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Istituto Superiore per la Protezione e la Ricerca Ambientale
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MEMORIE
DESCRITTIVE DELLA
CARTA GEOLOGICA D'ITALIA

VOLUME LXXXVII

Geomorphology and Cultural Heritage
Geomorfologia e beni culturali

In copertina: immagini relative al volume

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Geomorphology and Cultural Heritage
Geomorfologia e beni culturali

di

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Preface

This volume collects original articles related to the oral and poster presentations given at the following sessions and symposium: Topical Symposium T17.01 "Geomorphological sites in a cultural integrated landscape" of the 32nd International Geological Congress (32IGC) (Florence, Italy, 2004); sessions S16 "Geomorphology and natural-cultural heritage" and WG4 "Geomorphological Sites: research, assessment and improvement" of the Sixth International Conference on Geomorphology (Zaragoza, Spain, 2005); session T30 "Geomorphological heritage: assessment, appraisal and safeguard" of the Quinto Forum Italiano di Scienze della Terra, GeoItalia 2005 (Spoleto, Italy, 2005).

The Topical Symposium "*Geomorphological sites in a cultural integrated landscape"*, chaired by Mario Panizza (University of Modena e Reggio Emilia, Italy) and Emmanuel Reynard (University of Lausanne, Switzerland) aimed to study the relationships between the geomorphology and the culture. 25 abstracts were proposed and the session was attended by about 60-80 persons.

During the Sixth International Conference on Geomorphology held in Spain in September 2005, two different session had deal with the Geomorphological Heritage. The sessions S16 "*Geomorphology and natural-cultural heritage"* chaired by Lluis Pallí (University of Girona, Spain) and Mario Panizza (University of Modena e Reggio Emilia, Italy) and focused on two specific subjects: 1 - Geomorphology considered as a component of the cultural heritage (in a broad sense) of a territory, that is, by the same standards as works of art, historical or architectural monuments, scientific and biological assets etc., 2 - The relationships between some cultural components (in a strict sense) of a territory (archaeological, historical, architectural assets etc.) and the geomorphological context in which they are inserted (resources, risks, impacts etc.). 32 abstracts were proposed and the session was attended by over 100 persons.

The session WG4 "*Geomorphological Sites: research, assessment and improvement",* chaired by Emmanuel Reynard (University of Lausanne, Switzerland) and Paola Coratza (University of Modena e Reggio Emilia, Italy) had deal with all subjects related to the scientific study of Geomorphosites. One of the main objectives was to bring together people working in different aspects of Geomorphosites, including assessment, mapping, protection as well as geotourism and education. 26 abstracts were proposed and the session was attended by about 60-80 persons.

The session T30 "*Geomorphological heritage: assessment, appraisal and safeguard"*, chaired by Olivia Nesci (University of Urbino, Italy) and Mario Panizza (University of Modena e Reggio Emilia, Italy) had intend to assess the state-of-the art of the investigations on the topic of "geomorphosites", connecting and defining the course of research, also by outlining future perspectives. The main subjects had deal with assessment, appraisal and safeguard of geomorphosites. 14 abstracts were proposed and the session was attended by about 30-40 persons.

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Prefazione

Il volume contiene una selezione delle comunicazioni orali e dei poster presentati a: Firenze nell'agosto 2004, nel Topical Symposium T17.01 "Geomorphological sites in a cultural integrated landscape" del 32esimo Convegno Internazionale di Geologia (32IGC); Saragozza nel settembre 2005, nelle sessioni S16 "Geomorphology and natural-cultural heritage" e WG4 "Geomorphological Sites: research, assessment and improvement" della Sesta Conferenza Internazionale dei Geomorfologi; Spoleto nel settembre 2005 nella sessione T30 Patrimonio geomorfologico: valutazione, valorizzazione, e salvaguardia del Quinto Forum Italiano di Scienze della Terra, Geoitalia 2005, della Federazione Italiana di Scienze della Terra (FIST).
Il Topical Symposium *Geomorphological sites in a cultural integrated landscape*, presieduto da Mario Panizza (Università di Modena e Reggio Emilia, Italia) e Emmanuel Reynard (Università di Lausanne, Svizzera) aveva l'obiettivo di studiare le relazioni tra geomorfologia e cultura. Sono stati presentati 25 abstract e alla sessione hanno partecipato circa 60-80 persone.
Durante la della Sesta Conferenza Internazionale dei Geomorfologi tenutasi in Spagna nel settembre 2005, si sono svolte due differenti sessioni con tema principale il Patrimonio Geomorfologico. La sessione S16 *Geomorphology and natural-cultural heritage*, presieduta da Lluis Pallí (Università di Girona, Spagna) e Mario Panizza (Università di Modena e Reggio Emilia, Italia), si è incentrata su due specifici temi: 1 – la Geomorfologia considerata come componente del patrimonio culturale (in senso lato) di un territorio, alla pari dei beni storici, artistici, architettonici, biologici etc., 2 – le relazioni tra le componenti del patrimonio culturale (in senso stretto) di u territorio (beni archeologici, storici, architettonici etc.) e il contesto geomorfologico nel quale sono inseriti (risorse, rischi, impatti etc.). Sono stati presentati 32 abstract e alla sessione hanno partecipato oltre 100 persone.
Nella sessione WG4 *Geomorphological Sites: research, assessment and improvement,* presieduta da Emmanuel Reynard (Università di Lausanne, Svizzera) e Paola Coratza (Università di Modena e Reggio Emilia, Italia) sono stati affrontati i temi relativi agli studi scientifici dei Geomorfositi, includendo la valutazione, la cartografia, la protezione così come il geoturismo e la didattica. Sono stati presentati 26 abstract e alla sessione hanno partecipato circa 60-80 persone.
Durante la sessione T30 *Geomorphological heritage: assessment, appraisal and safeguard*, presieduta da Olivia Nesci (Università di Urbino, Italia) and Mario Panizza (Università di Modena e Reggio Emilia, Italia) è stato definito lo stato dell'arte delle ricerche sul tema dei Geomorfositi, definendo le ricerche in corso e prospettando future linee di ricerca. Sono stati presentati 14 abstract e alla sessione hanno partecipato circa 30-40 persone.

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Foreword

Mario PANIZZA, Sandra PIACENTE

The volume comprises some contributions concerning the relationships between geomorphology and the cultural elements of a specific territory. These relationships can be considered schematically according to two reciprocally-integrated viewpoints (PANIZZA & PIACENTE, 2003):

- *geomorphology* is then meant as a *component of a territory's cultural heritage* (in a broad sense), like works of art, historical monuments, scientific assets etc.

- the *relationships between some cultural components* (in a strict sense) of a territory (archaeological, historical, architectonic etc. heritage) and the *geomorphological context* in which they are inserted.

As a result of these statements, a need was felt to propose a definition of *Cultural Geomorphology* (PANIZZA & PIACENTE, 2003): *the discipline that studies the geomorphological component of a territory, which embodies both a cultural feature of the landscape and its interactions with cultural heritage of the archaeological, historical, architectonic etc. type*. In this volume are collected articles related to the first viewpoint, in particular some geomorphosites, and to the second viewpoint, with regard to geoarchaeology.

As regards the geomorphology as a component of a cultural heritage, the definition of *geomorphosite* is as follows (PANIZZA, 2001; PANIZZA & PIACENTE, 2003, REYNARD, 2005): "*a landform with particular and significant geomorphological attributes, which qualify it as a component of a territory's cultural heritage*". The attributes that can confer value on a landform, making it an actual geomorphosite, are: scientific, cultural, socioeconomic, scenic. The duties of Geomorphology in assessing the various attributes should be connected mainly to the scientific aspects: as a model of geomorphological evolution, e.g., a river meander; as an object of educational exemplarity, such as a littoral *tombolo*; as paleogeomorphological evidence, such as a Pleistocene relict glacial circus. A landform can also possess an ecological value, e.g., an exclusive habitat of certain vegetal or animal species such as a tidal marsh.

As regards the relationships between geomorphology and other cultural components, five phases may be identified (PANIZZA & PIACENTE, 2000). The first phase consists of the physical setting of the territory where the cultural asset (in a strict sense) is located; subsequently the geomorphological causes which conditioned the location of a given cultural asset should be considered; in the third phase the possibility should be assessed if a given cultural site being affected by geomorphological hazards and consequently subject to risk; in the fourth phase, the fruition of cultural assets will have to be considered, that might have a negative effect on the natural environment and environmental impact must be taken into account; in the fifth phase one should consider that the correct management of a cultural asset cannot be separated from the knowledge of its with the surrounding environment.

This cultural approach of Geomorphology concerns the dialogue and cultural integration between humanistic and scientific disciplines. Generally speaking, an effort should be made to give an answer to the ever-felt need for "neo-humanistic" culture, that is for the integration of culture.

The concept of *Cultural Geomorphology* can be extended to all the fields of Earth Sciences and can therefore introduce the concept of *Cultural Geology*.

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figg. 7

Geomorphosites and the conservation of landforms in evolution

Geomorfositi e la tutela di forme del rilievo in continua evoluzione

BINI M. (*)

ABSTRACT – Geomorphosites are in continuous evolution. They are developing forms constantly attempting to reach a temporary equilibrium depending on the current morphoclimatic regime. The dynamicity of the geomorphosites poses practical and theorical issues as regards to the management of such sites. In fact, if these forms are in evolution is it right to set about conserving a stage of that evolution? Moreover it is difficult to conserve with current rigid legislative procedures a dynamic element such as geomorphosites, their ongoing evolution poses problems for our system of limits, which are essentially based on geometrical considerations. Nevertheless, the dynamicity of geomorphosites represents an extraordinary tool for education, to fully understand and interpret the landscape and its complex equilibria.

KEY WORDS: Conservation, Geomorphosite, Landscape Evolution.

RIASSUNTO – I Geomorfositi sono forme in continuo divenire, alla ricerca di un equilibrio precario dettato dalle condizioni morfoclimatiche. La dinamicità di questi beni ambientali pone dei problemi teorici e pratici alla loro salvaguardia e gestione. Dal punto di vista teorico, infatti, se i geomorfositi sono forme in continua evoluzione ci si può domandare se sia giusto adoperarsi per conservare uno stadio dell'evoluzione, impedendo la formazione di quello successivo. Dal punto di vista pratico, la dinamicità di queste forme mette in crisi i rigidi sistemi normativi nazionali, che si propongono di tutelare i beni attraverso perimetrazioni e zonizzazioni rigide, poco adatte alle dinamiche naturali.
Tuttavia proprio la dinamicità dei geomorfositi, opportunamente valorizzata, può assumere un ruolo fondamentale nel far comprendere la continua evoluzione del paesaggio e ciò che regola i suoi complessi equilibri.

PAROLE CHIAVE: Conservazione, Geomorfositi, Evoluzione del Paesaggio.

1. – INTRODUCTION

Geomorphosites (PANIZZA, 2001) are landforms of the physical environment in continuous evolution, constantly searching for an equilibrium that is by definition temporary. It is precisely this characteristic that poses both practical and theoretical problems as regards the management of such sites, but which at the same time represents an extraordinary tool for environmental education.

It is within this context that geomorphosites, thanks to their dynamic nature, can assume a very important role in transmitting the concept of the continuous state of flux of the earth's surface, with all the possible implications that this presents.

2. – A CONCEPTUAL PROBLEM: WHAT TO CONSERVE

In the management of geomorphosites we must face a conceptual issue as to the identification of what landforms to protect and conserve. In fact, if these forms are in evolution is it right to set about conserving a stage of that evolution, in this way obstructing the possible successive phase of development? Given this premise, what stage should be conserved? How should we behave when faced with morphologies that are no longer in equilibrium with current morphoclimatic con-

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ditions? So the very question is what to conserve.

If, sometimes, due to scientific interest, it is useful to preserve a relict form, on the other hand we run the risk of producing "a fossil landscape" at the moment that we hinder its current evolution (FEDERICI, 2003). This issue is difficult to define and does not only regard environmental resources, but is equally applicable to cultural resources (strictly speaking) which always pose problems in Italy concerning the issues around the conservation of environmental resources.

In the field of cultural resources and particularly those regarding architecture, the issue of what it is right to conserve has deep roots and has been faced at least since the beginning of the 1800s with the origin, overlapping and often conflicts, of the various theories of restoration. Without going into the relative merits of individual theories, from that of stylistic restoration (1), up to the current lively debates on the opportunity or otherwise of preserving the historical centres of towns from the influence of modern architecture (2), it can be observed that historically the need to conserve important historical, social and artistic values, has made it legitimate to reconstruct buildings that had been entirely destroyed, following the diktat of the ancient formula of "how it was and where it was".

This is the case, for example, of the Santa Trinita bridge in Florence, destroyed by German mines on 3 August 1944 (fig. 1). There was lively debate as to whether there should be a faithful reconstruction with original materials or a completely modern and newly conceived architectonic structure. In the end the former project won the day, its supporters convinced that they were returning to the community the old bridge that belonged to the city. In this case it is the idea of "bridge", patrimony of the collective memory, which prevails over other considerations. Beyond the obvious differences of history, approach and culture, it is probably precisely this concept of identification of the community with the resource that represents a precious element to take into account also in the management of environmental resources such as geomorphosites (WIMBLEDON *et alii*, 1999).

In the field of environmental resources, however, the complexity of the issue in question is greater. Not only is there a more limited histori-

Fig. 1 – The Santa Trinita bridge in Firenze.
– Ponte di Santa Trinità a Firenze.

cal-cultural background involved, but there is also the fact that man is intervening in something that does not belong to him, of which he has less knowledge and over which he has less power of action. In identifying what to conserve there are undoubtedly absolute priorities. These often involve the safeguarding of elements of high scientific interest, unique and unrepeatable evidence of particular events, key points for the understanding of the geomorphological history of an area, for which, as far as is possible, it is worthwhile exerting pressure in order to conserve the resource.

In the Apuan Alps the morainic ridges, sporadic evidence of the last glaciation, are well worth attention even though they are no longer in equilibrium with the current morphoclimatic regime, and therefore an attempt at conservation should be made. This operation would certainly not preclude their possible evolution under the present morphoclimatic situation, for example through landsliding. However, it should safeguard these landforms against the marble mining activity of the area, which eats into the glacial cirques, takes away the rare erratic masses (MASINI, 1970) and destroys the roches moutonnées (fig. 2).

