees and stumps contribute to reconstructing glacier history and their present dynamics, and may represent also an important instrument for educational applications. The aim of this paper is also to discuss the meaning of ecological value assessed using tree vegetation.

The results obtained in two localities of the Italian Alps (Solda Valley in Ortles-Cevedale Group, Central Alps, and Veny Valley, in the Mont Blanc Massif, Western Alps) (Fig. 1) are summarised and used to discuss the ecological value and its related educational importance.

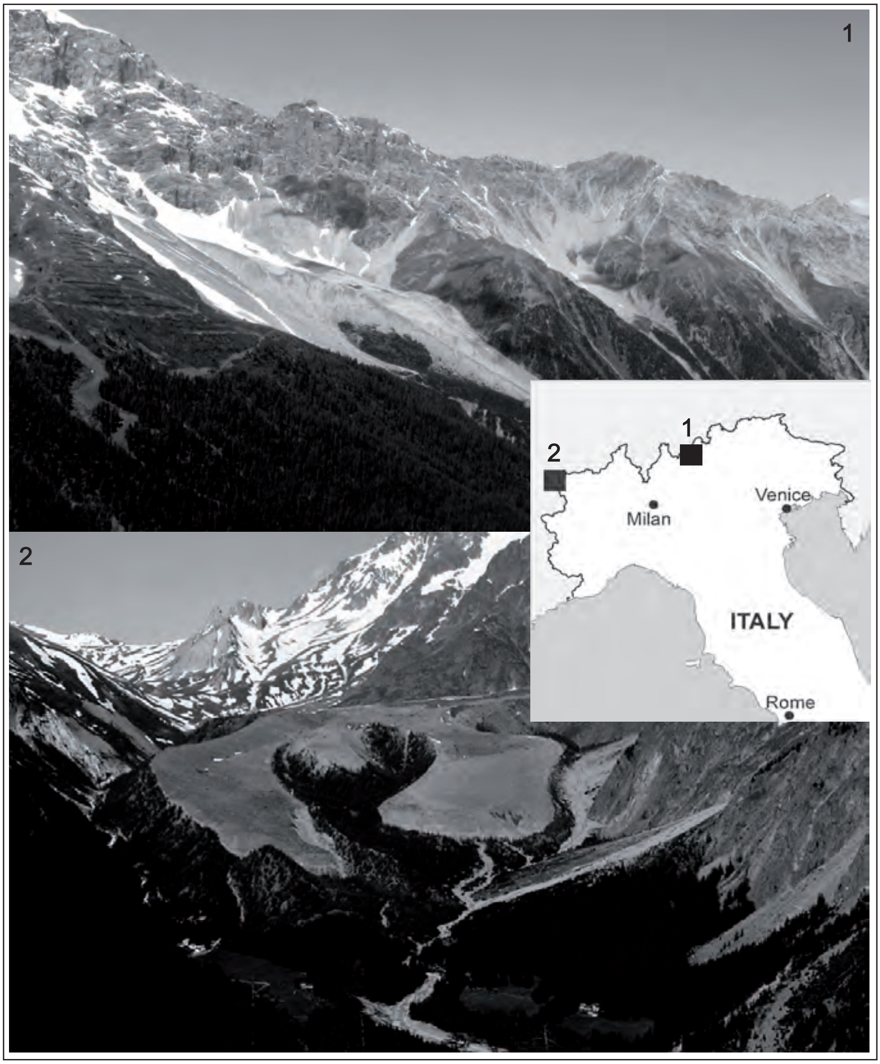

Fig. 1 Two panoramic views of the studied areas: 1) Marlet glaciers in the Solda Valley (Ortles-Cevedale Group, Central Italian Alps) and 2) Miage glacier in the Veny Valley (Western Italian Alps). Photos by V. Garavaglia and M. Bozzoni.

2. Glacial geomorphosites

The possibility of including glaciers and related morphologies in the geomorphosite framework, and consequently in natural and cultural heritage, was demonstrated by Pelfini & Smiraglia (2003). Glaciers can be defined as geomorphosites on the basis of scientific knowledge of natural assets, of natural laws that regulate their evolution and of their value relating to human perception. Glaciers represent beautiful landforms and frequently they are the goal of many hiking trails. Nevertheless, climatic changes in progress have led to profound changes of high-mountain environments, due to the rapid and intense shrinkage of the glacial masses (Oerlemans & Fortuin, 1992). The attributes and values that can be considered to identify these features as geomorphosites allow the glacier system to be considered not only as an assemblage of landscape elements but also as a sensible system and a significant example of geodiversity through their wide variety (Smiraglia, 2001).

The *cultural attribute* of glaciers begins with the evolution of the human species and its development, strictly related to glacier fluctuations, as Similaum man's history, around 5000 yr B.P., suggests (Mohen & Eluère, 1997). Populations living in mountain environments were influenced by glaciers in their history, behaviour, art, legends, etc. Other examples in the Alps can be carried out from the relationship between glacier environments and the First World War events (Pelfini & Smiraglia, 2003). The *economic attribute* is represented mainly by hydroelectric energy and tourism. Glacier meltwater represents an important resource for hydroelectric power: many reservoirs in Aosta Valley and Valtellina were realised using hollows and glacier basins. In the Alps, glacial scenarios represent the natural support for tourism development: from few visitors about two centuries ago, to a hundred thousand each summer, at the present day, in areas like Mont Blanc and Monte Rosa. The increasing number of mountain huts and their enlargement (Smiraglia & Diolaiuti, 2002) underline a development of mountain frequentation. Moreover, some glaciers have been used for summer skiing even if only very few of them are still working today due to glacier shrinkage and other economic causes. The *scenic attribute* is obvious; the beauty of glacier sites remains one of the main aims of tourist frequentation. The *scientific attribute* is well documented by all the parameters suggested by Panizza (2001). Glaciers are well widespread; they are characterised by a wide variety of types (geodiversity) and by dynamicity, the latter highlighting their role as climatic indicators. Glaciers are very sensitive indicators of climate changes (*glacier as model of evolution)*, with short response time (except for polar glaciers). The *exemplarity* of a glacier is directly related to this valence: in fact if a glacier is a good model of evolution, it has also a great exemplarity.

For example, the Forni glacier was proposed as a representative glacial geomorphosite (Pelfini & Gobbi, 2005) and the glaciological trail "*Sentiero Glaciologico del Centenario al Ghiacciaio dei Forni*", on the Lombardy side of Ortles-Cevedale Group, was opened in order to visit a geomorphosite of naturalistic, cultural and historical interest (Smiraglia, 1995). Nevertheless, as a consequence of the glacier tongue rapid shrinkage and of the instability phenomena, a new route was recently imposed, evidencing possible risk increase for users. *Paleogeomorphological evidences* in glacial systems are also paleoclimatic sources of information. Moraine ridges allow the positions reached during glacier advances to be identified, to calculate volumes, past glacial thickness, equilibrium line altitude fluctuations etc., and consequently they consent to obtain paleoclimatic information. Glaciers are important also as *ecological support*: life outposts like algae and insects (glacial flea) (Michler, 1980; Panizza, 2001) are strictly dependent on the glacier tongue conservation. This was also recognised by Barthlott et al. (1996), to be one of the incentives to geodiversity assessment. On the Forni glacier, the increasing debris coverage on the snout allows species of arthropods to live on ice, becoming biological indicators of climate changes (Pelfini & Gobbi 2005). Where debris layers become thicker, vegetation can colonise the glacial surface and also more stable trees can grow, as on the Miage glacier (Pelfini et al., 2007).

As mentioned before, the ecological value is included among the additional values (and not in the scientific one), when related to geotourism or integrated cultural landscapes contexts. Several case studies propose different approaches to ecological value assessment in relation to different geomorphological situations: Pereira et al. (2008) include the ecological value among the additional ones, quantifying it on the basis of the relationship between geomorphosites and biological features (Tab. 1); Zouros (2007) proposes to assess the aesthetic and the ecological values contemporarily (case studies from Greece). For the karst environment, the ecological value has been linked to the economic, touristic and heritage status by Héritier (2006); in this case the "heritage value" concept synthesises the recognised values basing on a mathematic evaluation or a synthetic analysis. González Trueba & Serrano Cañadas (2008) suggest two different approaches: i) to determine the *scientific* or *intrinsic value,* based on geomorphic topics and allowing a more objective and systematic knowledge of the site, and ii) to define the "cultural or added value", based on the consideration of cultural and environmental elements affecting and enriching the intrinsic value. They use the ecological criteria as the starting point for the geomorphosite assessment.

In the present work, the ecological value is underlined as a component of both the scientific (glacier fluctuation reconstruction) and additional (promotion and education) values.

Ecological value	
0	Without relation to biological features
0,38	Occurrence of interesting fauna and/or flora
0,75	One of the best places to observe interesting fauna and/or flora
1,12	Geomorphological features are important for ecosystem(s)
1,50	Geomorphological features are crucial for the ecosystem(s)

Table 1 Numerical assessment of the geomorphosite indicator of ecological value (from Pereira et al., 2008).

3. Case studies: the Marlet glaciers and the Miage glacier

Two examples are presented in order to underline the importance of the ecological value for the Earth and climate history and for an educational approach.

The first case is represented by the Marlet glaciers (Ortles Cevedale Group). The "Ghiacciaio Alto del Marlet" is a *debris-covered glacier* fed mainly by avalanches from the Ortles peak (3905 m a.s.l.) and shows a very steep and uneven topography. The "Ghiacciaio Basso del Marlet" moves down-valley from the Ortles northern crest and presents a half debris-covered tongue. The two Marlet glaciers deposited huge moraines ridges, principally built during the Little Ice Age and characterised by vegetation coverage. Among them, a small moraine system is present; it is colonised by well developed vegetation consisting of grasses, shrubs, living trees and stumps (principally *Larix decidua* Mill. and *Pinus cembra* L.) (Fig. 2). A dendrochronological analysis was carried out on living trees and stumps, using maximum tree cambial ages to obtain a minimum age for the surfaces and to reconstruct recent glacier evolution. It is a simple situation, appositely selected for educational applications.

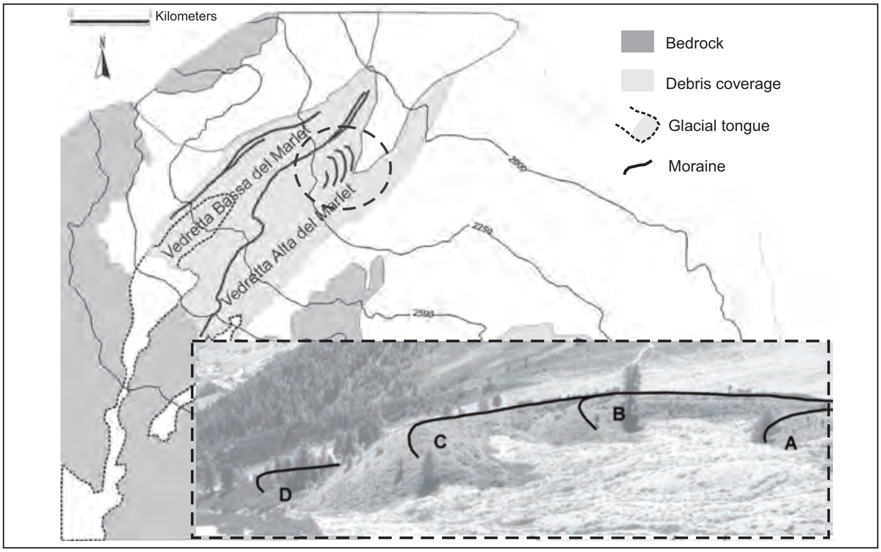

Fig. 2 Geomorphological sketch of the Marlet glaciers (Central Italian Alps). The moraine amphitheatre, studied using dendrogeomorphological methods, is represented (letters A, B, C, D mark the four moraine ridges) in the dashed circle. Photo by V. Garavaglia.