Besides the basic concept of safeguarding these features of high scientific interest, there are no pre-established solutions as to what it is right to conserve, but rather solutions that vary according to the **historical** and **cultural context.** Similarly to what happened regarding the Santa Trinita

(1) The origin of stylistic restoration can be traced to the chirograph of Leone XII in 1825, in which it is established (concerning the reconstruction of the Basilica of San Paolo Fuori le Mura in Rome) that "no innovation must be introduced in the architectonic forms and proportions and none in the ornamentations of the new building, unless this is to exclude a thing introduced after its first foundation purely for the fancy of the following age."

(2) We should not forget that also the historical centres as they have arrived to our day are very much the result of a stratification of events and often the result of violent intervention like for example the demolishing of pre-existing districts (eg. Altare della Patria in Rome). Note how European operations like the Louvre Pyramid and national projects like the Infobox le Gocce, by the architect Cuccinella have caused very mixed reactions depending on the differing degrees of identification of the general public with the new work.

bridge in Florence, in the choice of what to conserve we need to take into consideration what has become an integral part of the life and identity of the local community.

It would never enter one's mind to conserve a waste dump. However, in the Apuan Alps, the *ravaneti* (fig. 3), which are nothing more than residual marble quarry deposits, assume such an importance as to be conserved as resources in that they are a distinctive landscape feature that is typical of the history and culture of the area (D'Amato Avanzi & Verani, 1997; Baroni *et alii,* 2000).

It is the historical-cultural context, in this case, which typifies the resource to conserve. It is the long history of more than 2000 years of quarrying activity, typical of the Apuan Alps, which turns the *ravaneto* from a mere waste deposit into a resource. It is sufficient to shift geographical context and move for example across to the nearby Pisan Mountains, where similar landforms lose their significance and are considered a common quarry waste deposit of no interest whatsoever.

An equally typical example of conceptual evolution in terms of geoconservation is that of the very varied behaviour of man towards wetland areas. There are several examples in Italy of districts involved in the first reclamation projects of the Romans, or those carried out in the 20th century, today legislatively safeguarded as the habitats of protected species (Habitat directive 43/92CEE). There are clear examples of very different behaviour, in the regions of Lazio and southern Tuscany, for example the mouth of the

Fig. 2 – Roches moutonnées in the Orto di Donna valley (Apuan Alps, Tuscany): evidence of the last glaciation. Historical (photo by Domenico Zaccagna Accademia di Belle Arti di Carrara).
– *Rocce montonate nella valle di Orto di Donna (Alpi Apuane, Toscana): evidenze dell'ultima glaciazione (Fotografia storica di Domenico Zaccagna, Accademia di Belle Arti di Carrara).*

Fig. 3 – The residual marble quarry deposits as a typical element of the Apuan landscape.
– *Ravaneti delle cave di marmo, elemento tipico del paesaggio delle Apuane.*

River Ombrone reclaimed many times and today a protected wetland and site of the nature reserve of Diaccia and Botrona. A smaller, but equally significant, example is in the Apuan area, between the south-western limit of the Apuan Alps and the Tyrrhenian Sea, where there are some wetland sites classified as Sites of European Community Importance (Federici, 1998). In particular there is Lago di Porta (today dry) and the Lake and marshland of Massaciuccoli (fig. 4).

A final example is the relict of a series of wetlands that originate along the Apuan-Versilia coastline, caused by the isolation of waters produced by the barrier effect of sand-banks introduced after the Versilia Transgression (Sestini, 1950; Federici, 1983; Mazzanti *et alii*,1990). This area has a complex history which has seen man constantly intervene over the centuries with reclamation operations, (from the Etruscan-Roman period, to the Middle Ages, the Renaissance, and later in the centuries of the great reclamation schemes and even up until the immediate post-war period). In this way the landscape we see today is very much the result of a natural environment strongly influenced by man (Federici, 2003). Over the years the relationship of man with this environment has changed, but particularly from the 18th century there has been a prevailing philosophy of human intervention in order to eliminate the stagnant inland waters, and in this way most of the wetlands have disappeared. In particular, in 1900 the district of Massaciuccoli was classified as a 1st category reclamation area. From 1927 on various water consortia were founded and the reclamation process became very much a systematic development. Today, despite the clear need to maintain active the reclamation schemes, which have made the area habitable, attention has shifted to safe-

Fig. 4 – Historical map of Porta lake (named Beltrame) (Tuscany).
– *Carta storica del lago di Porta (chiamato Beltrame) (Toscana).*

guarding the wetlands and the Lake of Massaciuccoli and ex Lake of Porta are protected as Sites of Community Interest due to the rarity of their natural habitats.

3. – A PRACTICAL PROBLEM: MANAGING LANDFORMS IN EVOLUTION

Apart from issues of a conceptual sort, there are various practical problems associated with the management of geomorphosites. In fact, complicating the already difficult situation of their management is also the often inadequate Italian national legislation, which uses a very limited classic conservational model, based on a static and mummifying idea of conservation (POLI, 1999).

As reported in the European Landscape Convention (adopted in Florence on 20 October 2000) one of the most important item to obtain the safeguard of sites is the public promotion of their scientific value. This is patently unsuitable when dealing with a dynamic reality like that of the natural environment. It is difficult to conserve by means of rigid normative systems a dynamic feature such as a dune, the wandering of a river course, the incision of a gully or an active moraine. Their ongoing evolution hinders our typical systems of protection, which are unable to adapt to natural dynamics because the norms have been designed on the basis of strict measurements and zoning which are in turn associated with equally rigid legislative rules and regulations.

A river, for example, continually changes its course with slow and gradual transformations, such as the migration of its meanders or shifting of sand bars. Furthermore, following a flood event it can change its course very suddenly and begin flowing in a new bed and can, for instance, fan out into an alluvial cone. In this case, having to adjust the legislation so as to create diversified zones of protection relevant to the new course of the river is a difficult and laborious operation. There are cases in which water courses with their movements, be they gradual migrations or sudden variations, flow beyond the area that is administratively identified as a floodable district with a return time of 30, or even 200, years (fig. 5). It is clear that the legal norms associated with these measured limits lose both value and significance.

On the other hand, establishing that a natural feature is a geomorphosite does not necessarily mean subjecting it to specific limitations of use. Often the geographical conditions in which the resources are located are a guarantee of protection. It is sometimes necessary to focus attention on transmitting the inherent value of the resource because if this is universally shared then it can become a resource for the community in which it is located (BRANCUCCI & BURLANDO, 1998). This is the case, for example, of a little known geomorphosite connected with the glacier of Schiantala in the Maritime Alps.

During the Holocene, the Schiantala glacier has been present in the uppermost part of Vallone del Piz a lateral tributary of Valle Stura di Demonte in the Maritime Alps (fig. 6). Recently, in the cirque forefield of this glacier, thaw process involving glacigenic debris led to the formation of a glacial karst lake (FABRE & RIBOLINI, 2006). Although of the Schiantala glacier was never declared extinct, neither ice outcrops nor ice/snow patches are visible in the valley late in the meltout season. From the downvalley edge border of the glacial karst lake a huge rock glacier flows reaching the hollow

Fig. 5 – The example of the areas of diversified protection and new course of the Vara River (Liguria, Italy). Legend: Red: Floodable area with return time of 30 y; Yellow: Floodable area with return time of 200 y.
– *Esempio di aree a diversa protezione con indicazioni del nuovo corso del fiume Vara (Liguria, Italia). Legenda: rosso, area sondabile con tempo di 30 anni; giallo, area sondabile con tempo di ritorno di 200 anni.*

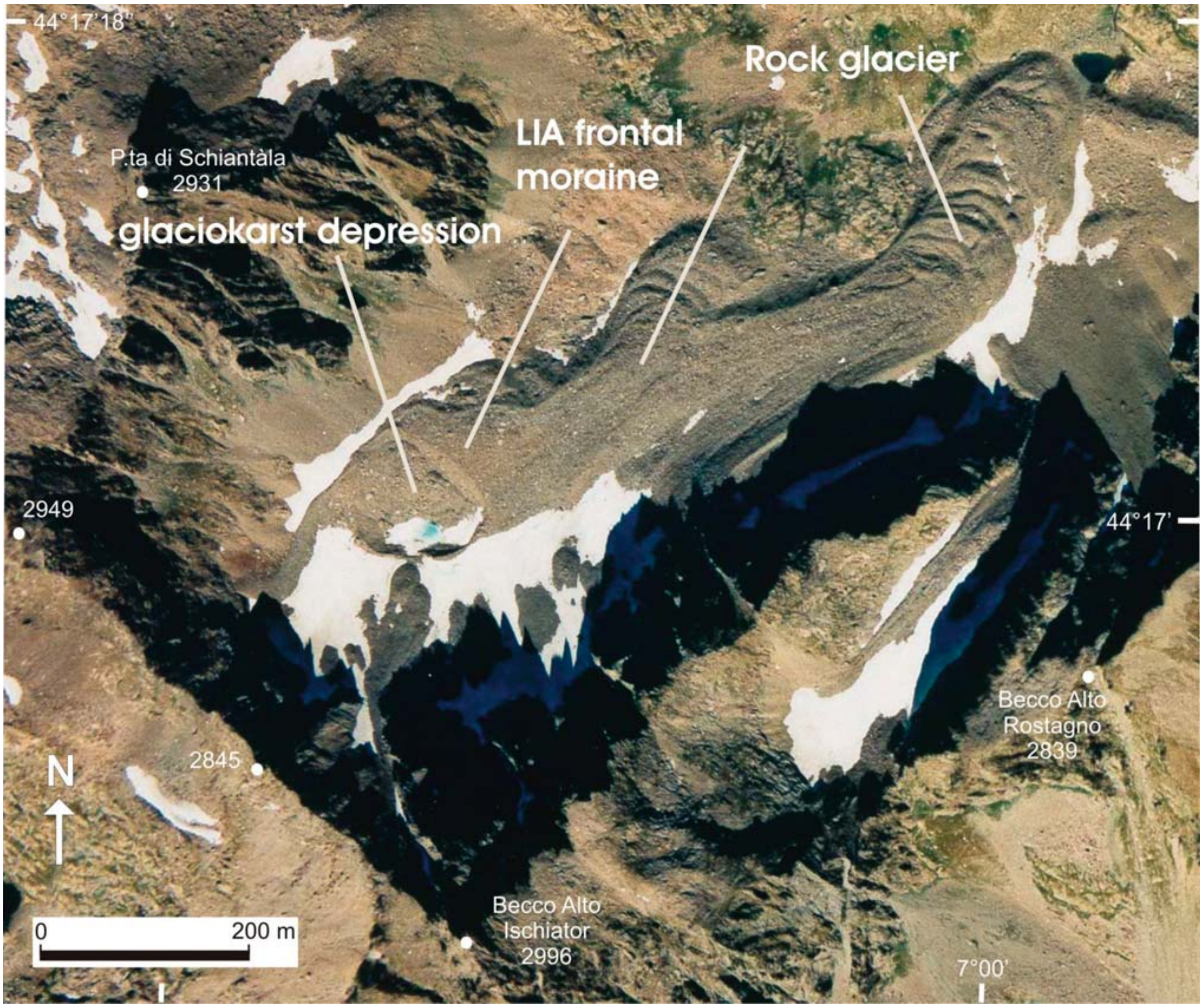

Fig. 6 – The till in the Schiantala cirque floor presently displays geometrical continuity with a huge rock glacier.
– Il deposito morenico sul fondo del circo glaciale Schiantala mostra continuità geometrica con un rock glacier di grandi dimensioni.

invaded by the Schiantala glacier during its maximum Holocene expansion. In the Schiantala Valley cirque a debris covered glacier was present in the late 1920s. Downvalley its most recent frontal moraine (Little Ice Age) stretches a well developed rock glacier. A remarkable lowering of the debris surface has been taking place during the last 70 years, due to ice melting and the glacial karst lake opened up in the middle of the cirque, showing, under the main debris cover, an ice lense very rich in debris layers. Today there is not evidence of glacial processes: rockfalls from the cirque wall and wings shelter the ice body, and permafrost creeping affects debris mantling the cirque floor and sides.

Recent geomorphological analysis and electrical resistivity tomography (BIANCHI *et alii,* 2004) have highlighted that in the Schiantala cirque the resistivity values of the ice bodies are very similar to those measured on the exposed ice in another site in the Maritime Alps (the Maledia cirque, in the Gesso valley). Approaching the Little Ice Age morain resistivity values gradually decrease, becoming consistent with ice progressively richer in debris. This suggests that the Schiantala cirque can represent a possible step in the glacial extinction process in which the Maritime Alps glaciers are involved (FEDERICI *et alii,* 2005). The Schiantala area is important as a geomorphosite because it represents the unique example of outcrop of massive ice buried by debris in the Maritime Alps, higlighting a possible style of glacier extinction process in this alpine region. In fact, this site represents significant example of the trasformation from clean glacier to debris covered glacier, in analogies with the tendency of the other glaciers in the Maritime

Alps. Morover the geomorphosite of Schiantala offers the opportunity to infer about the possible role of "glacial ice" in rock glacier formation.

4. – CONCLUSIONS

For an interpretation of the landscape and the understanding of its complex balances the most important thing to conserve and transmit is probably not so much a stage, but the concept and significance of the evolution of the earth. This fundamental phase enables the general public to expand their knowledge of natural phenomena, to understand their significance and their overlapping and interaction with the life of man. One of the many examples of the absolute lack of understanding of the evolution of the physical environment is that of the case of the repeated rockfalls that occurred in the Dolomites in the summer of 2004. The falls caused a great deal of public concern regarding the state of the mountains, almost as if they were about to disappear from one moment to the next. There was great speculation as to the reason for the phenomenon, drawing into the debate climatic changes and blaming man for his inconsiderate actions. In effect, however, the disintegration of the rocks is very much an aspect of the natural evolution of the mountain chain. It is a natural evolution not difficult to understand, as witnessed by the presence of the numerous detritic layers that surround the main Dolomitic peaks (fig. 7).

Therefore, it is important to transmit, by means of geomorphosites (in this case for example: detritic layers, cones, debris flows) how a mountain chain is formed, how long it has taken for its deposits to emerge from the ocean in which they formed, in order to become the peaks we know today, and which make up the skeleton of our landscapes. Furthermore, it is equally important to understand that what we see today is not the final frame of the film of the land, but only one of the frames in between. The engine of evolution that has brought a land to us in its present form has not stopped. The very same landscape will continue to evolve, and a mountain chain subject to the action of exogenous agents will be stripped down to the point where it becomes a plain and very possibly a new sea. It is therefore clear how the recent proposal to nominate the Dolomites as

Fig. 7 – Debris cones and talus scree on M. Paterno and Tre Cime di Lavaredo.
– Coni e falde detritici del M. Paterno e delle Tre Cime di Lavaredo.

a world heritage site of UNESCO will certainly safeguard the mountains from an environmental point of view, will undoubtedly enable a greater and more effective sustainable development, but it will not preserve them from their natural physical evolution.

By means of suitably exploited geomorphosites, it is possible to understand that geology is a story with a various and extensive chronology. Like history, also geology can be considered "Magistra vitae". It not only gives indications as to the past, but thanks to the evidence of the past it acts on the present and is able to "foresee the future".

The most glaring example of how this function of geology is unfortunately not recognised is that of extensive building on the slopes of volcanoes mistakenly believed to be inactive. Man often shows that he has little historical memory, but blatantly shows that he has absolutely no form of geological memory. If on the slopes of Etna, which has experienced eruptions only very recently, we come across the ongoing construction of new buildings, the case of Vesuvius is even more alarming. The long period of inactivity of the volcano has for the most part been interpreted as extinction, and building activity, not only the illegal construction, has proceeded unopposed almost right up to the very rim of the Somma crater. At the present time more than 700,000 people live on the slopes of the volcano. And still a great number of tourists visits the famous archaeological sites of Pompeii and Herculaneum every day, touching directly the history of this land devastated by repeated eruptions. This information that the tourist gleans, just like the solid patrimony of scientific knowledge that we have concerning the volcano, seem to have no effect on daily life. The first remains limited to the one-off experience of the tourist visit, the second only to the scientific community. Considering the great catastrophes of the past, be they floods or eruptions or whatever, seems to condition us into thinking that these events cannot be repeated, despite the continuous demonstration from various parts of the earth that the opposite is true. Geomorphosites could assume, precisely in this way, an important educational role, transmitting the message that what is often simplistically represented by the media as an "extraordinary event" is in reality nothing of the sort, and that some natural disasters are the result of our incapacity to take into account the evolution of an active and dynamic planet.

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figg. 14

Geomorphology, environmental geology and natural-cultural heritage of Palmaria, Tino and Tinetto Islands (Portovenere Park, Italy)

Geomorfologia, geologia ambientale e patrimonio naturale-culturale nelle Isole della Palmaria, del Tino e del Tinetto (Parco di Portovenere, Italia)

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ABSTRACT – The islands of Palmaria, Tino and Tinetto represent the western limit of the Gulf of La Spezia. They constitute the seaward extension of the Portovenere Promontory, part of the site inscribed on the UNESCO World Heritage List. The three islands comprise a small archipelago, which has been protected since 2001 as part of the Natural Park of Portovenere. Geomorphological features and numerous traces of the historic quarrying of the precious Portoro marble characterize the islands. The geology is marked by an overturned fold, with overlapping dolomitic limestone rock strata, affected by karstic phenomena that are also of archaeological importance. The geomorphological modeling is conditioned by the structural arrangement and the tectonic lineations: the processes in progress are mainly related to wave undercutting, which determines a cliffed coastal profile on the slopes facing SW and SE, while the other island sectors present coves with pocket beaches. The islands of Palmaria and Tino are well known for the extraction of Portoro marble during the Roman period. Portoro, quarried mostly underground, is a black marble with gold, white and rose-colored veining, utilized as ornamental stone. The islands are basically visited for hiking excursions and beach outings, and the environmental heritage they represent is of great value for tourism. Initiatives aimed at the valorization and protection of this heritage are needed. Based on the geological and geomorphological aspects, geotourist map of the Palmaria islands was prepared to promote an understanding of the landscape and to valorize the environmental values.

KEY WORDS: Geomorphology, Environmental geology, Cultural heritage, Palmaria Island, Ligurian sea.

RIASSUNTO – L'arcipelago delle isole Palmaria, Tino e Tinetto, ubicato al limite occidentale del Golfo di La Spezia (Liguria orientale), costituisce la naturale prosecuzione del Promontorio di Portovenere e rappresenta un sito di grande interesse geomorfologico-culturale, con importanti aspetti scientifici, paesaggistici, socio-economici e storici, in particolar modo legati alla plurisecolare attività estrattiva, anche in sotterraneo, del pregiato marmo Portoro.

Dal 1997 l'arcipelago è stato riconosciuto come Patrimonio Mondiale dell'Umanità dall'Unesco e dal 2001 è tutelato dal Parco Naturale Regionale di Portovenere.

L'assetto geologico-strutturale è caratterizzato da una piega anticlinale rovesciata con asse NW-SE nella quale si riscontra la sovrapposizione di strati calcareo-dolomitici, interessati da diffusi fenomeni carsici. Tra Palmaria, Tino e Tinetto sono infatti censite una trentina di cavità naturali, alcune delle quali di importanza anche archeologica, come la Grotta dei Colombi.

Il profilo costiero delle isole è condizionato dall'assetto tettonico ed in particolare le falesie che caratterizzano i settori sud-occidentali delle isole della Palmaria e del Tino sono impostate lungo una faglia diretta orientata NW-SE. I versanti nord-orientali degradano a mare con pendenze relativamente più modeste e si presentano bordati da piccole spiagge ghiaioso-ciottolose.

Tracce di modellamento dei versanti dovuto a processi gravitativi sono presenti soprattutto sulle pendici sud-occidentali dell'Isola della Palmaria, dove si osservano falde detritiche, talora frammiste a depositi colluviali. In alcuni casi questi depositi sono debolmente cementati e rappresentano un'interessante testimonianza di variazioni climatiche del passato.

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Sulla base degli aspetti geologici, geomorfologici e geoambientali rilevati, è stata preparata dapprima una carta geomorfologica-ambientale e successivamente una carta geoescursionistica dell'Isola della Palmaria, con lo scopo di favorire la comprensione del paesaggio e la sua valorizzazione estendendone la fruizione a diverse tipologie di escursionismo: didattico, scientifico, sportivo e turistico-culturale.

Lungo la rete escursionistica sull'Isola della Palmaria (sul Tino la visita è ad oggi interdetta per attività militari) sono stati evidenziati i principali geositi, con particolare riferimento a quelli connessi alla geomorfologia culturale. I sentieri, suddivisi secondo una scala semplificata di difficoltà, sono stati esaminati in rapporto ai pericoli naturali che possono coinvolgere l'escursionista, spesso associati a particolari condizioni meteorologiche, ed agli elementi di vulnerabilità legati alle loro caratteristiche strutturali (esposizione, larghezza, tipo di fondo).

Per la fruizione degli aspetti geomorfologico-culturali si propone la realizzazione di alcuni itinerari guidati: nell'Isola della Palmaria si può distinguere un percorso legato all'impiego dei materiali lapidei nell'architettura civile e militare ed uno storico-geominerario. Le peculiarità geomorfologiche delle isole, con particolare riferimento ai processi legati al modellamento costiero, possono essere infine pienamente apprezzate attraverso un percorso a mare.

PAROLE CHIAVE: Geomorfologia, Geologia ambientale, Patrimonio culturale, Isola Palmaria, Mar Ligure.

1. – INTRODUCTION

The archipelago of the islands of Palmaria, Tino and Tinetto (Ligurian Sea) represents a site of exceptional geomorphological and cultural value. The site's important scientific, scenic, socioeconomic and historical features offer an opportunity to broaden our understanding of geomorphological and geoenvironmental issues (BENNETT & DOYLE, 1997; PANIZZA & PIACENTE, 2003; GRAY, 2004).

The islands are characterized by a high rocky cliff on the western and southern slope, whereas the remaining coastline is more jagged, with small promontories and pocket beaches. There are many cave openings, including both karstic and sea caves, in the limestone and dolomite, which constitute the bedrock of the three islands. Some of these caves, such as the *Grotta dei Colombi*, have been object of research in the past and are of great importance not only in terms of their historical and archeological value, but also in terms of their scientific value, as they contain valuable evidence of past climatic variations (CIGNA, 1967). Settlements on the islands date back to prehistoric times. The islands were the seats of important monastic communities in the Middle Ages, and of military defense and naval bases starting from the end of the 19th century, when major defense works were built, including the *Punta della Scola*, the *Batteria Semaforo* (today a center for environmental education), *Forte Cavour* and *Forte Umberto I*.

The islands also took on social and economic importance, owing to their geomine features: extraction of the precious Portoro marble has been traced back to the Roman period, and continued on through to the end of the 20th century.
For these reasons, there has been recent growing interest in educational and recreational activities made possible through and linked to the development of geomorphological and geomine trails (BRANDOLINI *et alii*, 2005; ROBBIANO *et alii*, 2005). The islands of Palmaria, Tino and Tinetto have been protected by the *Cinque Terre* network of protected areas in the Liguria Region since 1985 (BRANDOLINI & ROLLANDO, 1995). As of 2001, they have represented part of the Regional Natural Park of Portovenere, and in 1997, the archipelago was recognized as a World Heritage Site by UNESCO. These places have fascinated Romantic and contemporary poets and have served as inspiration for literary works, musical compositions and paintings. In fact, the area is of exceptional value, one that reveals the relationship between humankind and nature, the source of a landscape of extraordinary scenic beauty.

The objective of this work is to broaden the knowledge of the geology and geomorphology of the area as cultural elements of the landscape, as well as their interaction with the presence and activities of humans, with the aim of valorizing the area culturally and in terms of tourism.

Additionally, existing geomorphological hazards that could affect the numerous visitors along the hiking trails in Palmaria Island, were also taken into consideration, with the objective of guaranteeing sustainable tourism and helping tourists become informed and aware; Tino and Tinetto islands were not examined because they are military zone.

2. – GEOGRAPHIC FRAMEWORK

The islands of Palmaria, Tino and Tinetto are located along the western limit of the Gulf of La Spezia in eastern Liguria (fig. 1). They constitute the natural extension of the Portovenere Promontory (fig. 2). In fact, the islands present an approximately NW-SE alignment and the possibility that at least Tino and Tinetto were once joined cannot be excluded (CIGNA, 1967).

The island of Palmaria, Liguria's largest island with a land area of 1,65 km^2, has an approximately triangular shape with three sides that are about 3 km in length. The maximum elevation (about 190 m) is found in the central-southern sector, where the *Fortezza* (*Batteria Semaforo*) was erected. The SW

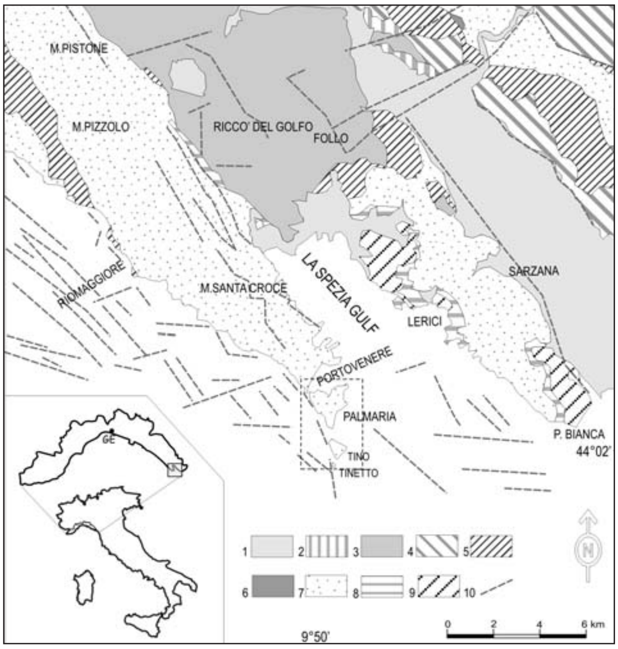

Fig. 1 – Geological sketch map of Portovenere Promontory and surrounding areas: (1) Olocenic covers; (2) Mt. Antola Tectonic Unit; (3) Mt. Gottero T.U.; (4) Ottone T.U.; (5) Canetolo T.U.; (6) Marra T.U.; (7) Tuscan Nappe (*Falda Toscana*); (8) Tectonic breccias; (9) Massa T.U.; (10) Fault. The dashed rectangle indicates the study area.
– *Schema geologico del Promontorio di Portovenere e delle aree circostanti: (1) coperture Oloceniche; (2) Unità Tettonica del M. Antola; (3) Unità Tettonica del M. Gottero; (4) Unità Tettonica di Ottone; (5) Unità Tettonica di Canetolo; (6) Unità Tettonica di Marra; (7) Falda Toscana; (8) Brecce tettoniche; (9) Unità Tettonica di Massa; (10) Faglia. Il rettangolo tratteggiato indica l'area di studio.*

side, with its characteristic cliff, is rectilinear with some inlets of modest dimensions in the southern part. In comparison, the SE and N sides are very indented, with a low rocky coast with accumulated sediment locally, which permits vessels to berth in the bay known as the *Seno del Terrizzo* and the cove known as *Cala del Pozzale*.

The island of Tino is located about 500 m S of Palmaria and it extends in a NW-SE direction, with a maximum length of 700 m and a width of 350 m. The highest point reaches an elevation of 99 m, where the lighthouse is located. Today the island is still a base for military operations. The SW and W sectors present an impressive cliff, whereas the remaining sectors are more indented, especially to the NE and S.

Tinetto, 150 m long and 18 m high, is little more than a rock ledge; it represents the south-eastern border of the carbonate sequence outcropping in the Ligurian sea.

The climatic characteristics of the islands are shown in figure 3, according to data recorded at the station located on Palmaria Island at 190 m ASL during the 1949 - 1985 observation period.