The second case is represented by the Miage glacier in the Mont Blanc Massif (Fig. 3), the most representative debris covered glacier in the Italian Alps with a forest vegetation growing on its debris layer (Pelfini et al., 2007) (Fig. 4). Here the relationship between glacier activity and tree dynamics is complex and represents an important support to glaciological investigations.

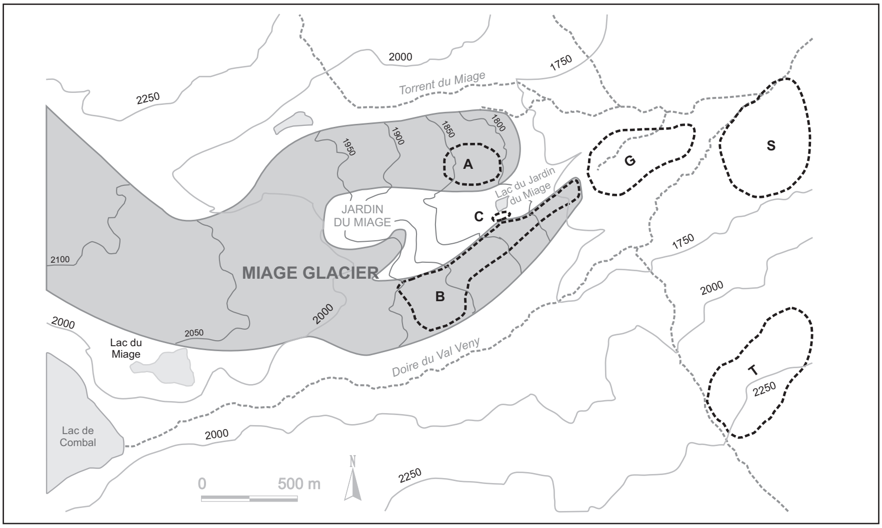

Fig. 3 A sketch of the Miage glacier front. The dashed circles show the sampling areas chosen for the dendrogeomorphological survey. Letters A, B, C indicate the three groups, sampled to date glacier movements; letters G, S and T are the groups of undisturbed trees used to build the reference chronologies.

Fig. 4 Supraglacial tree cover on the Miage glacier. European larches colonise debris coverage and react to the glacier movements producing growth anomalies in annual rings permitting a precise dating of surface movements. Photos by M. Bozzoni.

3.1 Dendrochronological sampling and analysis

All the samples were collected and prepared according to the traditional methods (for details see Schweingruber, 1988). For the analysis, the cambial age of each sample was determined by counting the number of annual rings. Missing rings, in samples without pith, were estimated according to Jozsa (1988) and Villalba & Veblen (1997). Tree-ring width was measured precise to 0.01 mm, using the LINTAB system and TSAP software (Rinn, 1996) and through image analysis technique, with the WinDENDRO software (Regent Instrument Inc., 2001). The crossdating of the dendrochronological series was performed using COFECHA (statistical analysis) and TSAP software (visual analysis).

All the dendrochronological curves were averaged in an indexed chronology. The standardisation was realised through the ARTSAN software (Holmes, 1994). A double process of standardisation was chosen to eliminate the growth trend (Cook & Kairiukstis, 1990): as the first step, a negative exponential or a linear regression was applied, then a *cubic smoothing spline*, with a wave length of 100 yr and a variance conservation of 50 %, was performed.

Near the Marlet glaciers, 29 European larches were sampled to establish the minimum age of older and well-vegetated ones. A mean tree-ring chronology was created from 12 living trees and, successively, 13 samples from stumps were crossdated using local references and other chronologies available at the International Tree-Ring Data Bank (ITRDB; Grissino-Mayer & Fritts, 1997).

On the Miage glacier, 52 European larches were sampled on the lower part of the tongue. Three reference chronologies, based on undisturbed larches growing outside the glacier, were constructed for a comparison with the tree-ring data from the supraglacial trees. They were used to identify growth anomalies induced in the supraglacial trees by the glacier surface movements. In order to identify the temporal distribution of the growth disturbances in the supraglacial trees, two main approaches were adopted: i) a tree-ring growth series analysis performed on ring-width measurements (looking for pointer years and abrupt growth changes) and ii) skeleton plots made by a visual assessment of the samples (event years) (for a complete description of the methods, see Pelfini et al., 2007).

3.2 Dendrogeomorphological results on the Marlet glaciers

Dendrochronological results evidence how tree rings allow different ages to be attributed to the moraine systems (relative dating) and, indirectly, to identify an ancient glacier advancing phase drawing a glacier shape completely different to the Little Ice Age one. Moreover, the difficulties in absolute dating reveal a not unique advancing phase. In fact moraine disposition suggests an age progressively increasing down-valley (from A to D in Fig. 2). The cambial age and the reconstructed real tree ages represent a minimum age because errors might have affected dating procedure

(Heikkinen, 1994). The mean larch chronology, that covers the period 1396-2004, was used for crossdating samples from dead trees, alive between 1411 and 1947. The germination period was certainly older, also because some samples from stumps were decayed in their inner part. So, on the basis of the added rings, we estimated that on moraines B, C and D (Fig. 5) some tree germinations could be dated almost to the 14th century: about 1430 on moraine A, 1320 on moraine B, 1370 on the C one and 1300 on the D one (Fig. 5). The obtained ages do not follow an age increase trend down-valley. The moraines' minimum ages are probably underestimated; in any case moraine depositions seem to be attributable to a period before 1300, for the most external one (D), and before 1430, for the inner one (A) (unpublished data). This could be a moraine system built during advancing phases before the Little Ice Age or in its earlier phases, as observed in other areas (Grove, 1988; Pelfini et al., 2002), even if it is not possible to establish how many years before. In any case, the colonisation seems to have taken place in a small time interval (about 130 yr); the advancing phases were probably quite close in time.

The Marlet glacier site is easily accessible for users and attributes and valences are easily observable in a restricted area. The presence of clean and debris covered glaciers in the valley reveals the changes happening in glacial environments, while the moraine systems and the relative forest vegetation allow the paleoenvironmental and paleoclimatic values to be assessed. In this case, the vegetation role in assessing the ecological value and the dendrochronological investigations' role in improving the scientific value are highlighted, confirming the possibility of a didactic application.

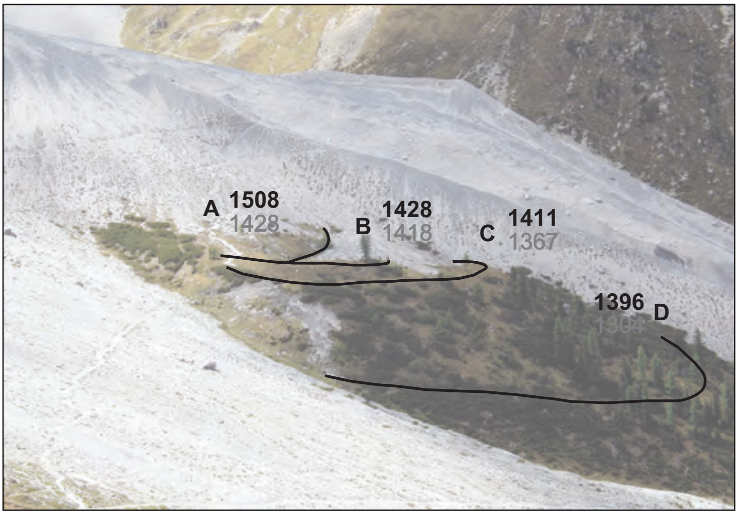

Fig. 5 The Marlet moraine amphitheatre. The letters indicate the four moraine ridges; the black numbers represent the maximum age of the oldest sampled trees obtained by tree rings counting; the grey numbers show the maximum age of the oldest sampled trees, estimated on the basis of the sampling height and distance to the pith. Photo by V. Garavaglia.

3.3 Dendroglaciological results on the Miage glacier

On the Miage glacier, an evaluation of tree coverage represented the first step to assessing the ecological value related to the uniqueness of this supraglacial vegetation; nevertheless dendroglaciological analysis highlights the importance of growth anomalies to analyse glacier geomorphosite evolution and their present dynamics. The tree colonisation depends on the debris thickness and on the glacier stability; in fact only the main lobes are colonised by trees, especially the southern one (*Larix decidua* Mill. and *Picea abies* Karst.). Morphological situations such as hollows, depressions or niches, facilitate the tree growth. Trees and tree ring morphologies (e.g. respectively deformed, twisted trunks, eccentric rings and compression wood) document in detail the vertical and lateral tilting, the ice sliding down-valley, the transmission of kinematic waves, glacio-karst phenomena, and debris cover instability. The growth disturbances are well recorded in tree-ring width, characteristics, morphology and other indicators. The latter were identified and dated, confirming the passage of a kinematic wave (also documented through aerial photographs and glaciological investigations) and adding a great detail about the kinematic wave arrival and its different intensity in the two lobes. The growth disturbance signals mainly occurred since the middle of 1980s on the southern lobe and during the beginning of 1990s on the northern one, with a delay of about five years (Fig. 6) (for details, see Pelfini et al. 2007).

The tree ability to record glacier movements is controlled by the glacier surface velocity and by the evolution of ice cliffs (backwasting and downwasting) that lead to the roots' exposure, near the ice cliff edges, and the final fall of trees towards the escarpment.

The dendrochronological investigations on the Miage glacier highlight the wide scientific value of the most important Italian debris-covered glacier, a geomorphosite with a vegetational component improving its ecological value. The dating of the tree reactions to the glacier movements highlights the link between biological and glacial components and its importance in studies both on glacier dynamics and on valorisation of glacier geomorphosites.