The annual mean is about 900 mm of rainfall and annual mean temperature is about 15°C. The mean monthly rainfall pattern in the observation

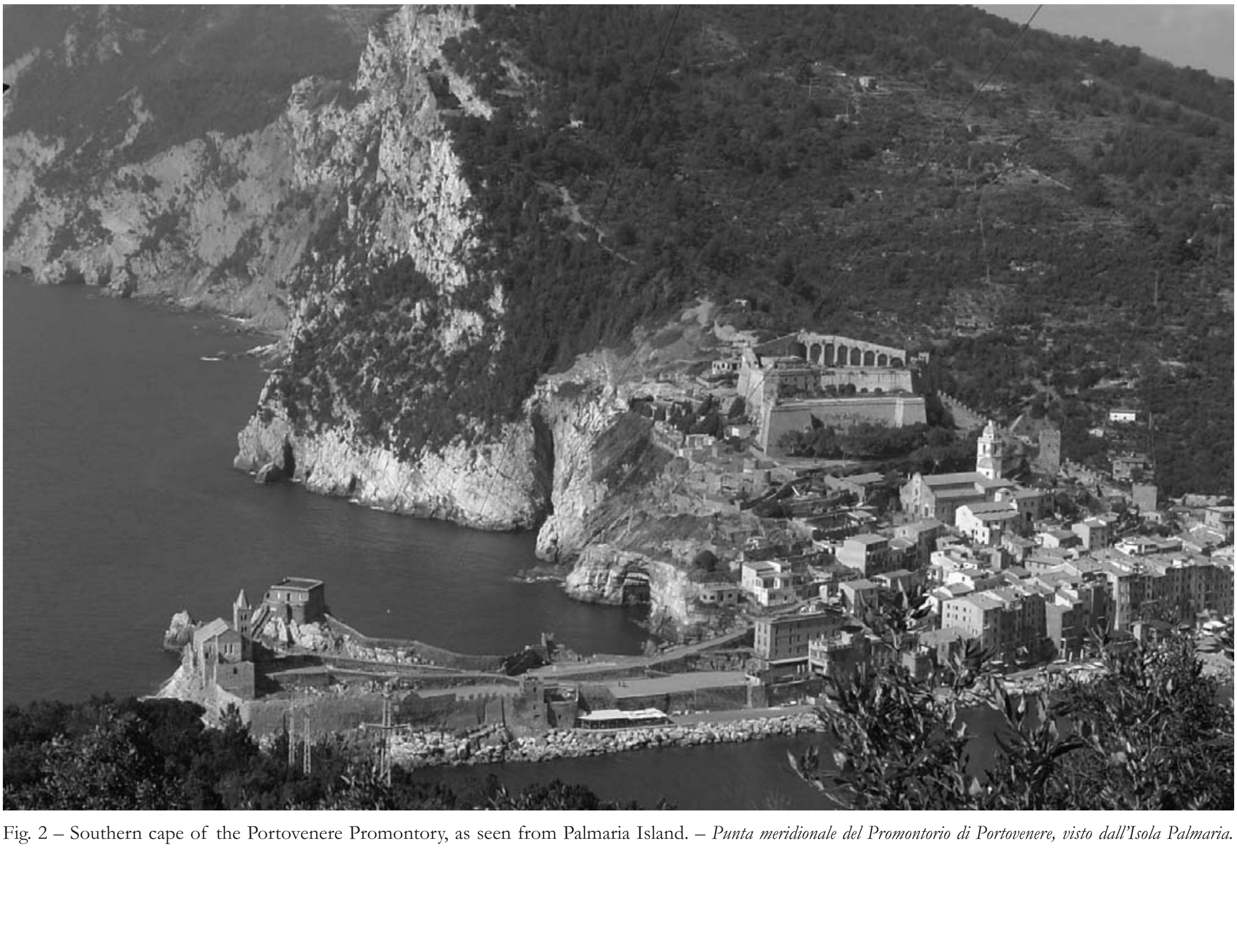

Fig. 2 – Southern cape of the Portovenere Promontory, as seen from Palmaria Island. – *Punta meridionale del Promontorio di Portovenere, visto dall'Isola Palmaria.*

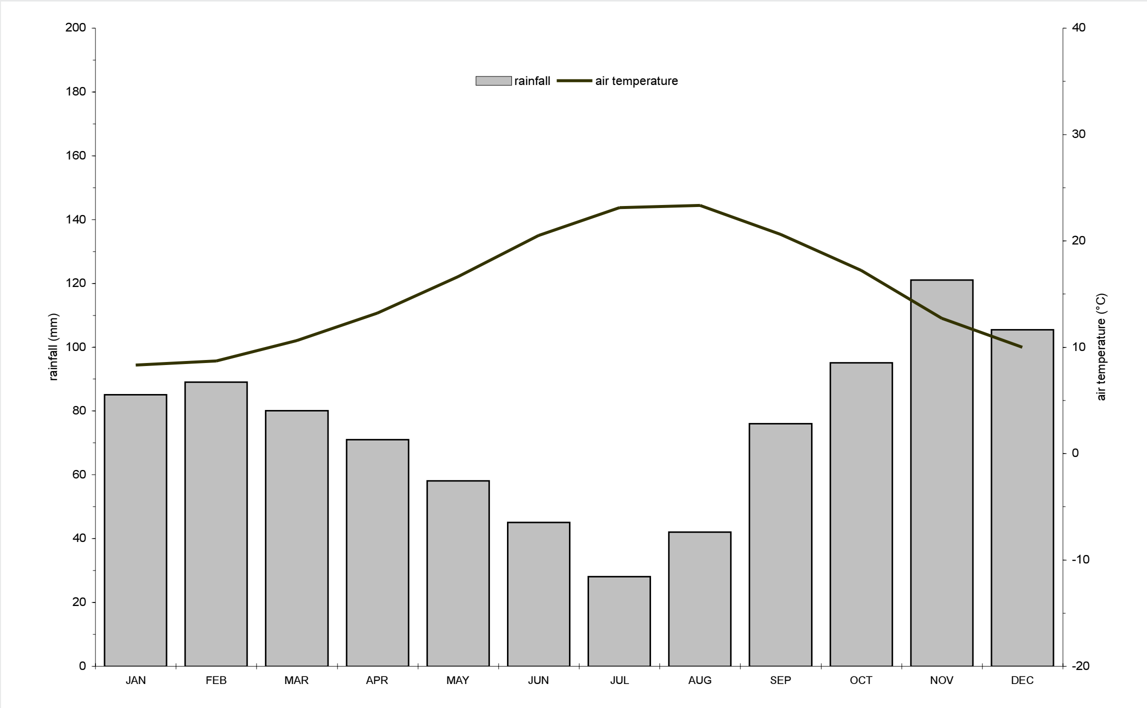

Fig. 3 – Climatic diagram, referring to 1949-1985 observation period of Palmaria Island meteorological station data (190 m asl).
– *Diagramma climatico, riferito al periodo di osservazione 1949-1985, della stazione meteorologica dell'Isola Palmaria (190 m slm).*

period shows an absolute maximum in October (120 mm) and a relative maximum in February (89 mm), while the minimum proved to be in July with values below 30 mm. Air temperature data for the same period showed a minimum in the winter months of January and February (i.e., 8-9°C) and a maximum in the months of July and August (i.e., slightly above 23°C).

The above mentioned data indicate a Mediterranean climate (POTENTI & VITTORINI, 1995).

Intense, but brief rain storms are frequent in autumn, when in just a few days the amount of rainfall can reach at least half the annual total. These events are generally the triggering factor leading to geomorphological instability phenomena.

As explained below in further detail, the geomorphology of the three islands indicates strong modeling by the action of sea waves. The wind velocity spectrum at the ground surface indicates that there are less than 30 calm days (velocity of less than 6 km/h) in a year, while the modal value ranges between 30 and 40 km/h. Wind directions are mainly from NE and SW quadrants, and to a lesser degree from the SE, while winds from NW are obviously blocked by a natural barrier, the Promontory of Portovenere.

3. – GEOLOGICAL OUTLINE

The outcropping Formations on the islands of Palmaria, Tino and Tinetto belong to the *Falda Toscana* (fig. 1) and they are represented, from bottom to top, by the La Spezia Formation, which is subdivided into the Mt. Santa Croce Limestone and Marl Member and the Portovenere Limestone Member, and by Portoro and Mt. Castellana Dolomites; the Formation has been attributed to the Upper Triassic (Norian-Rhaetian-Hettangian).

The Mt. Santa Croce Limestone and Marl Member is present in the eastern and central sectors of the islands. It is made up of strata and beds of dark grey limestones irregularly alternating with grey and yellowish marly layers. There are also interlayers of beds of whitish, saccharoidal dolomites and of oolitic-bioclastic limestones; storm-graded layers with sea snails and prevalent pelecypods are frequent.

The Portovenere Limestone Member prevails in the southwestern sectors of the islands. This member is made up of layers, of thicknesses in the range of decimeters, composed of dark grey limestones alternating with fewer marly or dolomitic layers and very infrequently, layers of storm deposits with sea snails; the *Strati di Grotta Arpaia* lithofacies is distinguishable at the top.

The latter strata are made up of sholes and blackish marls, which are sometimes nodular, and thin interlayers of sea snails.

The western portion of the islands, represented by the impressive subvertical cliff, is characterized by the Mt. Castellana Dolomites at the base, including saccharoidal dolomitic limestones that are whitish or yellowish, and massive or coarsely stratified (fig. 4). The Portoro marble is found intercalated between the Mt. Castellana Dolomites at the base and the La Spezia Formation at the top. The Portoro consists of beds of dark grey to black limestones that are nodular and have white- and yellow-colored dolomitic vein patterns. These beds alternate with beds in the range of meters, consisting of whitish and yellowish, coarsely crystalline dolomites (SERVIZIO GEOLOGICO D'ITALIA, 2004).

The structural pattern of the Promontory of Portovenere, including the three islands, is characterized by an overturned anticlinal fold with Tyrrhenian vergence and a fold axis dipping NW-SE. (CIARRAPICA & PASSERI, 1981; FEDERICI, 1987). This zone is distinguished by a system of normal faults that is also oriented in a NW-SE direction, and by an approximately orthogonal system oriented NE-SW. The latter has determined the pattern of the limited drainage system on Palmaria Island and defined the channels that separate the islands themselves and the islands from the Promontory (FEDERICI & RAGGI, 1975).

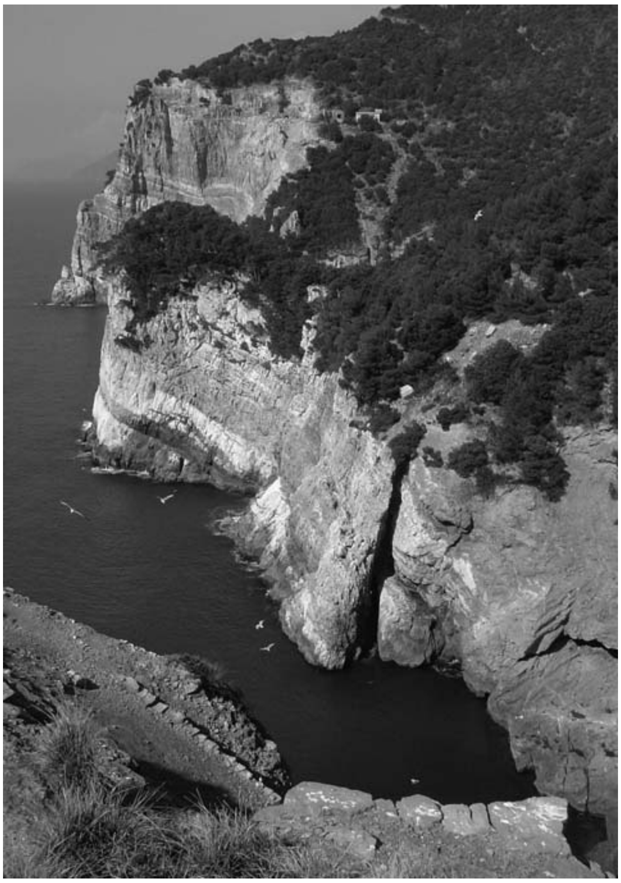

Fig. 4 – Palmaria Island cliff modeled in the Mt. Castellana Dolomites (*Caletta*).
– *Falesia dell'Isola Palmaria modellata nelle Dolimie di M. Castellana (Caletta).*

Depending upon the stratigraphy and tectonic style of the area, the valuable Portoro layer outcrops discontinuously solely in the western sectors of the islands. In addition, it is only found between dolomites and dolomitic limestones at the base and marly limestones at the top.

Portoro layer consists of a deep black matrix with very fine-grained, uniform micrite with veining of another color, called *macchie* in commercial terms. There may be yellow veins, owing to the presence of limonite and sulphides, in which the pigmentation appears in the form of intergranular veining between the dolomite crystals, violet veins consisting of dolomitic mosaics that have zones more intensely colored by a hematitic pigment, and veins of recrystallized calcite.

Commercially, a basic distinction is made between two main types of Portoro marble: Portoro *a macchia larga* (i.e., with a wide vein pattern) and Portoro *a macchia fine* (i.e., with a thin vein pattern). These two types are also subdivided into four different quality grades, making for a total of eight types, based on the intensity of color of both the vein pattern and the matrix; current restrictions have limited commercial distribution and not all of the eight types are available on the market (CIMMINO *et alii*, 2003).

4. – DETAILED GEOMORPHOLOGICAL CHARACTERISTICS

The geomorphological modeling is conditioned by the structural arrangement and tectonic lineation: the processes in progress are mainly related to marine, gravity and running water activities, subordinately to karstic phenomena. Man-made landforms related to quarry and mine, agricultural terracing and military structures are also very important.