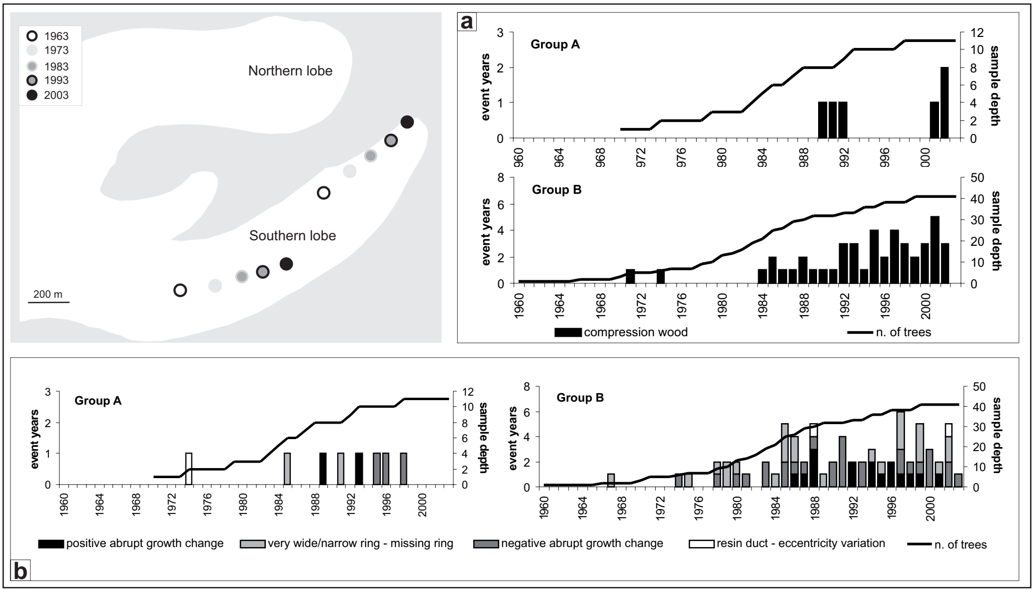

Fig. 6 Reconstructed position of the two oldest sampled trees on the Miage glacier every 10 years assuming a mean velocity of 10 ma^{-1} (Diolaiuti et al., 2005). The compression wood (a) and other growth anomalies (b) identified by skeleton plots of supraglacial trees on the northern (group A in Fig. 4) and southern (group B in Fig. 4) lobes, are represented in the four graphs adapted from Pelfini et al., 2007.

4. Conclusions

Generally the ecological value is represented by the element of rarity like the presence of exclusive animals or vegetation components.

As mentioned before, recently the rigor and objectivity that characterise the scientific value assessment, compared to the more intuitiveness of the cultural and added ones, have been highlighted. On the placement of the ecological value as a fourth scientific valence or among the additional values depends on the meaning given to it (e.g. Panizza, 2001; Pralong, 2005). In the specific case of this paper, if dendroglaciological analyses are considered as precise technical methodologies, the ecological value that they represent should be assessed among the scientific valences.

In the case of the Marlet glaciers (as in many other study cases in the Alpine environment, e.g. McCarthy & Luckmann, 1993; Luckmann, 1998), the dendrochronological dating of small moraine amphitheatres allowed us to assess the importance of tree vegetation in reconstructing glacier history and, as a consequence, to improve the geomorphosite scientific attribute. The simplicity of the morphological situations better relates to the didactical applications. Images of cores can be proposed to students in order to help them to reconstruct landscape changes and to approach dating methods without the necessity of dedicated instruments. The different morphologic characteristics of moraines and their dating allowed us to introduce the concept of glacier fluctuation in the educational applications.

In the Miage debris covered glacier, the presence of widespread supraglacial vegetation reinforces the rarity concept and improves the glacier ecological value. The dendroglaciological analysis allows the assessment of the importance of trees in analysing the present glacier dynamics and, as a consequence, to contribute to the scientific evaluation of a geomorphosite. Moreover, in this case, trees represent a precious instrument to investigate glacier dynamics and contribute also to improving the geomorphosite valence. At the same time, the good accessibility to the Miage and Marlet glaciers represents a possibility of spreading the glacial geomorphosite knowledge to a wide public, from hikers to scholar users. In both the studied areas, the use of dendrochronology allowed us to increase the knowledge on the ecological and educational values. By inserting these applications in educational trails, it may be possible to popularise scientific results generally discussed only in academic environments, transmitting the notions of climate change impact, valorisation and conservation of geomorphosites.

Acknowledgments

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GIS and geomatics application for the evaluation and exploitation of Piemonte geomorphosites

Luca Ghiraldi, Paola Coratza, Mauro Marchetti
Department of Earth Sciences
University of Modena and Reggio Emilia, Largo San Eufemia 19
I-41100 Modena
E-Mail: luca.ghiraldi@gmail.com

Marco Giardino
Department of Earth Sciences
University of Torino
Via Valperga Caluso 35
I - 10125 Torino
E-Mail: marco.giardino@unito.it

In Regolini-Bissig G., Reynard E. (Eds) (2010). *Mapping Geoheritage,* Lausanne, Institut de géographie, Géovisions n°35, pp. 97-113.

1. Introduction

Landscape is a complex combination of landforms and processes in constant change. These forms and processes are important evidence of the Earth's history and enable us to understand the evolution of our world (Avanzini et al., 2005). Geomorphological heritage may refer to a collection of sites of geomorphological interest defined as geomorphosites (Panizza, 2001). In this paper, the term "geomorphosites" is used to refer to geomorphological landforms, which are important for the knowledge of Earth history and characterised by scientific, cultural/ historical, aesthetic and social values on the basis of human perception and appraisal (Panizza & Piacente, 1993; Panizza, 2001).

Among Italian regions, the Piemonte (Piedmont) is noteworthy because of its variety of environments and, similarly to other regions, it has started an activity of acknowledging, describing and making sites, which bear witness of the Earth history, available for people. In the past few years, several attempts to investigate the geological heritage of the Piemonte region were carried out. The first step was the publication of the "*Carta geomorfologica degli elementi di interesse paesaggistico del Parco Nazionale del Gran Paradiso*" (Giardino & Mortara, 2001). Subsequently, a remarkable impulse was given by the publication of two books for the general population on the appraisal of geomorphosites in Turin Province (Giardino & Mortara, 2004). At the end of 2004, the cooperation between the managing Authority of Asti Province Natural Parks and the Department of Earth Science of Turin University, allowed the inventory of 219 geosites located in the Asti Province and the Turin hills (Various Authors, 2004).

This paper describes the steps followed to evaluate and appraise the geomorphological heritage located in the southern Piemonte plain (Cuneo Province) by means of assessment procedures, GIS (Geographic Information System) and geomatics instruments. It suggests programs of appraisal and popularisation by means of GIS and geomatics applications, in order to translate the complex Earth system with simple language, allowing a knowledgeable approach not only for the persons involved in the field of geosciences, but also for a general public and consultants involved in educational activities.

2. Geographical and geomorphological outline of the study area

The study area is located in north-western Italy, in the Cuneo province (Piemonte Region, Fig. 1). To the south, the area extends as far as the town of Bene Vagienna; it encloses the Stura area of the Demonte River to the west, the Tanaro River to the east; and to the north, the area extends as far as the urban centres of Bra and Pocapaglia.

From the geomorphological viewpoint, the area can be divided into two sectors. The first one is characterised by river terraces standing out as islands from the plain. The morphogenesis of these landforms is due both to Pleistocene climate changes and to the NNE diversion of the drainage system, triggered by neo-tectonic activity. The terraces consist of Pleistocene deposits; they gradually join with the main plain surface to the west; in other places they are abruptly connected to the present valley floors of the Tanaro and the Stura area of the Demonte rivers. To the east, the Pleistocene plateaux are grading to Holocene terraces suspended above the Tanaro riverbed. As a consequence of the capture of the Tanaro River, the whole terraces are cut by streams that dug deep gorges in their distal sector, where marine deposits of the Piemonte Tertiary Basin crop out (Costamagna, 2005).

The second sector is located in the north-eastern part of the study area. It is characterised by a complex set of narrow and deep valleys due to retrogressive river erosion, which is a consequence of the Tanaro NNE diversion. This kind of processes, at present no longer active, created badlands and dramatic landforms, locally well known with the name of "Rocche di Pocapaglia".

3. Assessing the geomorphological heritage

In order to identify natural assets in a geomorphologically and scenically heterogeneous and complex region such as the one previously described, the inventory of the geomorphosites was carried out by the Earth Science Department of Turin University, based on a clearly defined methodological process. The first stages of the process were the study of both scientific and popular bibliographies, archive studies and analysis of specialised maps. The second phase was a detailed survey that resulted in the exploration of those areas considered the most representative for the geodiversity of the territory. In the whole area, ten geomorphosites of different contents and interests were identified, and eight of them were selected following the methodology proposed by Reynard et al. (2007). They all show a high educational value, allowing the understanding of the geomorphological evolutionary stages and the morphodynamic processes affecting this territory.