4.1. – SLOPE LANDFORMS AND DEPOSITS DUE TO GRAVITY AND RUNNING WATERS

Evidence of morphological modeling of slopes due to gravitational processes is mainly visible on the southwestern slopes of Palmaria (fig. 5). In particular, above *Cala Grande* and *Caletta*, at about 175 m, below the *Fortezza*, a wide scarp edge is identifiable; it is carved into the limestone and marly layers with a prevalently unfavorable structural orientation. Several scree slopes have formed,

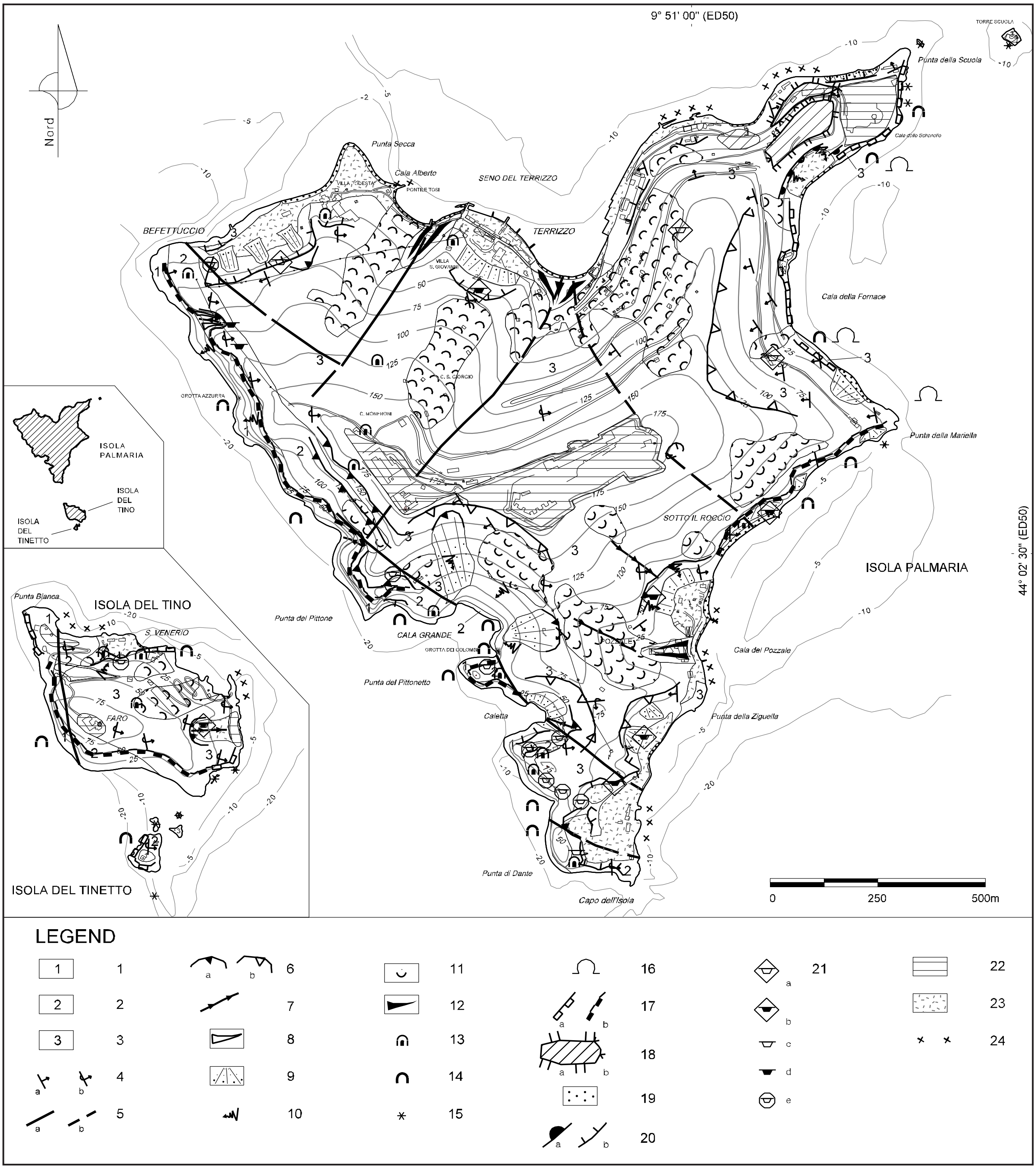

Fig. 5 – Geomorphological and geo-environmental map. Legend: Geological data - 1. Calcareous dolomite; 2. Portoro marble; 3. Limestone and marly limestone; 4. Attitude: a. dipped; b. overturned; 5. Fault: a. certain; b. assumed or covered; Slope landforms due to gravity and running water – 6. Edge of scarp: a. active; b. dormant; 7. Small rock valley crossed by debris flow; 8. Talus cone; 9. Scree slope, sometimes mixed with debris flows and landslides; 10. Area affected by rill wash; 11. Colluvial deposit with agricultural terraces; 12. Alluvial fan; Karst landforms – 13. Cave; Marine landforms – 14. Sea cave; 15. Stack; 16. Notches; 17. Edge of scarp due to wave erosion: a. h<25 m; b. h>25 m; 18. Planation surface: a. edge; b. root; 19. Pebble and gravel beaches; Man-made landforms – 20. Edge of scarp due to: a. waste; b. quarry; 21. Abandoned quarry: a. limestone used for dam blocks and lime; b. only for lime; c. opencast Portoro, *macchia larga* quality; d. opencast Portoro, *macchia fine* quality; e. underground Portoro, *macchia larga* quality; 22.Denudational area; 23. Areal embankment, land reclamation, waste; 24. Protective structure along the shoreline.

– Carta geomorfologica e geo-ambientale. Legenda: Dati Geologici – 1. Dolomie calcaree; 2. Marmo di Portoro; 3. Calcari e calcari marnosi; 4. Giacitura: a. strati inclinati; b. strati rovesciati; 5. Faglia: a. certa; b. presunta o coperta; Forme di versante dovute alla gravità e alle acque correnti – 6. Orlo di scarpata: a. attiva; b. quiescente; 7. Canalone di roccia con scariche di detrito; 8. Cono di detrito; 9. Falde di detrito, talvolta mescolate a debris flows e frane; 10. Area interessata da dilavamento diffuso; 11. Depositi colluviali con terrazzamenti coltivati; 12. Cono alluvionale; Forme Carsiche – 13. Grotte; Forme marine – 14. Grotte marine; 15. Faraglione; 16. Arco, ponte naturale; 17. Orlo di falesia: a. h<25 m; b. h>25 m; 18. Spianata di erosione: a. orlo; b. base; 19. Spiagge di ciottoli e ghiaia; Forme antropiche – 20. Orlo di scarpata dovuta a: a. discarica; b. cava; 21. Cava abbandonata: a. calcare usato per blocchi per sbarramenti e per la calce; b. solo per calce; c. cava a cielo aperto di Portoro, qualità macchia larga; d. cava a cielo aperto di Portoro, qualità macchia fine; e. cava in sotterraneo di Portoro, qualità macchia larga; 22. Area di sbancamento; 23. Terrapieno, area di bonifica, area incolta; 24. Strutture di protezione lungo la costa.

sometimes intermingled with colluvial deposits, associated with rockfall and toppling phenomena, some of which are still active.

In some cases, these deposits appear to be weakly cemented and comparable to slope breccias (CIGNA, 1967). As for the period of formation, by analogy with similar deposits found on the nearby Promontory of Monte Marcello, they are probably attributable to the early Middle Ages, a period characterized by a cold, damp climate (CHELLI & TELLINI, 2001).

NE of *Punta del Pittone*, active edges of landslide scarps were found at about 125/150 m, affecting the outcrops of limestones and of Portoro. The debris deposited on the slope below has been largely redistributed by mass movements triggered by running water (debris flow) or transferred to the foot by marine erosion.

The drainage system on the island of Palmaria is not extensively developed, limited as it is to first order stream that flow into the *Seno del Terrizzo* or *Cala del Pozzale* inlets. These watercourses are rectilinear; the alluvial fans of limited sizes that they form are partly reworked by wave cutting. With particularly heavy rains, the sharp steepness of the longitudinal profile and the presence of debris in narrow and small valleys trigger quick flows that can become hazardous.

On the island of Tino, there are only a few watersheds that drain into the sea only with heavy rainfall. Lastly, relatively moderate colluvial deposits are present in the sectors that are not as steep, where the availability of soil led to widespread terracing of the slopes for agricultural purposes.

4.2. – KARST LANDFORMS

The island's name Palmaria is thought to have originated from the Ligurian etymon *balma*, the meaning of which, *grotto*, is clearly indicated in literature and by the existence of the term *barma* or *arma* referring to grottoes. *Isola della Palmaria* (or *Balmaria*) would thus mean *island of the Grottoes*. In fact, about thirty natural caves have been inventoried on the islands of Palmaria, Tino and Tinetto; these caves are part of the karst site *SP-2, Lama di La Spezia* defined by Regional Law no. 14/1990. The site consists of a narrow outcrop of Mesozoic limestones that extends in a NW-SE direction (*Lame della Spezia*). The outcrop is characterized by karstifiable rocks in which caves develop, frequently with swallow-hole entrances, as do surface landforms, like the doline fields of Mt. Parodi and the extensive closed depressions of *San Benedetto* and *Caresana* (FEDERICI, 1970; SOCIETÀ SPELEOLOGICA ITALIANA, 1987).

Surface karstic phenomena are not very evident on the islands in the gulf, for karstic phenomena are more limited to microforms of corrosion. As concerns the hypogenic landforms, the caves are always of modest dimensions, at least compared to what has developed on the mainland. Although most of these caves are of karstic origin, some cases are related to the effects of marine erosion of the clayey and/or marly fraction and to subsequent collapses.

The caves always appear to fossil forms and together with the limited dimensions of the caves, this aspect leads us to think that the karstification process lasted for a limited period of time – only about ten caves extend further than 25 m and an analysis of the distribution of the cave entrance elevations shows that most entrances are found between sea level and 50 m ASL (CIGNA, 1967).

The cave entrances are essentially located along the coast of the western sector, where the bedrock outcrops over vast areas, in the Formation of the Mt. Castellana Dolomites and in the Portoro, both of which are characterized by a very high carbonate content.

The caves in the La Spezia Formation, however, are even smaller due to the subhorizontal arrangement of the bedding and the prevalence of the clayey fraction with respect to the carbonate fraction.

The most significant caves are the *Grotta dei Colombi* and the *Grotta Azzurra*. The former, with its entrance at about 32 m asl, extends for just slightly less than 80 m (fig. 6), whereas the entrance to the *Grotta Azzurra* is at sea level and the cave itself extends for about 58 m. The *Grotta dei Colombi* is of great importance because of the information

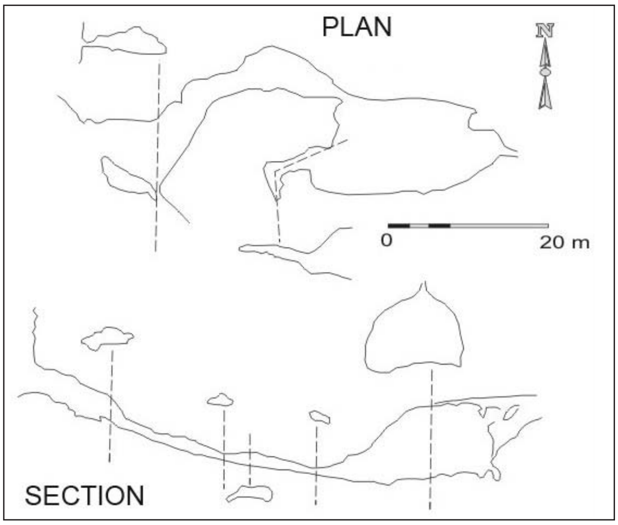

Fig. 6 – *Grotta dei Colombi*, plan and section (modified from SOCIETÀ SPELEOLOGICA ITALIANA, 1987).
– *Grotta dei Colombi, in pianta e in sezione (modificata da SOCIETÀ SPELEOLOGICA ITALIANA, 1987).*

it has contributed to research in Quaternary Geology and Paleoanthropology. In fact, in this cave, an upper level was found containing human bones attributed to the Eneolithic-Bronze Age, as well as a lower level of Pleistocene age, containing cold-climate faunas (CAPPELLINI, 1896; FORMICOLA, 1983). The *Grotta Azzurra* is particularly fascinating with the special light created inside as sunset nears. It is of karstic origin and the fact that the bottom of the cave is located at a depth of 14 m below sea level, testifies to a rise in sea level occurring after its genesis (CIGNA, 1967).

4.3. – MARINE LANDFORMS

The coastline is interlinked with the geological and structural features of the area, particularly the cliffs characterizing the southwestern sectors of the islands of Palmaria and Tino, sectors lying along a normal fault that has a NW-SW orientation.

Exposed to the swells generated by the *Libeccio*, the south-west wind, these cliffs present retreating scarps with heights that often exceed 100 m and the sea floor become rapidly deep, reaching a depth of 20 m in the nearshore zone (fig. 7).

The rectilinear shoreline in the southwestern sector of Palmaria Island is broken up by two small inlets (*Cala Grande* and *Caletta*), where several bedding-plane sea cave entrances are found; sometimes these caves overlie other caves of karstic origin.

Palmaria's eastern sector has a jagged coastline, with two main inlets, *Cala della Fornace* and *Cala del Pozzale*, which are separated by *Punta della Mariella*. Both inlets are delimited by high cliffs, active also for gravity processes. The cliffs are generally lower in height (20-40 m) and there are some pocket beaches at the base that are supplied by the slope processes (fig. 8).

Fig. 7 – Cliffs on the southwestern slope of the islands of Tino (in the foreground) and Palmaria; the rock walls of the Mt. Muzzerone sea cliff along the Portovenere Promontory (in the background).
– *Scogliere nel versante sud-occidentale delle isole di Tino (in primo piano) e della Palmaria; sullo sfondo le pareti rocciose della scogliera del M. Muzzerone lungo il Promontorio di Portovenere.*

Fig. 8 – *Cala del Pozzale* beach (Palmaria Island), supplied by debris of thecliff slopes.
– *Spiaggia di Cala del Pozzale (Isola Palmaria), seppellita dai detriti provenienti dai versanti della falesia.*

The sea floor slopes more gently here and is characterized by two morphological elevations of the bedrock, to a depth of 5 and 10 m at about 150 m from the shore, linked to the tectonic style of this area.