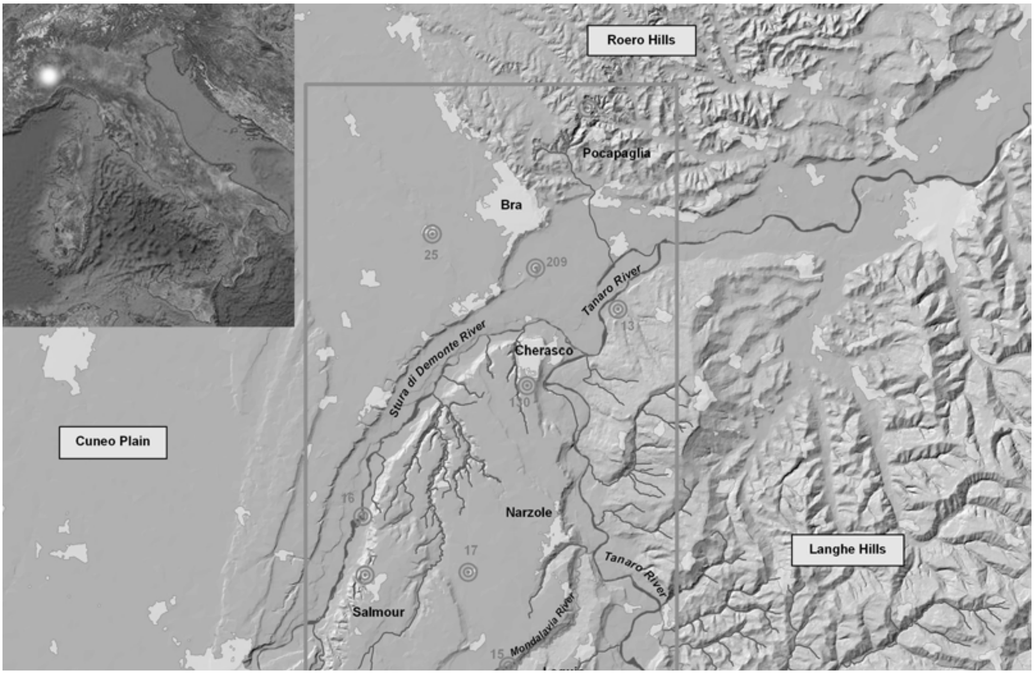


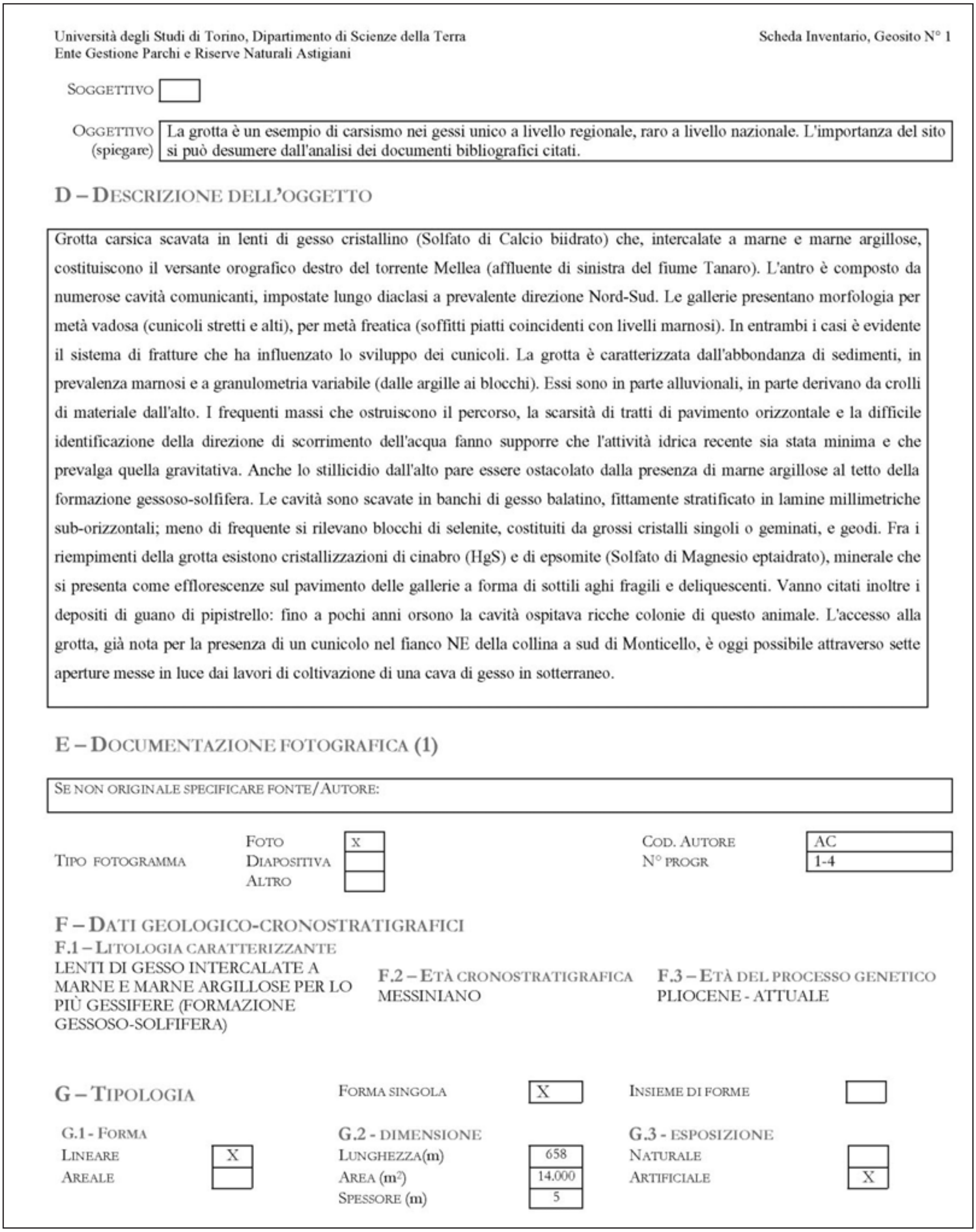
Fig. 1 Geomorphological outline of the study area and geomorphosites identified. 25 Valle relitta Tanaro; 209 Monte Capriolo; 13 Alveo del Tanaro; 130 Gola di Cherasco; 15 Forra del Mondalavia;16 Aveo dello Stura; 17 Altopiani di Benevagienna; 143 Rocca di Benevagienna.

All information was collected using description forms and maps loaded into a pocket PC (Fig. 2).

The description form holds all the fields requested by the Italian National Geological Survey (managed by ISPRA) and, in addition, it includes additional sections allowing the assessment of geomorphosites from scientific, aesthetic, accessibility, historical, cultural and ecological points of view. An experimental section was added concerning the main geomorphological hazards related to geomorphosites (Table 1).

Part one of the card deals with the collection of general data including location, description, essential features (forms and dimension, property, planning restrictions, soil use, lithology, chronostratigraphy, geomorphic age). Part two of the card deals with parameters for the assessment of the scientific value:

- rareness (rarity of the site);
- integrity (state of conservation of the site);
- representativeness (site exemplarity and educational value);
- paleogeographic value (importance of the site to tracing the geomorphological evolutionary stages of the study area).



Università degli Studi di Torino, Dipartimento di Scienze della Terra
Ente Gestione Parchi e Riserve Naturali Astigiani

Scheda Inventario, Geosito N° 1

SOGGETTIVO ☐

OGGETTIVO (spiegare): La grotta è un esempio di carsismo nei gessi unico a livello regionale, raro a livello nazionale. L'importanza del sito si può desumere dall'analisi dei documenti bibliografici citati.

D – DESCRIZIONE DELL'OGGETTO

Grotta carsica scavata in lenti di gesso cristallino (Solfato di Calcio biidrato) che, intercalate a marne e marne argillose, costituiscono il versante orografico destro del torrente Mellea (affluente di sinistra del fiume Tanaro). L'antro è composto da numerose cavità comunicanti, impostate lungo diaclasi a prevalente direzione Nord-Sud. Le gallerie presentano morfologia per metà vadosa (cunicoli stretti e alti), per metà freatica (soffitti piatti coincidenti con livelli marnosi). In entrambi i casi è evidente il sistema di fratture che ha influenzato lo sviluppo dei cunicoli. La grotta è caratterizzata dall'abbondanza di sedimenti, in prevalenza marnosi e a granulometria variabile (dalle argille ai blocchi). Essi sono in parte alluvionali, in parte derivano da crolli di materiale dall'alto. I frequenti massi che ostruiscono il percorso, la scarsità di tratti di pavimento orizzontale e la difficile identificazione della direzione di scorrimento dell'acqua fanno supporre che l'attività idrica recente sia stata minima e che prevalga quella gravitativa. Anche lo stillicidio dall'alto pare essere ostacolato dalla presenza di marne argillose al tetto della formazione gessoso-solfifera. Le cavità sono scavate in banchi di gesso balatino, fittamente stratificato in lamine millimetriche sub-orizzontali; meno di frequente si rilevano blocchi di selenite, costituiti da grossi cristalli singoli o geminati, e geodi. Fra i riempimenti della grotta esistono cristallizzazioni di cinabro (HgS) e di epsomite (Solfato di Magnesio eptaidrato), minerale che si presenta come efflorescenze sul pavimento delle gallerie a forma di sottili aghi fragili e deliquescenti. Vanno citati inoltre i depositi di guano di pipistrello: fino a pochi anni orsono la cavità ospitava ricche colonie di questo animale. L'accesso alla grotta, già nota per la presenza di un cunicolo nel fianco NE della collina a sud di Monticello, è oggi possibile attraverso sette aperture messe in luce dai lavori di coltivazione di una cava di gesso in sotterraneo.

E – DOCUMENTAZIONE FOTOGRAFICA (1)

SE NON ORIGINALE SPECIFICARE FONTE/AUTORE:

TIPO FOTOGRAMMA	FOTO	X	COD. AUTORE	AC
	DIAPOSITIVA		N° PROGR	1-4
	ALTRO			

F – DATI GEOLOGICO-CRONOSTRATIGRAFICI

F.1 – LITOLOGIA CARATTERIZZANTE
LENTI DI GESSO INTERCALATE A MARNE E MARNE ARGILLOSE PER LO PIÙ GESSIFERE (FORMAZIONE GESSOSO-SOLFIFERA)

F.2 – ETÀ CRONOSTRATIGRAFICA
MESSINIANO

F.3 – ETÀ DEL PROCESSO GENETICO
PLIOCENE - ATTUALE

G – TIPOLOGIA

FORMA SINGOLA ☒ INSIEME DI FORME ☐

G.1 - FORMA		**G.2 - DIMENSIONE**		**G.3 - ESPOSIZIONE**	
LINEARE	X	LUNGHEZZA(m)	658	NATURALE	
AREALE		AREA (m²)	14.000	ARTIFICIALE	X
		SPESSORE (m)	5		

Fig. 2 a Description form used during the inventory.

Fig. 2 b Pocket PC with maps.

Part three of the card deals with parameters for the assessment of aesthetic value:

- visibility;
- view points.

Part four of the card deals with parameters for the assessment of accessibility value:

- best way to access the site;
- road conditions;
- distance (potential) to be covered on foot and difficulty of the path; distance from facilities (hotels, restaurant, shops, etc.).

Part five and six of the card deal with parameters for the ecological and cultural-historical values: according to Reynard et al. (2007), the ecological section takes into account the importance of geomorphosites for the development of a particular ecosystem or the presence of particular fauna and vegetation, whereas the cultural-historical one takes into account several sub-criteria dealing with important religious, historical and literary aspects or popular legends.

The last part deals with the possible hazards relative to the use of geomorphosites, which, according to Panizza & Menella (2007), may be seen as dynamic components of the environment. This section contains information about: spatial characteristics of the area, potential frequency of the phenomenon, and a description of the hazards, also considering possible bad weather conditions.

It is possible to assign a quantitative value to the sections from 2 to 6 in order to obtain a table with a score for each geomorphosite, divided into scientific and additional values (Tables 2a, 2b). There are five possible values, expressed in part 1, with 0 reflecting no value and 1 a very high value. According to Reynard et al. (2007), the results from the scientific assessment and the mean of the results from the additional values are not combined in order to underline the different qualities of the two value sets. Geomorphosites with a low score in the scientific and additional values, or a low score in the scientific value and a medium score in the additional value have been discarded (Table 2c).

Parts	Criteria
1. General and descriptive data	Location, description, essential features
2. Scientific value	Rareness, integrity, representativeness, paleogeographical value
3. Aesthetic value	Visibility, view points
4. Accessibility value	Best method of access, road condition, path difficulty, distance to cover from facilities
5. Ecological value	Particular ecosystem or importance for fauna and vegetation
6. Cultural-historical value	Religious, historical, literary or popular legend
7. Geomorphological hazards	Spatial characteristics, potential frequency, bad weather conditions

Tab. 1 Parts of the description forms, including criteria used for evaluation.

	Integrity	Rareness	Representativeness	Paleogeographical value	Scientific value
Rocche di Pocapaglia	1	1	0,75	1	0,94
Valle Relitta Fiume Tanaro	0,75	0,25	1	1	0,75
Alveo del Tanaro a Cherasco	0,5	0,5	0,5	0,5	0,5
Monte Capriolo	0,75	1	1	1	0,94
Gola di Cherasco	1	0,25	0,75	1	0,75
Alveo dello Stura	0,5	0,75	0,25	0,75	0,63
Rocche di Salmour	0,75	0,25	0,25	0,25	0,38
Altopiani di Benevagienna	1	0,75	1	1	0,94
Rocca di Benevagienna	0,5	0,5	0,25	0,25	0,38
Forra del Rio Mondalavia	0,75	1	0,75	1	0,88

Tab. 2 a Geomorphosite assessment concerning the scientific value.

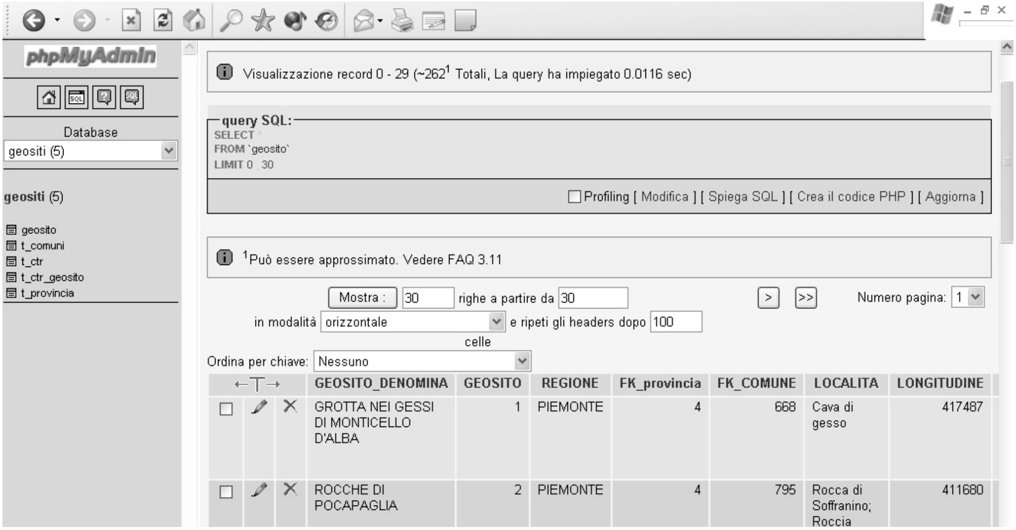
	Aestheticvalue	**Accessibility value**	**Ecological value**	**Cultural-historical value**	**Additional value**
Rocche di Pocapaglia	1	0,5	1	1	0,88
Valle Relitta Fiume Tanaro	0,25	1	0,25	0	0,38
Alveo del Tanaro	0,75	0,75	0,5	0	0,5
Monte Capriolo	0,25	1	0,25	0,75	0,56
Gola di Cherasco	0,75	0,75	0,75	0,75	0,75
Alveo dello Stura	0,75	0,5	0,5	0	0,44
Rocche di Salmour	0,5	0,75	0,5	0,5	0,56
Altopiani di Benevagienna	0,75	1	0,5	0,75	0,75
Rocca di Bebevagienna	0,25	1	0,25	0,75	0,56
Forra del Rio Mondalavia	0,5	0,75	0,25	0,75	0,56

Tab. 2 b Geomorphosite assessment concerning the aesthetic, accessibility, ecological and cultural-historical values.

	Scientific value	Additional value
Rocche di Pocapaglia	0,94	0,88
Altopiani di Benevagienna	0,94	0,75
Monte Capriolo	0,94	0,56
Forra del Rio Mondalavia	0,88	0,56
Gola di Cherasco	0,75	0,75
Valle Relitta Fiume Tanaro	0,75	0,38
Alveo dello Stura	0,63	0,44
Alveo del Tanaro	0,5	0,5
Rocche di Salmour	0,38	0,56
Rocca di Bebnevagienna	0,38	0,56

Tab. 2 c The geomorphosites final ranking. The last two sites have been discarted.

Data from bibliographic research, field survey and assessment results were stored using the relational database MySQL Community edition released under General Public License (GNU) (http://www.mysql.com) in order to reduce the costs of computer programme royalties. This structure consists of related tables, which also include fields that can be used to store binary data (images and multi-media contents). Furthermore, all information was organised in a methodical way in order to eliminate repetitions and queries, and making information retrieving much easier. The operation was implemented from the web with an interface written using PHP scripting language, which has full support for communicating with MySQL databases (Fig. 3a, 3b).



Visualizzazione record 0 - 29 (~262[1] Totali, La query ha impiegato 0.0116 sec)

query SQL:

```
SELECT *
FROM `geosito`
LIMIT 0 , 30
```

[1] Può essere approssimato. Vedere FAQ 3.11

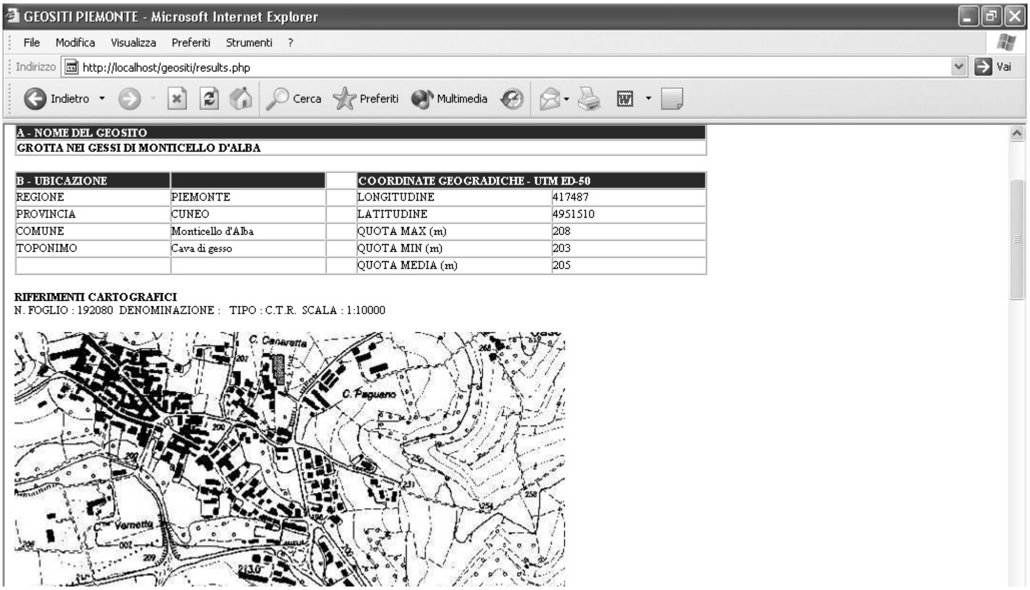
Mostra : 30 righe a partire da 30 Numero pagina: 1

in modalità orizzontale e ripeti gli headers dopo 100 celle

Ordina per chiave: Nessuno

←T→			GEOSITO_DENOMINA	GEOSITO	REGIONE	FK_provincia	FK_COMUNE	LOCALITA	LONGITUDINE
☐	✎	✕	GROTTA NEI GESSI DI MONTICELLO D'ALBA	1	PIEMONTE	4	668	Cava di gesso	417487
☐	✎	✕	ROCCHE DI POCAPAGLIA	2	PIEMONTE	4	795	Rocca di Soffranino; Roccia	411680

Fig. 3 a Graphic interface of MySQL DB.



http://localhost/geositi/results.php

A - NOME DEL GEOSITO
GROTTA NEI GESSI DI MONTICELLO D'ALBA

B - UBICAZIONE			COORDINATE GEOGRADICHE - UTM ED-50	
REGIONE	PIEMONTE		LONGITUDINE	417487
PROVINCIA	CUNEO		LATITUDINE	4951510
COMUNE	Monticello d'Alba		QUOTA MAX (m)	208
TOPONIMO	Cava di gesso		QUOTA MIN (m)	203
			QUOTA MEDIA (m)	205

RIFERIMENTI CARTOGRAFICI
N. FOGLIO : 192080 DENOMINAZIONE : TIPO : C.T.R. SCALA : 1:10000

Fig. 3 b Web Interface to navigate MySQL DB.

4. Mapping issues

Data stored in the database created the basis for building a Geographic Information System (GIS) for geomorphosites, which allowed us to relate and combine various layer information with georeferenced data in order to produce thematic maps combining geological and geomorphological characters and other elements of the territory. Loading different layers and managing them at different scales is possible using zoom and pan procedures. Furthermore, with query tools it is easy to retrieve georeferenced "objects" on the map and to access the attributes associated with them.

The aim of this project was to develop a useful information tool, easy to access and suitable for people interested in the geomorphological assets for educational or tourist purposes. For this reason, it was very important to angle towards an application usable by the general public but at the same time preserving scientific rigour. Following the methodology developed by the University of Modena and Reggio Emilia (Castaldini et al., 2005a, 2005b; Bertacchini et al., 2007), a geomorphological map was created combining a terrain survey with the development of DEM (Digital Elevation Model) with a 7 m resolution and an orthomosaic with 70 cm resolution from a photogrammetric stereoscopic model (Fig. 4). At the end of the process, the geomorphological map was simplified leaving only the elements that can be easily observed and recognised by the general public within the area affected by the presence of geomorphosites.

Geographical data were organised in two different groups in order to provide a complete and exhaustive frame where basic information and geomorphological entities are located. The first group includes colour-shaded relief background derived from DEM raster cartographies, topographic maps and vector files providing information about characteristic features of the territory (utility services, network of infrastructures and tourist and cultural-historical features). The second group includes different layers, symbolising the main geomorphological features: geotourist itinerary, points of view or interest, and tourist information.

Using a GIS software, the scale problem is less important if compared with traditional maps but, in accordance with Carton et al. (2005), the accuracy of representation depends on the scale at which the data was mapped. In our case, geomorphosites were represented by dots on maps of 1:100,000 scale or less, whilst in large-scale maps they were represented by means of linear, point-like or polygon geomorphological symbols divided into different layers (Fig. 5a, 5b).

Fig. 4 Hillshade derived from DEM and orthomosaic obtained from photogrammetric steroscopic model.

The cards associated with each geomorphosite include four main sections:

- in the first section, a general outline of the geosite gives a description of the geomorphological features in relation to their formation processes;
- the second one contains a set of pictures, stratigraphic sections, 3D views and texts useful to understand the morphogenesis of the geosite and to relate it with the general evolution of the whole territory;
- in the third section, possible hazards were reported, informing users on potential dangers related to the use of the geomorphosite;
- in the last section, curiosities, popular legends, cultural or ecological notes concerning the geomorphosite and its relations with the surrounding environment and local traditions were reported.

Starting from the GIS project, and in order to promote the knowledge and appraisal of the selected geomorphosites, a Web-GIS application was then developed by integrating GIS and RDBMS (Relational Database Management System). It allows information to be shared among a wide range of users. Geographic data was implemented in a Web-GIS based on MapServer (http://www.mapserver.org) and P.Mapper (http://www.pmapper.net). Mapserver is an open source platform developed by the University of Minnesota. For this project, the MS4W package was installed, designed to perform a full installation of Apache, PHP, MapServer CGI and MapScript.

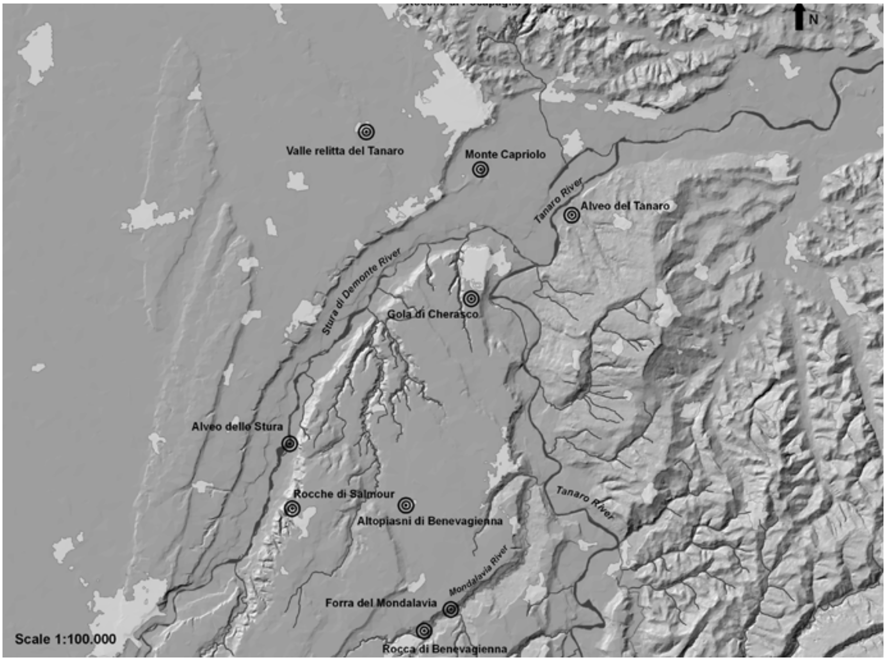


Fig. 5 a Geomorphosites in the study area represented with dots at 1:100,000 scale.