A small marine abrasion platform is observable at the bottom of the cliff in the northern part of *Cala della Fornace*; it overlies calcareous subhorizontal bedding surfaces. In addition to causing constant cliff retreat, the convergence of swells from the S and SE, particularly against the southeastern *Punta della Mariella* sector, has contributed to the formation of a number of sea caves.

At *Punta della Scola*, on the northeastern tip of Palmaria Island, traces of several level surfaces are identifiable. They are found at elevations of 15-40 m and despite the considerable reworking of the original morphology brought about by human activity, their genesis can be traced back to marine erosion.

The presence of several notches at about 10 m ASL on the cliffs in the southern part of the island of Tino (DEL SOLDATO, 1995) provides evidence of sea levels during the Tyrrhenian stage (Silenzi & *alii*, 2004). Beach deposits found in the *Grotta Riparo del Pozzale* at 0.6 m below current sea level also mark an ancient sea level attributable to the Roman period (CHELLI *et alii*, 2005).

Reflecting the bedrock structure, the northern sectors of the three islands present stretches with rock cliffs of a few meters in height, alternating with slopes that are much gentler and bordered seaward by small stretches with accumulated sediments locally, consisting of narrow gravelly-pebbly beaches, sometimes with boulders, alternating with stretches with rock cliffs just a few meters high. Human intervention that has modified the morphology of the coast consists in a number of fill projects along the shores and coastal defence works.

4.4. – Man-made landforms

Landforms that have been affected by anthropic activity on the islands are mainly related to mining and quarry activity, agricultural terracing and military installations. They have led to significant changes in the morphology.

4.4.1. – *Quarry and mining activities*

There are at least ten Portoro marble quarries on the islands of Palmaria and Tino. They are located along the coastal areas facing SW and are now all abandoned sites. For the most part, these deposits consist of the *macchia larga* variety; initially, the deposits were worked in opencast quarries and exploitation continued later using the stope pillar technique. Some of these quarries still bear many visible signs of this historical activity (Cimmino *et alii*, 2006).

Exploitation of the underground deposits began by means of the excavation of an exploratory tunnel using a pick and sledgehammer. More specifically, in the only Portoro quarry existing on the island of Tino, it is possible to observe examples of "*anime*", or vertical pits made at the ends of the blocks, where the quarrymen in charge of block-cutting would place themselves.

On the island of Palmaria, several iron rods can be seen inserted in the rock at the quarry overlooking the *Caletta* inlet. A penetrating pulley system is assembled on the rods to drive the helicoidal wire, which was still used in recent times to cut Portoro marble.

There are recognizable signs of the use of explosives in the quarry located at *Capo dell'Isola,* although blasting was used only to free blocks that had already been cut. Here, there is also a small tunnel that was used to store the explosives.

In the *Cala Grande* area, the old sledge route (*via di lizza*) can still be seen. The pathway was used to lower the blocks of marble on sledges down to the sea. Wooden beams of oak, holm oak or beech were soaped or greased, and placed under the sledge, which the men then guided with the force of their own strength or with the help of hand-powered winches. Hemp ropes were wound around stakes located along the route in order to control and navigate the descent (fig. 9). The blocks were then loaded onto the transport vessels by means of a *bigo*, or derrick; two of these hoisting devices are still present in the southern part of Palmaria Island, and there is another on Tino Island.

Fig. 9 – *Cala Grande* sledge route (Palmaria Island).
– *Sentiero a Cala Grande (Isola Palmaria).*

The southern part of Palmaria Island is also the location of stone buildings used as shelters for the quarrymen (fig. 10).

As concerns the utilization of the marble, a monolithic Portoro marble column discovered in the 1930s during the excavations of Luni and now housed in the La Spezia Museum of Archaeology is evidence of the interest the Romans had in marble as a material for ornamental use and for use in construction, given the utilization, again in Luni, of small blocks for the amphitheater and slabs used to build the *cardo maximus* and *cardo decumanus* (Del Soldato & Pintus, 1985).

Fig. 10 – Panoramic view of the Portoro marble quarry situated at the *Capo dell'Isola* (Palmaria Island).
– *Panoramica della cava di marmo di Portoro situata a Capo dell'Isola (Isola Palmaria).*

In the 12th century, the Genoese made ample use of Portoro to build defense works and for construction of the impressive cathedrals and magnificent villas along the Ligurian coast (PANDOLFI, 1971).

In any case, it was mainly during the Renaissance period that Portoro marble was to see its most important application, that is, in architecture. In fact, it was during this period that the Genoese Senate granted the concession to the sculptor Domenico Casella for the extraction of marble in the region under the jurisdiction of the Podestà of Portovenere (MARCHI, 1994).

However, according to CASELLI (1914), the credit for having opened new and old quarries, also on Palmaria island, should actually be given to a sculptor from Sarzana, Giovanni Morello, for in 1600 signed a contract with the Olivetan monks of the *Santuario delle Grazie*, owners of the island (MORELLO, 1626*)*. The very first blocks extracted from the island's quarries were used for the baptistery of the Church of S. Maria in La Spezia and for the palace of the *Marchesi Castagnola*, and Portoro was used later to embellish the churches of the Jesuit Fathers in Palermo and Genoa (CIMMINO *et alii*, 2003).

There are many later reports regarding the Portoro marble quarries: at the end of the 18th century on the occasion of a visit made by Lazzaro Spallanzani, the scientist and philosopher, to see the numerous quarries on the islands, and in the early 19th century when, upon conclusion of the special mission assigned by Napoleon I to Professor Pierre Cordier, Chief Inspector of the Mine Corps, the latter gave an account of the deposits of ornamental stone existing in the area of La Spezia, among which he cited two particularly important quarrying sites on the island of Palmaria (CAPPELLINI, 1864; 1902).

In the 19th century, CAPPELLINI (1864) provided an inventory and reported on the geographical distribution of the thirty quarries existing in the La Spezia area. One quarry is listed for Tino Island and five for Palmaria Island, all active quarries. Among these, the quarry directly facing Portovenere was named *Cava Carlo Alberto*, to commemorate the King of Sardinia's visit on October 2, 1838.

Extraction of the black marble continued on the islands in the 20th century with alternating periods of good and bad fortune. In the early 1900s, exploitation was quite substantial. Then, at the end of the 1930s the entire Portoro marble industry experienced a crisis (GIACHINO, 1930), with partial recovery only after World War II. In the decades that followed, owing to operative difficulties hindering continuation of further exploitation of the deposits, some of which were nearing depletion, and owing to environmental protection restrictions, quarrying gradually decreased and came to an end in the early 1980s: the last site active was located at *Capo dell'Isola* (fig. 10).

There are also numerous limestone quarries on Palmaria Island. They are mainly situated along the coast and are currently no longer in use. These quarries vary in size, ranging from small borrow pits to large amphitheater-like quarries that have supplied thousands of cubic meters of material.

On the basis of the characteristics of the limestones in terms of stratigraphy, chemical composition and fracturing of the various deposits, the extracted material was utilized to produce lime or the blocks were used to construct offshore structures, above all, La Spezia's outer breakwater.

4.4.2. – *Agricultural terraces*

As in the rest of Liguria, vast sectors of the islands of Palmaria and Tino have been terraced for agricultural use. The dry stone walls made of ashlar of varying dimensions and of local origin, sustain debris that have been leveled in order to obtain level terraces on steep slopes. It has been observed that these man-made terraces are situated on slopes characterized by significant debris covers, prevalently on marly limestones, whereas it is much more unlikely to find terraces built on dolomites, also because of the steepness of such slopes.

A significant example of dry stone walls built with marly limestone ashlar of various dimensions, shapes and dressing, and perfectly laid, can be observed on the southwestern slope of the *Fortezza*, and also in the natural amphitheater behind the *Seno del Terrizzo* inlet. The terraces that are recognizable on the northeastern slope of the island of Tino (DEL SOLDATO, 1995) - part of which have witnessed the effects of geomorphological instability phenomena - are interesting also in relation to the buildings erected in the early Middle Ages by the Olivetan monks. The terraces, an effective defense against soil erosion, are of great environmental value in terms of their structural characteristics, state of preservation, the extension of the area involved, and the modeling of the slopes themselves. They represent part of our cultural and historical heritage, as they continue to stand as evidence of the efforts of humankind to adapt areas for agricultural use.

4.4.3. – *Military structures*

The last aspect that is related to anthropic morphogenesis on the islands concerns military structures and activity on the island of Palmaria and on Tino Island, starting mainly at the end of the 19th century. In fact, fortifications such as the *Fortezza*, *Forte Cavour* and *Forte Umberto I* required the leveling of extensive surface areas and quarries to be opened to supply the necessary stone. In addition to the construction of landing places, especially in *Seno del Terrizzo*, but also in *Seno del Pozzale* and on Tino Island, landfill projects were also carried out.

One last aspect is less evident, but equally important in terms of modification of the environment. It involves the numerous rapid transit tunnels, passing through extensive stretches of land on both of the larger islands.

5. – GEOTOURISM

Based on the geological, geomorphological and environmental aspects described above, geotourist map of the Palmaria islands was prepared to promote an understanding of the phenomena and to valorize them, broadening utilization options to include various types of excursions based on educational, scientific, sports-oriented, cultural/tourist interests (fig. 11).

The main geosites are marked using specific symbols. Those related to cultural geomorphology have been given particular attention, as concerns the network of hiking trails on Palmaria Island (as yet public access is not permitted on Tino Island because it is a military zone). The hiking paths were subdivided according to difficulty, using a simplified scale. Then, any natural hazards that could affect hikers along the paths were marked; these hazards are often associated with particular weather conditions. Any elements involving vulnerability in connection with the path characteristics were also marked.

Among the geological features on Palmaria Island, we note the significant outcrops of Portoro at *Capo dell'Isola*, at the *Carlo Alberto* quarry (*Befettuccio*) and in the *Cala Grande* inlet (fig. 12).

These are geosites that have been affected by significant exploitation, even in the recent past. Among the geomineral features, besides the various Portoro marble quarries, which have been subdivided into open-cast or underground quarries, the quarry fronts at *Punta della Ziguella* and in the *Seno del Terrizzo* inlet are also indicated; they are often important in terms of their educational value. Among the numerous geomorphological features, above all, we note the magnificent cliff in the southwestern sectors of the islands, a typical example of the evolution of a stretch of rocky coast with carbonate cliffs (figures 13, 14), but also the various beaches tucked into the *Pozzale*, *Fornace* and *Terrizzo* inlets, as typical examples of pocket beaches.

On the slopes above *Cala Grande* and the *Caletta* inlet, hikers walk through cemented scree slope deposits, which testify to ancient gravitational phenomena attributable to climatic conditions differing from current conditions. In addition, the geosites of speleological value appear to be significant; among these we note the karstic caves such as the *Grotta Azzurra* and the *Grotta dei Colombi*, which present important traces of changes in sea level, as well as traces of the presence of man in the Prehistoric Age.

As regards the dense trail network created on the island of Palmaria, we note that several trails present difficulties in connection with sharp steepness, unstable or slippery ground, high steps, and/or narrow paths; among these, we find the trail *dei Condannati*, which climbs up along the northern ridge of the *Batteria Semaforo*, and the one passing by the entrances to the underground quarries along the stretch between *Capo dell'Isola* and *Cala Grande*.

Several geomorphological hazards 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, possible triggering of debris flows and lastly, hazards connected with strong sea storms, particularly from the SW and SE. All of these hazards can easily become geomorphological risks, depending upon the tourist influx, particularly when little or poor knowledge of natural phenomena is a component, and extreme weather conditions come into play at the same time (BRANDOLINI *et alii*, 2004).

The first trail departs from *Terrizzo* and heads towards *Punta della Scola*. The first important stop is at the fort, *Fortezza del Mare*, now a maritime museum. Visitors then reach *Forte Cavour* via the steep *Sentiero dei Condannati* and then visit the environmental education center at the Batteria Semaforo at the top of the island. A paved road is used to return back to *Terrizzo*.

The second trail route is more difficult, with a higher level of tourist vulnerability. *Pozzale* is the departure point and from there, the trail heads towards *Capo dell'Isola*, where a first stop is possible at the opencast quarry. The trail then continues up a steep climb over the waste due to quarry activities (*ravaneto*) to the mouths of various underground sites of interest at the *Caletta* and *Cala Grande* inlet. The path then continues towards the *Batteria Semaforo* and abruptly descends down to the locality of *Befettuccio*, where the impressive *Carlo Alberto* quarry is found; *Terrizzo* wharf is then reached, just a short distance from there.