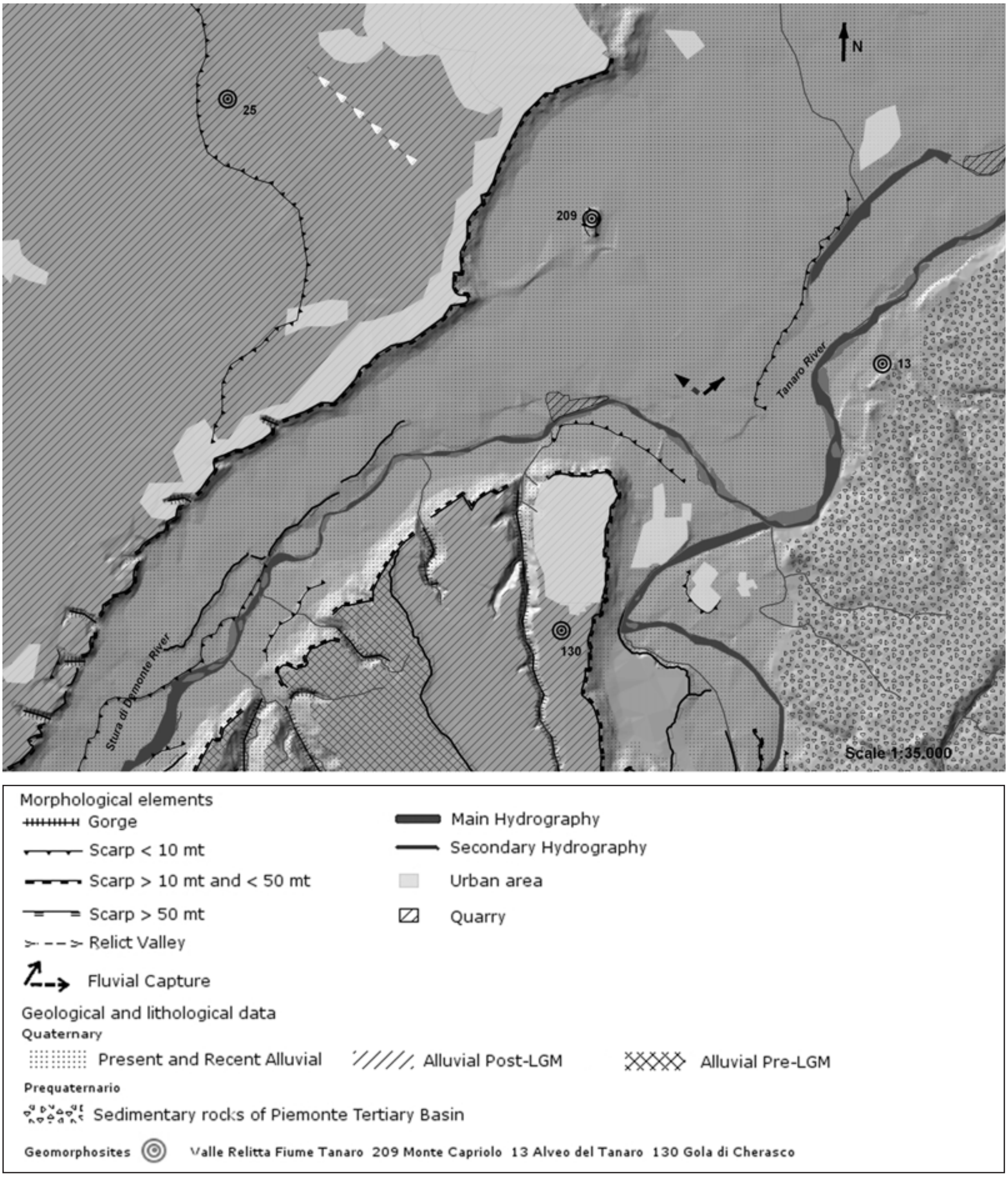
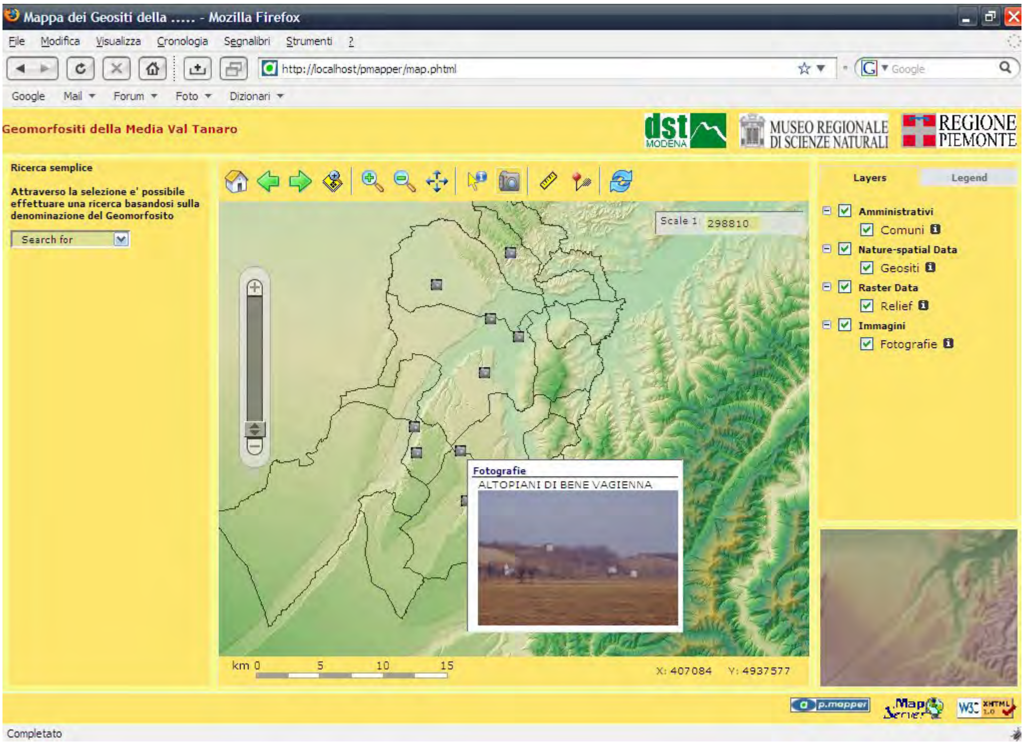


Fig. 5 b Portion of the study area at 1:35,000 scale. Geomorphosites are represented with a point-like symbol and with conventional geomorphological symbols.

P.Mapper is a framework, developed by DM Solutions, intended to offer broad functionality and multiple configurations in order to facilitate the set-up of a MapServer application based on PHP/MapScript. PHP scripting language has full support for communicating with the MySQL database and it allows objects represented in the Web-GIS application with MySQL database, and vice versa, to be linked together.



Ricerca semplice

Attraverso la selezione e' possibile effettuare una ricerca basandosi sulla denominazione del Geomorfosito

Search for

☑ Amministrativi
  ☑ Comuni
☑ Nature-spatial Data
  ☑ Geositi
☑ Raster Data
  ☑ Relief
☑ Immagini
  ☑ Fotografie

Fig. 6 Web-GIS application based on GIS project. Clicking on a hyperlink makes it possible to go back to the information stored in Web Server included in the MySQL Database.

5. Conclusion

Undoubtedly, the publication process on the Internet has shown the chance of translating the complex Earth system into simple language by means of a shared application providing users with a complete instrument for a free on-line use and a knowledgeable approach. Compared with traditional maps, Web-GIS applications present several advantages:

- they are cheaper if developed with Open Source software and less time-intensive to produce;
- they are easier to be distributed to a wide audience and easier to be updated and maintained;
- they allow interactive possibilities (e.g. the ability to change scales

and turn layers on/off) and connections to related information by means of hyperlinks.

Although it is tempting to think that Internet-based maps are preferable to paper maps in every way, this is certainly not the case. The most obvious disadvantages are:

- they require high band-width access to the Internet;
- they are vulnerable to server and network problems;
- they need a certain familiarity with GIS application.

The project described in this paper is still in progress and is open to future improvements, both for data increasing or updating and new system function implementation. The project was carried out in cooperation with territorial facilities such as local natural history museums, since their experience is absolutely necessary to obtain good results in a strategy of spreading scientific knowledge relative to the geological and morphological evolution of the territory of the Piemonte Region.

Acknowledgements

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http://www.mapserver.org

http://www.mysql.com

http://www.pmapper.net

Creation and test of a mobile GIS application to support field data collection and mapping activities on geomorphosites

Marco Giardino, Luigi Perotti, Roberto Carletti, Stefano Russo
GeoSITlab, GIS and Geomatics Laboratory
Department of Earth Sciences
University of Torino
Via Valperga Caluso 35
I - 10125 Torino

E-Mail: marco.giardino@unito.it

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1. Introduction

Classical methods for field data collection on geological and geomorphological features are based on the use of relatively simple tools, such as paper notebooks, coloured pencils, base maps, etc., together with the personal skills of researchers. So far, data collected on the field had to be interpreted, summarised and redrawn in order to create base geological and geomorphological maps and/or more elaborated geothematic ones.

In the last 15 years, the use of computers and other electronic devices for collection, analysis and distribution of field data has had a notable development also in the Earth Sciences and their applications to environmental analysis. This triggered effective improvements not only in the field activities, but also in the laboratory ones, in terms of enhancement in both rapidity and precision of data processing, interpretation, and representation. Still, many not-yet-resolved problems concern either the conceptual framework or the practical solutions for field data collection and their transposition onto maps.

As regards geothematic applications in the study of natural heritage, in particular, they need to share, compare and exchange data between researchers and users in unambiguous and accessible ways, possibly following codified standards for map production and user-friendly technologies for communication of the results.

In order to fulfill the above-mentioned requirements, the authors aimed to develop a new application for palm computers to support field data collection and mapping activities on geomorphosites. This paper presents and discusses the results of this research, including some considerations on the essentials in mapping activities, attributes of geological/geomorphological features and characteristics of geomatics tools and methodologies.

2. Mapping and description of geomorphosites

Looking for faster and more suitable procedures for mapping and describing geomorphosites in the field, as a first step, standards of geomorphological techniques have been considered.

Geomorphological studies are devoted to collecting and interpreting information on the Earth's surface forms, materials, processes and age of formations. Geomorphological maps are synthetic ways of showing the above-mentioned information (Goudie, 2004) and are suitable both for geodiversity studies and geoheritage protection activities. As stated by the Working group on applied geomorphological mapping (AppGeMa) of the International Association of Geomorphologists (IAG), geomorphological maps are, in fact, not only important as end products of scientific studies but also as tools for technical applications by professionals dealing with the landscape and landforms (Pain et al., 2008).