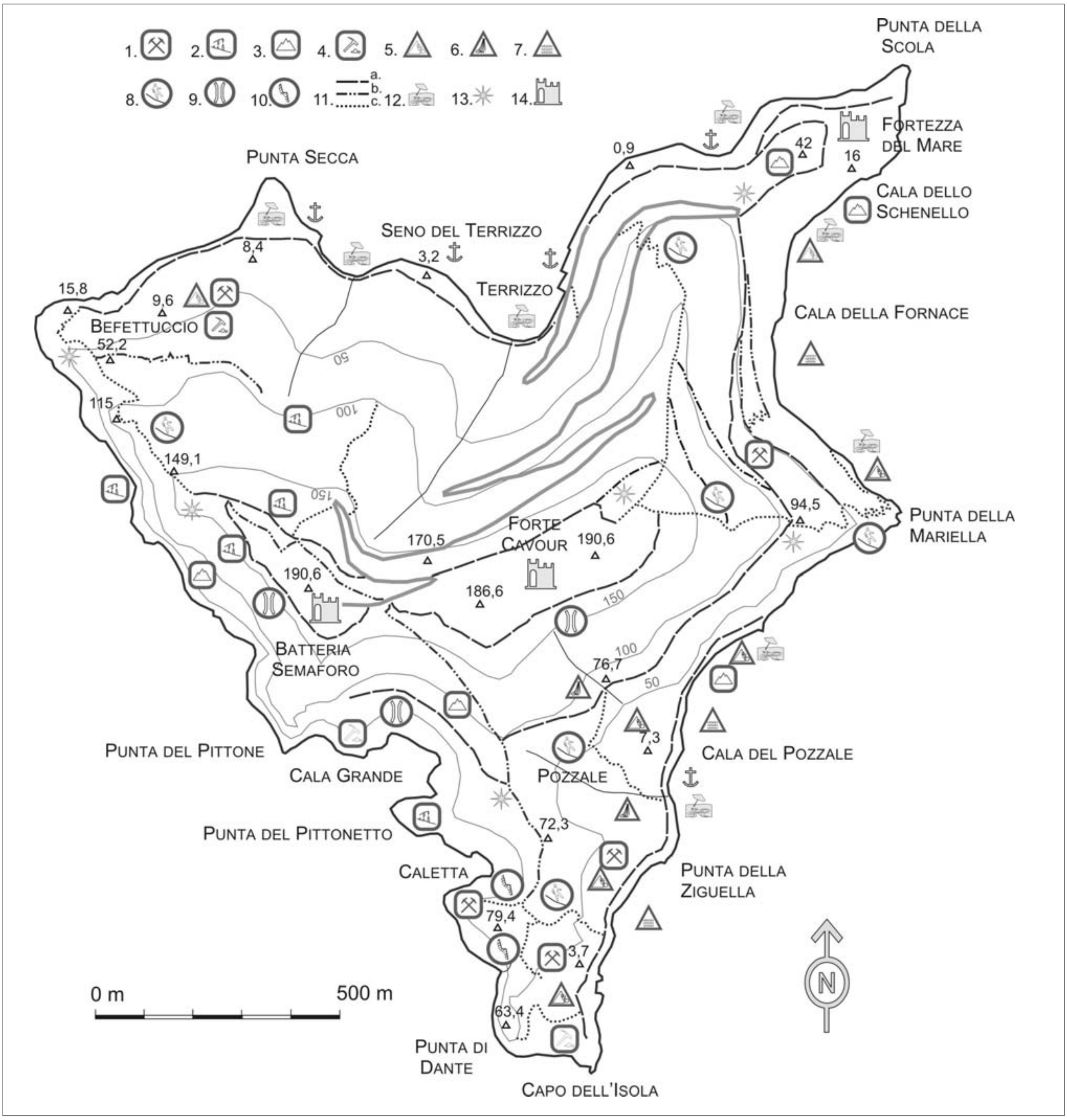

Fig. 11 – Geotourist map of Palmaria Island. Legend: GEOSITES – 1. Geomine; 2. Karstic; 3. Geomorphological; 4. Geological; GEOMORPHOLOGICAL HAZARDS – 5. Rock fall; 6. Debris flow (associated with heavy rainfall); 7. Sea storm; TOURIST VULNERABILITY (hiking path features) – 8. Slippery or rambling track; 9. Narrow trail; 10. Exposed path; 11. Track steepness: a. low; b. medium; c. high; OTHER GEOTOURISTIC EMERGENCES – 12. Beach; 13. Geo-panoramic point; 14. Military structures.

– Carta Geoturistica dell'Isola di Palmaria. Legenda: GEOSITI – 1. Geominerari; 2. Carsici; 3. Geomorfologici; 4. Geologici; PERICOLOSITÀ GEOMORFOLOGICHE – 5. Crolli; 6. Debris flow (in corrispondenza di piogge intense); 7. Burrasca; VULNERABILITÀ TURISTICA (caratteristiche dei sentieri escursionistici) – 8. Tratto sdrucciolevole o sconnesso; 9. Tratto stretto; 10. Tratto esposto; 11. Pendenza del tratto: a. bassa; b. medio; c. alta; ALTRE EMERGENZE GEOTURISTICHE – 12. Spiaggia; 13. Punti geo-panoramici; 14. Strutture militari.

6. – FINAL REMARKS

The islands of Palmaria, Tino and Tinetto constitute the natural seaward extension of the Portovenere Promontory and represent a landscape of exceptional value that simultaneously embodies attributes of a scientific, cultural, socioeconomic and scenic nature.

Over an overall surface area of slightly less than 2 km^2, it is possible to observe examples of morphological modeling linked to marine erosion, gravitational phenomena, running waters, karstic processes and lastly, to human activities. Many aspects of a scientific nature, but also of educational value and interest at an international level, allow for the observation of models of geomorphological evolution and the investigation of paleogeomorphological evidence related to various climatic stages of the past. In this context, the presence of settlements linked to prehistoric man takes on particular significance and relevancy.

The definition of the historical-cultural value of this area is linked to the ancient monasteries on the three islands, communities that certainly contributed to the atmosphere of spirituality of the islands. However, this value is especially linked to the Portoro marble quarries, which had been exploited as far back as the Roman period. Lastly, the presence of 19th-century military forts also contributes to the valorization of the landscape in historical and architectural terms.

Fig. 12 – Cliff between *Punta di Dante* and *Caletta* (Palmaria Island): note the entrances to the underground Portoro marble quarries in the upper part, the entrance to the *Grotta dei Colombi* in the center, and several bedding-plane sea caves below.
– Falesia tra Punta di Dante e Caletta (Isola Palmaria): da notare gli ingressi alle cave di marmo sotterranee di Portoro nel parte superiore, l'ingresso alla Grotta dei Colombi in centro e numerose grotte lungo i piani di stratificazione nella parte inferiore.

Fig. 13 – Tinetto Island.
– Isola di Tinetto.

Fig. 14 – Rock fall phenomena on southern cliff of Tino Island.
– Fenomeni di crollo nella falesia meridionale dell'Isola di Tino.

In more recent times as a result of the development of seaside vacation activities, the coast has taken on significant socioeconomic value with the creation of bathing establishments and accommodation facilities. Appreciation of all of the features described above is an option made possible through the creation of some guided tour routes, defined on the basis of their geodiversity value: a trail route on the island of Palmaria is based on sites linked to the utilization of stone in architecture, including both civil and military works, while another trail route is based on historical and geomine sites.

Owing to its very small size, the guided trail route through Tino Island covers all of the aspects described above, particularly those related to the geomorphosites and the monastery.

A double looped route along the coast allows for full appreciation of the geomorphological features specific to these islands, particularly concerning the coastal modeling processes. The route starts from Portovenere; first the waters separating Portovenere and Palmaria are crossed, offering an immediate view of the high cliff with the quarry sites at the top and the sea caves at the base. Then the route continues through the channel between Palmaria and Tino, to circle the two smaller islands, offering a direct comparison of the different morphology characterizing the western and eastern coasts. The last part of the route follows the eastern coastline of Palmaria, to observe the *Pozzale* and *Fornace* inlets, and then heads back to Portovenere after reaching *Punta della Scola*.

In conclusion, the islands of Palmaria, Tino and Tinetto present an intrinsic scenic component, while also constituting a preferential observation point with reference to the southwestern sector of the Portovenere promontory. Owing to all of these aspects, the archipelago can be considered an important cultural and scenic asset, an asset that fully justifies its protection as part of the Natural Park of Portovenere, as well as its valorization as part of our World Heritage.

Acknowledgement

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figg. 8

Geomorphological and Geotourist Maps of the Upper Tagliole Valley (Modena Apennines, Northern Italy)

Carte geomorfologica e geo-turistica dell'alta Valle delle Tagliole (Appennino Modenese, Italia settentrionale)

CASTALDINI D. (*), VALDATI J. (**),
ILIES D.C. (***)

ABSTRACT – This paper considers the geomorphological map and the criteria and methodology used for the production of a geo-tourist map of the upper Tagliole Valley – which is located in the Frignano Park (high Modena Apennines, Italy). These documents, at the 1:10,000 scale, elaborated by means of ArcView GIS computer programme, should help to explain the landscape of this area to tourists. The Regional Technical Map (CTR) of the Emilia-Romagna Region was used as the topographic basis for their elaboration.

The geomorphological features of the study area are represented in detail in the geomorphological map. The landforms and deposits of the upper Tagliole Valley, characterised by arenaceous rock types, may be grouped according to the following systems or groups of morphogenetic factors and processes: structural landforms, glacial landforms and deposits, cryogenetic landforms and deposits, landforms and deposits due to running waters, slope landforms, deposits due to gravity, anthropogenetic landforms.

The geo-tourist map was derived (with appropriate simplifications and integrations) from the geomorphological map. The geo-tourist map combines the most evident geological-geomorphological features (e.g. bedrock, hydrography, glacial landforms and deposits, scarps, ridges, saddles, waterfalls) – which can be observed and recognised even by non-experts – with basic tourist information (e.g., parking places, excursion trails, refuges, picnic areas). The geo-tourist map is the characterising document of a tourist-environmental map of the upper Tagliole Valley.

This article proves that geomorphological research can effectively contribute to the implementation of documents and maps useful in the field of tourism.

KEY WORDS: Glacial landforms, Geomorphological map, Geo-tourist map, Tagliole Valley, Modena Apennines.

RIASSUNTO – Il presente lavoro descrive la carta geomorfologica e i criteri e la metodologia applicati per la realizzazione della carta geo-turistica dell'alta Valle delle Tagliole compresa nel Parco del Frignano nell'Alto Appennino Modenese. Questi documenti, a scala 1:10.000, elaborati utilizzando come strumento tecnologico il Sistema Informativo Territoriale ArcView e come base topografica gli elementi della Carta Tecnica Regionale della Regione Emilia Romagna, sono stati realizzati per aiutare il turista nella lettura e nella comprensione del paesaggio dell'area di studio.

Gli aspetti geomorfologici di dettaglio sono rappresentati nella carta geomorfologica elaborata secondo i criteri classici che prevedono l'indicazione degli aspetti morfogenetici, morfodinamici e morfometrici. In particolare, nell'alta Valle delle Tagliole, dove affiorano esclusivamente rocce arenacee della Formazione del Macigno (Oligocene medio/superiore-Miocene inferiore?), sono state riconosciute forme e depositi appartenenti ai seguenti sistemi di fattori e processi morfogenetici: forme strutturali, forme e depositi glaciali, forme e depositi crionivali, forme e depositi per acque correnti superficiali, forme e depositi gravitativi di versante, forme antropiche.

Nella Valle delle Tagliole il turismo invernale non è sviluppato come in altri settori ma è invece frequentata da escursionisti specialmente nel periodo estivo per l'affascinante paesaggio. Nella valle si rinvengono infatti gli ampi circhi glaciali del M. Rondinaio e del M. Giovo e i laghi Santo, Baccio, Torbido e Turchino.

La carta geo-turistica è stata derivata (con appropriate semplificazioni ed integrazioni) dalla carta geomorfologica e coniuga la rappresentazione dei più evidenti aspetti geomorfologici (es. roccia affiorante, idrografia, forme e depositi glaciali, crinali, selle, scarpate, cascate), che possono essere osservati e riconosciuti anche da persone non esperte,

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con l'indicazione delle informazioni turistiche fondamentali (es. parcheggio, sentieri del Club Alpino Italiano, aree di sosta attrezzata, rifugi). La carta geo-turistica è il documento caratterizzante della carta turistico-ambientale dell'alta Valle delle Tagliole realizzata per il Parco del Frignano.
Il presente lavoro rappresenta un'ulteriore testimonianza di come la ricerca geomorfologica possa efficacemente contribuire alla realizzazione di documenti utilizzabili nel settore turistico.

PAROLE CHIAVE: Forme glaciali, Carta geomorfologica, Carta geo-turistica, Valle delle Tagliole, Appennino Modenese.

1. – INTRODUCTION

This paper describes the geomorphological map and the criteria and methodology used for the production of a geo-tourist map of the upper Tagliole Valley, which is located in the high Apennines of Modena Province, Italy (fig. 1). The geo-tourist map of the upper Tagliole Valley was implemented following the example of the geo-tourist map of the Natural Reserve of Salse di Nirano which is located at the Modena Apennine foothill (BAROZZINI *et alii,* 2004; CASTALDINI *et alii,* 2005b). These "original" geo-tourist maps are part of the initiatives enterprised by public boards for improving the knowledge, utilisation and appraisal of the environment of protected areas.

The upper Tagliole Valley is located in the Frignano Park (the term "Frignano" derived from the ancient pre-Roman people of "Liguri Friniati"), or Park of the High Modena Apennines, which was established in 1988 by the Emilia-Romagna Region.

This Park safeguards a considerable portion of the Modena Apennines in the proximity of the Tuscan-Emilia watershed and stretches over 15.791 ha. The highest peaks of the Northern Apennines are found in this area such as Mt. Cimone (2165 m a.s.l.), Mt. Giovo (1991 m) and Mt. Rondinaio (1964 m). The protected area is subdivided into zones with different levels of conservation (the actual Park covers about 9.000 ha and the so-called pre-Park about 6.000 ha) and is managed by a consortium of public boards whose administrative centre is in Pievepelago. The Park's protected zones are located in the municipalities of Fanano, Sestola, Montecreto, Riolunato, Pievepelago, Fiumalbo and Frassinoro.

2. – GEOGRAPHICAL SETTING

The Tagliole Valley is located on the Po Plain side of the Northern Apennines, within the catchment of the Panaro River, in proximity of the main watershed (fig. 1). This valley, located in the municipality of Pievepelago, is one of the most relevant valleys of the Apennines of Modena. The valley takes its name from the Tagliole Torrent which flows through it from south to north; the main hamlets are Le Tagliole, Ronchi and Rotari. In this valley winter tourism is not developed as much as in other areas of the Modena Apennines like, for example, at the Mt. Cimone area. Hikers visit frequently the valley, especially in the summer, because of several lakes in the area.