In the case of geoheritage, geomorphological maps can enhance assessment, planning and geomorphosite management projects. Still, standards of mapping procedures and legend systems for different scales have to be followed, in order to provide precise and unequivocal information on distribution of landforms, soils and rocks. Thus, by means of proper geomorphological mapping, a correct identification and interpretation of features created by surface processes can be performed, therefore enhancing the modelling of past and present evolutionary stages of the geomorphosites. This can turn out to be very useful for achieving different objectives: to assess values of natural resources, to disseminate scientific knowledge to the general public and/or to prevent geomorphological hazards in the exploited areas (Embleton, 1988; Panizza, 1999).

Methodologies were tested in Italy for creating maps and descriptions suitable for both scientific and educational purposes (Giardino et al., 2004; Carton et al., 2005; Castaldini et al., 2005). Some case studies evidenced the importance of supporting terrain surveys and mapping products by 3D imagery (combination of DEMs and remote sensing images; Bertacchini et al. 2007). Some others showed the importance of structuring geodatabases and using GIS technologies for better collection, management and presentation of geosite data for geotourism purposes (Avanzini et al. 2005; Gregori & Melelli, 2005; Ghiraldi et al., this volume).

3. Geomatics support for a new methodology

Simplicity, precision and rapidity of field survey techniques are some ingredients for achieving better results in the collection and organisation of data on geomorphosites. In this perspective, a key factor offered by digital techniques is the possibility of organising a complete dataset during field activities, avoiding time-consuming laboratory operations, such as copying data from paper forms and/or repeated drawing of maps.

To develop a digital methodology for mapping and describing of geomorphosites, different studies on computer applications for field-based geological/geomorphological activities were compared, conducted by universities, research centres, and technical institutions (e.g. Haugerud & Thoms, 1999; Walsh et al., 2000; Clarke et al., 2002). Geomatics support to field surveying was also tested for developing skills at an educational level (e.g. International conference: "Supporting fieldwork using information technology", University of Plymouth). As a common conclusion of the above mentioned works, light, easy-to-handle hardware and user-friendly software have been selected, in order to offer a precise, uniform standard technological path to be followed when collecting and processing data in the field.

The geomatics methodology suggested here consists in the integrated use of digital pictures and maps from different sources (topographic maps, orthorectified aerial photographs, other technical geothematic maps), which become either a base or an output for data collection and representation of geomorphosites, by using dedicated forms for geomorphological descriptions and mapping. The equipment for such activities consists in a pocket PC based on Windows CE, with dedicated GIS software and Bluetooth GPS for ground positioning (Fig. 1). The use of palm/pocket PC is an innovative solution with respect to the use of tablet PC as a field mapping tool proposed by other research teams. Juxtaposition of the two alternatives revealed that palm computers are more convenient tools for supporting field activities, according to several criteria: size, weight, autonomy power of batteries, rapidity and simplicity of use, and overall cost of instrumentation.

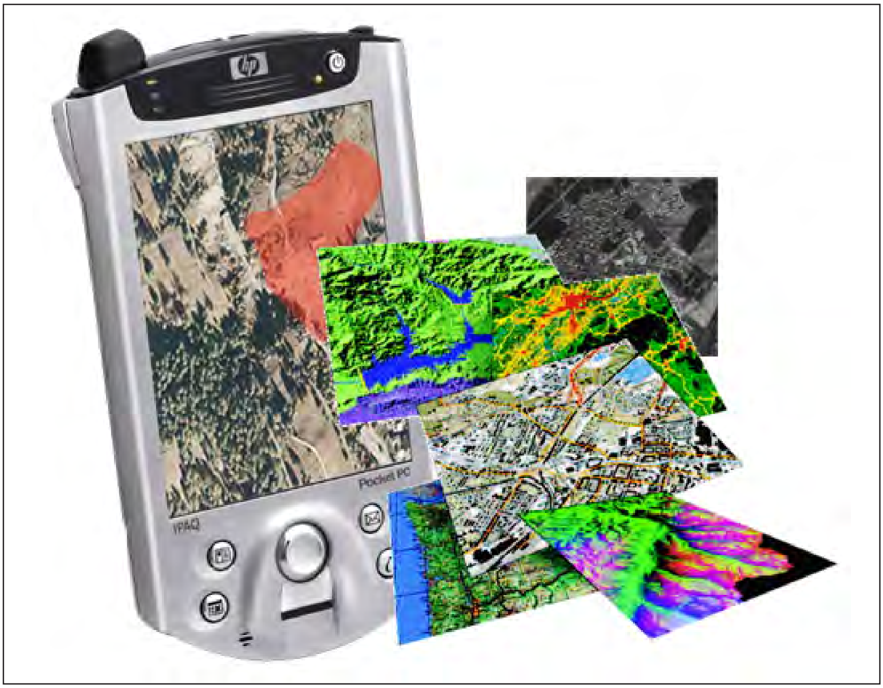


Fig. 1 Geomatics supports for digital mapping and description of geomorphosites: palm/pocket PC and digital imagery (topographic maps, orthorectified aerial photographs, other technical geothematic maps).

4. Functioning of SRG^2 application

Looking for faster and more suitable procedures of field mapping and data collection on geosites, either for scientific research and technical management, an application called "SRG^2" (acronym for the Italian: "Supporto al Rilevamento Geologico/

Geomorfologico"; Support to Geological/Geomorphological Surveys) was created, as an extension for ArcPad (GIS-ESRI for palms) developed in Visual Basic. Into the ArcPad environment, the SRG^2 application adds a toolbar, vectors and tables made up of several functions for a useful mapping and classification of geological and geomorphological features (Fig. 2). ArcPad software generates vector shapefiles, of large use in GIS projects and of great utility in assessment and management of geomorphosites.

Fig. 2 Left; SRG^2 shape files and toolbar into ArcPad. Right; List of the 16 layers used in test sites. Geometries, legend and visual representations are available for areal, linear and point features.

In order to catalogue features relevant to geomorphosites studies (erosional and depositional landforms and related deposits, characteristic processes of different morphogenetic environments, lithological and structural elements, anthropic features and infrastructures, location points for sampling and picture views), the SRG^2 application was structured into different layers (shape file format) and associated (Fig. 2).

During field activities, as a first step, distinct elements are classified by geometry (points, linear, areal features). Drawing elements in the map can be manually operated, through visual recognition in the field, or automatically, by means of a GPS tracking option.

Then, surveyed features are classified by typology: 1) genetic environments and related processes, either endogenic or exogenic, are interpreted ("glacial", "fluvial", "gravity-induced", "tectonic", "complex", etc.) or left unknown; 2) further alphanumeric data (morphometrical, chronological, lithological, etc.) are requested to com-

Forma osservata
Conoide alluvionale > 10%

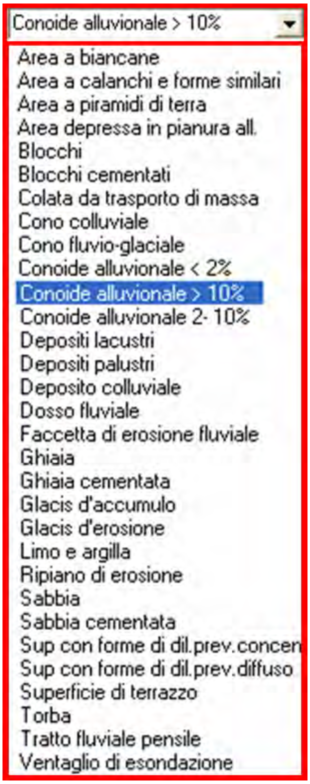
Litofacies
Sabbie da molto fini a grossolane

Struttura sedimentaria
Nessuna gradazione

Tessitura
Clast supported

Nessuna gradazione
- Da laminate a massive
- Embricazione
- Laminazione incr. a basso angolc
- Laminazione fine
- Laminazione incr. concava
- Laminazione incr. planare
- Laminazione orizzontale
- Massive con molluschi
- Nessuna gradazione
- Pante e pellicole di fango
- Radici e bioturbazione
- Ripple mark
- Scour
- Stratificazione incr. concava
- Stratificazione incr. grossolana
- Stratificazione incr. planare
- Stratificazione orizzontale
- Strutture pedogenetiche

Sabbie da molto fini a grossolane
- Ghiaie massive o gross strat.
- Ghiaie massive a supp. di matrice
- Ghiaie stratificate
- Sabbie da medio a molto grossola
- Sabbie da molto fini a grossolane
- Sabbie e materiale fine
- Erosione di scour con intraclasti
- Sabbie da fini a grossolane
- Sabbie
- Sabbia, silt, sedimenti argillosi
- Silt, sedimenti argillosi
- Sedimenti fini argillosi
- Sedimenti argillosi, silt dissecamer
- Carboni,sedimenti fini carbonatici
- Suoli carbonatici



Conoide alluvionale > 10%
- Area a biancane
- Area a calanchi e forme similari
- Area a piramidi di terra
- Area depressa in pianura all.
- Blocchi
- Blocchi cementati
- Colata da trasporto di massa
- Cono colluviale
- Cono fluvio-glaciale
- Conoide alluvionale < 2%
- Conoide alluvionale > 10%
- Conoide alluvionale 2- 10%
- Depositi lacustri
- Depositi palustri
- Deposito colluviale
- Dosso fluviale
- Faccetta di erosione fluviale
- Ghiaia
- Ghiaia cementata
- Glacis d'accumulo
- Glacis d'erosione
- Limo e argilla
- Ripiano di erosione
- Sabbia
- Sabbia cementata
- Sup con forme di dil.prev.concen
- Sup con forme di dil.prev.diffuso
- Superficie di terrazzo
- Torba
- Tratto fluviale pensile
- Ventaglio di esondazione

plete description and to support interpretations. Each typology of classified elements has a dedicated list of selectable attributes (Fig. 3), useful both for achieving a complete scientific description of the surveyed features and for indicating relevant features to be considered by technical operators in the geomorphological heritage, for planning and management purposes. As an example, by using SRG[2] application, badland areas were mapped as part of the geodiversity of the Piemonte region; their full description allowed not only the selection of features to be protected as geomorphosites (according to assessment methodologies; Reynard et al., 2007), but also proper management of the geomorphological risk related to geotourism activity in a dynamic environment.

Fig. 3 Examples of selectable attributes to support interpretation of geomorphological features.

5. Test sites in the geoheritage of the Italian Western Alps

Tests for SRG^2 were performed in the mountain and piedmont areas of the Italian Western Alps (Piemonte and Valle d'Aosta Regions).

In the Upper Susa Valley, Montgenèvre area (along the border between France and Italy) field mapping activities by using SRG^2 were conducted during a national research project devoted to geomorphological analysis in the mountain area of the Torino 2006 Winter Olympic Games (Panizza et al. 2005). Landform distribution and activity were surveyed and compared to landuse patterns and infrastructures. The Upper Susa Valley ski resort area includes the Monti della Luna and Val Thuras geosites (Fig. 4). Here, SRG^2 supported mapping and collecting information of the intense human activity and landuse in the area and also of the long-term gravitational deformations on mountain slopes. Detailed field analysis was based on geothematic maps by satellite monitoring and digital aereo-photogrammetric image processing. Data concerning the territory and vegetation were available for the SRG^2 geodatabase thanks to the partnership with the Upper Susa Valley Forestry Commission and the municipality of Cesana Torinese.

Other applications of SRG^2 were performed in the Aosta Valley, in the Espace Mont-Blanc area and the Gran Paradiso National Park. Both active and relict landforms of glacial environments were surveyed (Fig. 5). Geomorphosites of the Espace Mont-Blanc area were considered in order to enhance the protection of a territory rich in natural and tourist resources. Here, the Miage glacial basin (Mont-Blanc, Italian side) was selected both for its scientific value and geomorphological risks. The Miage glacier is a debris covered glacier characterised by a substantial stability in the area dimension, but with noteworthy volumetric variations in the last decades, related to instability phenomena on the side moraines. The abundant debris cover in the ablation zone is caused by the diffused gravitational instability of the surrounding rockwalls, controlled by particular morphoclimatic and morphostructural conditions on the southern slope of Mont-Blanc. Its easy access makes the Miage a highly frequented tourist area, not only for alpinists. This is why in the case of instability phenomena the amount of people involved could be very large. SRG^2 helped to individualise sectors of natural hazards and their possible interaction with human elements (paths, tracks, alpine roads and shelters). A 3D model of the glacier was also created for spreading scientific information on premonitory signals of the instability phenomena.

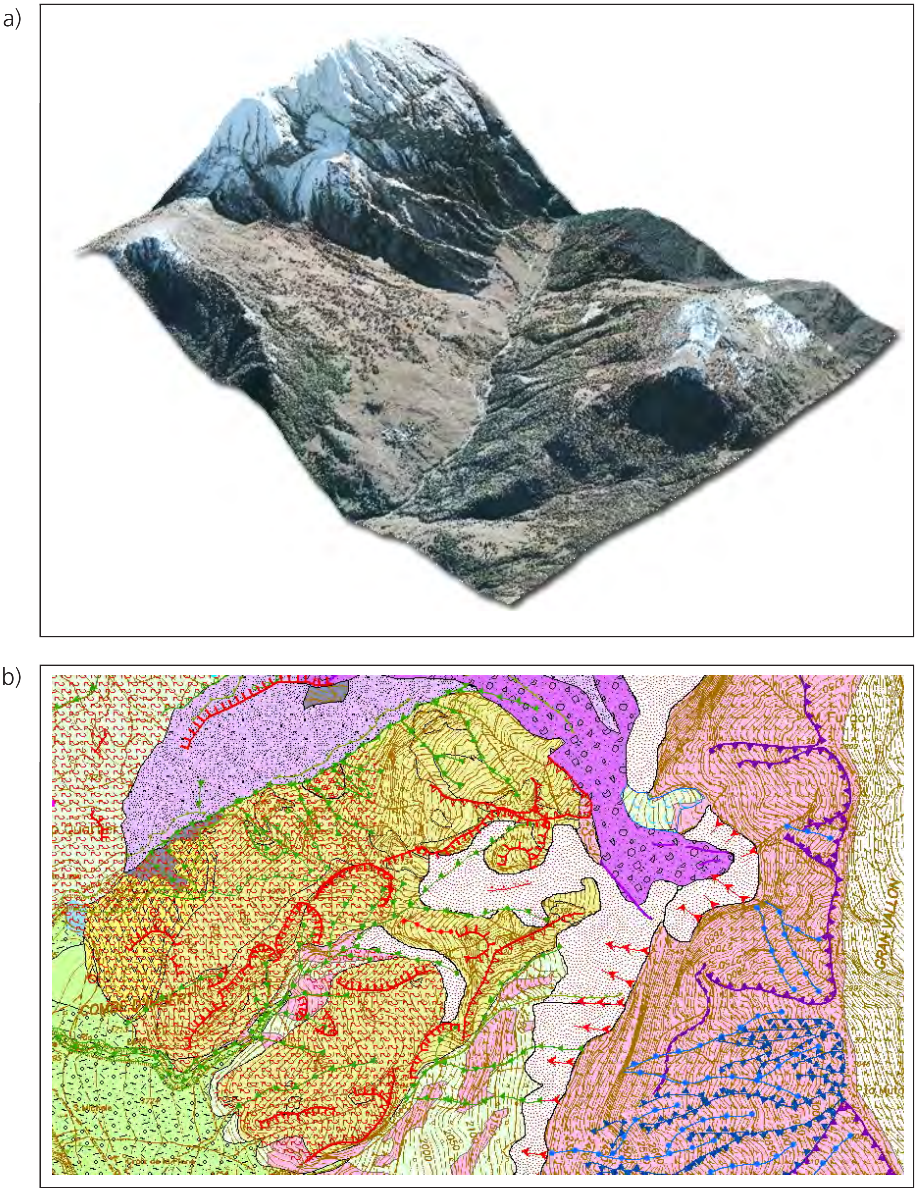
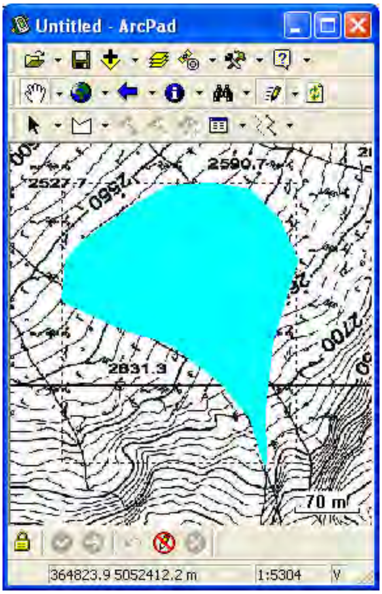


Fig. 4 3D view of the Thuras Valley (a) and particular of the geomorphological map obtained using SRG^2 application (b).

In the Gran Paradiso National Park, including the high valleys of the Valle d'Aosta and Piemonte Regions around the Gran Paradiso Massif (4061 m), use by both alpinists and tourists of the area has been consolidated since a long time, through the valley itineraries and the glacial high altitude slopes. The on-going climate change



364823.9 5052412.2 m 1:5304

Edit Form

ELEMENTI AREALI

GHIACCIAIO

Grivola

TIPO

conoide di valanga

- conoide di valanga
- Drift
- lago effimero
- lago periglaciale
- lago proglaciale
- Ogiva
- Rocce montonate
- Rock glacier
- seracco
- Till
- verve

Fig. 5 3D view of the Miage glacier (Mont-Blanc massif) and examples of forms developed for ArcpPad to acquire glacial landforms and other characteristics, both in the Espace Mont-Blanc area and in the Gran Paradiso National Park.

determines rapid transformation of the mid-high slopes characterised by large fractured rock masses and by the activation of geomorphological instability phenomena.

The authors conducted research by using SRG² to analyse hazards on rock walls and glaciers in sectors of interest for alpine routes and/or hiking tracks (Tribolazione and Trajo Glaciers; Cogne Valley; Fig. 6). For the field surveys, a geomorphological map (Giardino et al., 2000) and a digital track network realised by the University of Torino research unit for the Park were used. In addition, a visual monitoring of the unstable sectors was developed by means of digital instrumentation, in collaboration with Park rangers. Results on the hazard and risk studies were used as teaching material for Park rangers and as popularised information for the general public.

In both above-mentioned case studies, SRG² tests allowed the automatic import with legend transposition of field structured geodatabase data, resulting in the immediate creation of publishable maps. In this way, the field survey became an integral part of a complete and easy-to-update GIS, without other intermediate stages.

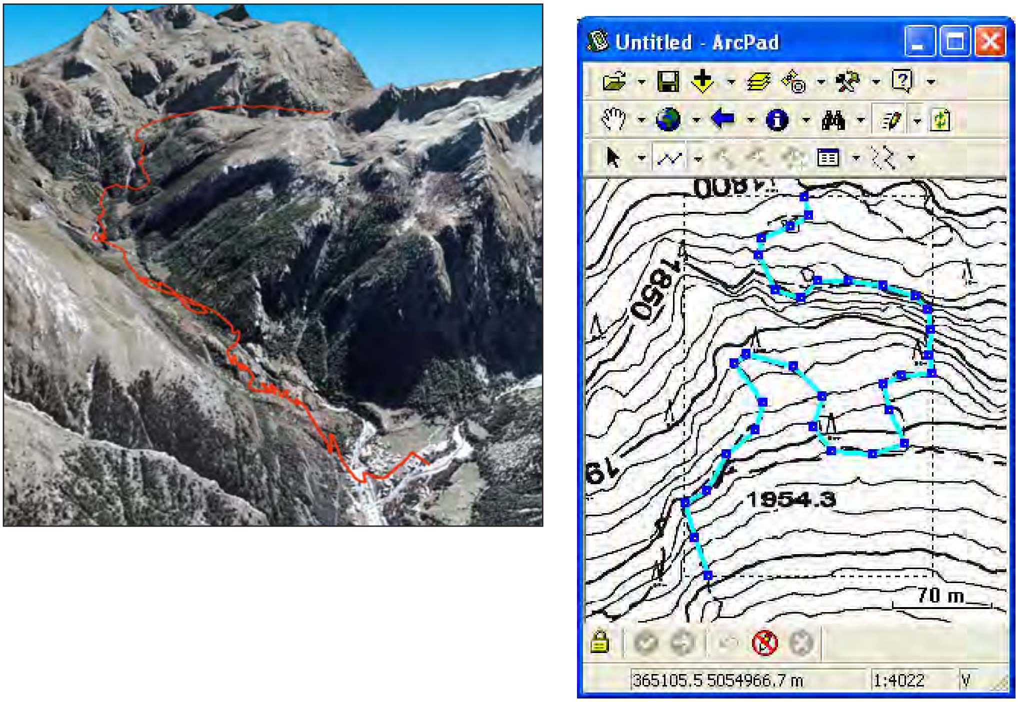


Fig. 6 3D view of the Cogne Valley (Aosta Valley - NW Italy) and example of map developed with ArcpPad to check trail operability and their characteristics.

6. Conclusion

The experimental mobile GIS application called SRG^2 (*Support to Geological/ Geomorphological Surveys)* provides a "customised" interface to support field data mapping and to describe geomorphosites in the field. SRG^2 was aimed at simplifying field data collection activities: tests were successful and also allowed users, once back in the laboratory, to print processed information directly through an automatic graphic refining of the field-data legend in a simplified form.

The direct production of thematic maps "in the field" and immediate "recording" of data in a specific geodatabase seem to be the most promising aspects of the method, which was successfully used not only by researchers but also by technical staff operating in parks and other territorial institutions involved in the inventory and management of geomorphosites. SRG^2 also allowed a "skill transfer" between researchers and operators to be developed, based on the practical use of geomatics tools. Sector technicians working in the territory full time were given a simplified key to read and interpret instability processes, which will enable them to get easier surveys and detailed description of geomorphosites.

A similar procedure could also be easily used for teaching and/or demonstration purposes for tourists and students. This could be applied in supporting field activities of university students, but also be specifically addressed for training alpine guides and the tourists themselves in geomorphosite knowledge and protection.

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