Climate is considerably influenced by several geographical factors, among which the altitude and location near the watershed (PIACENTE, 1992; SERVIZIO METEOROLOGICO REGIONE EMILIA-ROMAGNA, 1995). Below 1000 m a.s.l., the average annual temperature is 10 °C, whereas above this elevation it progressively decreases to 6 °C. Annual precipitation ranges from 1250 mm in the

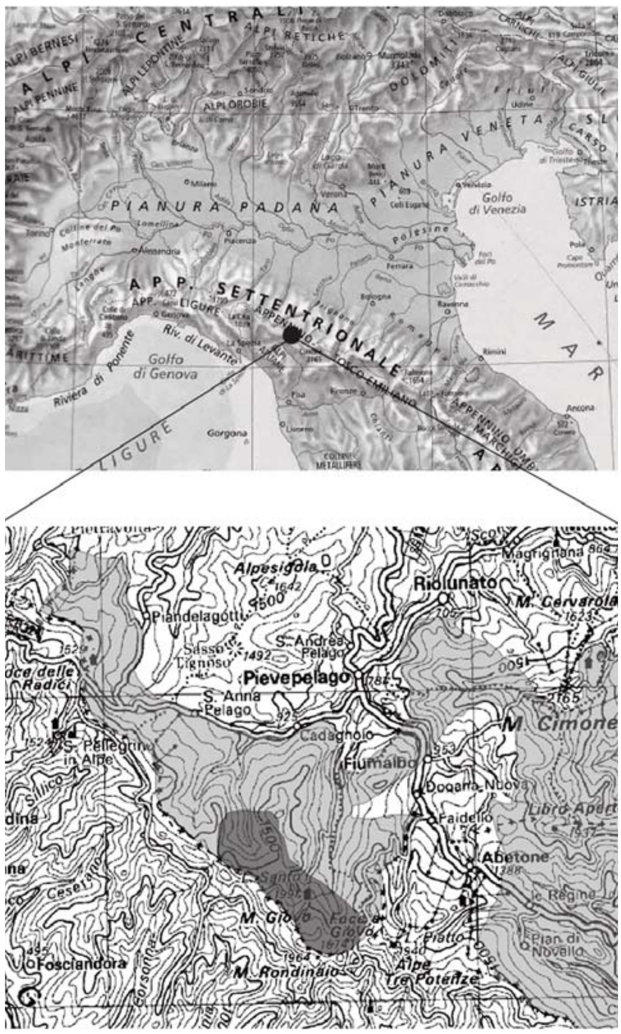

Fig. 1 – Location of the upper Tagliole Valley (Frignano Park, Modena Apennines). Dark grey: study area; Light grey: Frignano Park area.
– *Ubicazione dell'alta Valle delle Tagliole (Parco del Frignano, Appennino Modenese) Grigio scuro: area di studio; Grigio chiaro: area del Parco del Frignano.*

lower part to over 2000 mm in the upper part. The annual mean values for the most rainy days range from 80 mm up to 125 mm and the ground is snow-covered for about 100 days a year.

3. – GEOLOGICAL SETTING

The Modena Apennines belong to the Northern Apennines which are a fold and thrust belt resulting from a complex and multi-staged evolution. The geological structures of the chain are quite complicated (e.g. see BOCCALETTI *et alii,* 1981, CERRINA FERONI *et alii*, 2002).

The main geological units forming the Modena Apennines include (BETTELLI *et alii,* 1989):

1) Tuscan Units, made up of Tertiary siliciclastic deep-water turbidites, continuously cropping out along the Apennine chain's axis.

2) Ligurian Units consist of deep-sea oceanic sediments including Jurassic ophiolites followed by thick sequences of late Cretaceous to middle Eocene calcareous or terrigenous turbidites.

3) Mainly terrigenous epi-Ligurian sequences of Middle Eocene to Late Messinian, age unconformably resting on the deformed Ligurian Units. The epi-Ligurian sequences and the Ligurian Units are exposed in the mid-Apennines.

4) The belt of Plio-Quaternary marine terrigenous deposits unconformably overlying the Ligurian Units and the epi-Ligurian sequence cropping out at the Apennine margin and dipping under the alluvial deposits of the Po Plain.

In particular, the Macigno Formation (belonging to the Tuscan Units) and the Mt. Modino Complex (belonging to the Ligurian Units) crop out in the Tagliole Valley (PLESI *et alii,* 2002). The Macigno Formation (Mid-LateOligocene-Early Miocene?) crops out in the study area; it is made up of sandstones with interbedded thin layers of fine-grained sandstones, siltites and shales. In three different sites, polygenic breccias (Late Oligocene-Early Miocene?) composed of grey and black shales, with grey calcareous marlstone blocks and strongly tectonised multicoloured shale beds and calcareous marlstones with dark shales interbedded, are tectonically found in-between the Macigno Formation and Mt. Modino Complex.

The latter crops out in the northern portion of the valley (Late Oligocene-Early Miocene?). In its lower portion, this formation is composed of multi-coloured shales, marlstones, silty marlstones and siltstones (belonging to the Argilliti di Fiumalbo Formation), followed by thick layers of mid-coarse to fine grained sandstone, with intercalations of marly clays (belonging to the Arenarie di Mt. Modino-Mt. Nuda Formations).

4. – PREVIOUS GEOMORPHOLOGICAL STUDIES AND GEOMORPHOLOGICAL SETTING

On the whole, the Northern Apennines are a NW-SE oriented mountain chain. In the study sector, though, the main ridge does not follow a linear trend but, in many places, the ridge is segmented and shifted to the east, along a series of reliefs aligned in the same direction.

The transversal section of the Apennine chain is asymmetrical, with a rather steep and rugged Tyrrhenian side, since it was modelled on dip-upstream strata, whereas the Adriatic one is much smoother and regular since it was shaped on dip-downstream strata.

The geomorphological studies in this sector of the Northern Apennines have mainly dealt with landforms linked to glacialism. The first investigations on glacialism began at the end of the 19th century.

For instance, DE STEFANI (1887) and SACCO (1893) described moraine deposits, valley lakes and glacial cirques. On the other hand, PANTANELLI (1886) tried to explain the Apennine morphogenesis by means of simple slope processes, even though he admitted the existence of striated pebbles and landforms of uncertain origin.

In the first half of the 20th century many authors produced other mainly qualitative contributes (e.g. DESIO, 1927; SESTINI, 1936; SACCO, 1941; LOSACCO, 1948, 1949a).

LOSACCO (1949b) proposed a new synthetic description of the Quaternary glaciations in the Northern Apennines. Some decades later, the same Author carried out an updated and well organised paper on the same topic (LOSACCO, 1982). This Author is perhaps the only one who provided us with a rather complete and accurate overview of glacial traces in the Northern Apennines.

During the past decades, FEDERICI & SCALA (1966), FEDERICI (1977, 1980), GRUPPO RICERCA GEOMORFOLOGIA C.N.R. (1982), FEDERICI & TELLINI (1983), BERTOLINI & TREVISAN (1984), CARTON & PANIZZA (1988) and CASTALDINI *et alii,* (1998) carried out several investigations on glacial landforms in this sector of the Apennines. Some of them significantly contributed to the knowledge of the geomorphological processes and the methods for reconstructing the Apennine glacial chronology. In fact, in the preceding papers, the glacial traces of the Northern Apennines were always attributed to a single glaciation event, correlated to the Alpine Würm I. Since the late 1970s many authors reported glacial deposits whose location, morphology, lithology and weathering rate could be explained only by previous glaciations

(Federici 1977, 1980; Gruppo Ricerca Geomorfologia C.N.R., 1982; Federici & Tellini, 1983). The lack of traces of glacial periods older than the Würm in the high Modena Apennines may be explained with the hypothesis that they might be obliterated by erosional processes linked to the considerable uplift of this sector occurring from the Mid-Late Pleistocene and continuing to date (Bartolini, 1999).

Jaurand (1999) reviewed the knowledge of the glacialism in the Apennines by trying to attain a more accurate outline of both the last glacial period (maximum of the recent Würm and retreat phases) and the traces of more ancient glaciations.

In this sector of the Nothern Apennines the evidence of glacial traces is represented by both erosional (glacial cirques, overdeepened hollows, *roches moutonnées*) and depositional forms (moraines, moraine ridges), containing locally small lakes or impoundments. According to Castaldini *et alii,* (2002b) the most accepted origin (about 65%) of the lakes of the high Emilia-Romagna Apennines is due to glacial processes.

Landforms resulting from periglacial processes (e.g. block streams, block fields, gelifluction deposits etc.) and from the action of surface running water (e.g., gullies, alluvial and colluvial fans, debris flow lobes, waterfalls etc.) are also quite common.

The most typical slope landforms, resulting from physical weathering of arenaceous rocks, are scree slopes and talus cones. The watershed areas are locally characterised by double ridges, trenches, concavities and reverse slopes which have been interpreted in some cases as the surface expression of "Deep-seated Gravitational Slope Deformations" and, in other cases, as rock slides.

Anthropogenetic landforms mainly linked to winter tourism, which has been particularly accentuated in the past decades, are rather widespread in some areas of the Northern Apennines.

Among the papers of the past decades containing geomorphological data on the Tagliole Valley the following should be quoted: Alagna *et alii* 1987, Mazza & Panizza (1988), Bortolotti (1992), Ferrari & Panizza (1992), Panizza (1992), Bertacchini *et alii* (1999), Castaldini (2003).

In particular, Mazza & Panizza (1988) studied the geomorphology of the entire Tagliole valley and published the first geomorphological map of this territory. The topographic basis for its elaboration was the Istituto Geografico Militare (IGM) Map (1: 25.000 scale, updated in 1947).

Bertacchini *et alii,* (1999) described the main features of the Tagliole Valley within the framework of an inventory of the geological heritage of the Province of Modena (whose elements are defined, according to the various authors, as "Earth Sciences Sites", "Geological Assets", "Geotopes", "Geosites" or "Geomorphosites"; see Reynard, 2004).

Castaldini (2003) illustrated the geomorphological characteristics of the Tagliole Valley in a guide on the morphology of the Apennines of Modena. In this work, the orographic setting of the valley is effectively shown by a Digital Elevation Model (DEM) which was computer-elaborated through the transformation of altimetric data of the Regional Technical Map (CTR) of the Emilia-Romagna Region (5 m equidistance contours) into a Triangular Irregular Network (TIN).

5. – STUDY METHODOLOGY

Geomorphological and geo-tourist maps, at a 1:10,000 scale, were produced by means of ArcView GIS computer programme to provide information on the physical landscape of the upper Tagliole Valley. The Regional Technical Map (CTR) of the Emilia-Romagna Region was used as a topographic basis for their elaboration.

The detailed morphological features of the study are illustrated in a geomorphological map (see enclosed map), produced from bibliographic research, analysis of aerial photographs and satellite images from various periods (1955, 1973, 1994, 2000 and 2003) and field survey. In implementing this map the legends used for recent geomorphological maps were applied (e.g., Castaldini *et alii*, 1998; Pasuto *et alii*, 2005).

The ages shown on the geomorphological map result from bibliographic data and field survey, since no chronological determination was conducted on deposits and related landforms. From a morphodynamic standpoint, landforms and deposits are classified as active (i.e., active processes during field work), or inactive (i.e., not processes tangible during the period field survey was carried out). Obviously, structural and anthropogenetic landforms were excluded from these distinctions.

At a further step of research, a geo-tourist map was derived from the geomorphological map (see enclosed map). As underlined in Castaldini *et alii,* (2005b), a geo-tourist map is a thematic map which focuses on a particular aspect and is, consequently, directed to specific users. First of all, in the preparation of a thematic map, the data set to be used should appropriate to a specific language and mapping system (Papotti, 2002). Therefore, a geo-tourist map combines the most evident geological and geomorphological aspects with basic tourist information. The legend consists of two clearly distinct categories one with symbols representing the geomorphological characteristics and a second showing symbols concerning to tourist information.

5.1. – Geomorphological Map of the Upper Tagliole Valley

The general morphological context of the upper part of the Tagliole valley is provided by the DEM elaborated by Castaldini (2003) (fig. 2). The Torrent Tagliole flows across this valley from south to north and from 1400 to 1050 m of altitude. On the left hand-side of the stream, at the head of the valley, the wide glacial cirques of Mt. Rondinaio (fig. 3) and Mt. Giovo are quite evident.

The significant difference in elevation between the highest peaks and the valley floor reflexes the high relief energy of this valley. Glacial deposits and moraine ridges occurs at various altitudes; glacial landforms have caused the formation of lacustrine depressions and ponds owing to the barrage of runoff waters. Lake Santo, with its typical "bean-shaped" form, and Lake Baccio, a subcircular small impoundment, are of particular evidence and interest. The slightly inclined wide flat area at north-east of Lake Santo corresponds to a bedding surface. The landforms found on the valley's right-hand side are the result of slope processes.

Detailed information on the geomorphological characteristics of the upper Tagliole Valley are depicted in the geomorphological map (enclosed map). In particular, the study area is on the left hand-side of the valley and includes the northern slopes of Mts. Rondinaio and Giovo.

A comparison of the geomorphological map produced by Mazza & Panizza (1988) with the geomorphological map elaborated in this research, it comes out that the latter takes into account a smaller sector of the Tagliole Valley,which has a more recent topographic basis at a greater scale (1:10.000 scale, updated in 1988 vs. 1:25.000 scale, updated in 1947), and makes reference to legends used in recent geomorphological maps.

The landforms and deposits of the Tagliole Valley may be mainly classified according to the following systems or groups of morphogenetic factors and processes: glacial landforms and deposits, cryogenetic and nivation landforms and deposits, structural landforms, landforms and deposits due to running waters, slope landforms and deposits due to gravity, anthropogenetic landforms.

The hydrographic characteristics of the study area include perennials streams, lakes and ponds (distinguished in perennial and temporary) and springs. The main streams are Fosso del Lago Santo, Fosso del Lago Baccio and Fosso del Balzone, which are left hand-side tributaries of Torrent Tagliole and Rio delle Fontanacce which, in turn, is a right hand-side tributary of Rio Perticara.

The latter shows a SSE-NNW trend whereas the tributaries of the Torrent Tagliole have a SW-NE direction.

In the study area there are numerous springs, (e.g. Fonte Acqua Fredda, Fonte Ricca, Fonte Rondinara, Sorgente delle Fontanacce). They are located at the boundary between moraine deposits and the sandstones of the Macigno Formation. The latter is characterised by a lower permeability than the overlying deposits. In the summer, the flow rate of these springs is extremely low; usually less than 1 l/s due to the small feeding area of their catchments (Franchini, 1996).

The action of surface running waters is evident on slopes affected by rill wash, gullies, alluvial and colluvial fans, fluvioglacial and palustrine deposits and by waterfalls, V-shaped valleys and gorges found along the Torrent Tagliole tributaries.

The sandstones of the Macigno Formation are exposed in the upper Tagliole Valley showing a NNE trend monocline attitude, dipping 20° (fig. 3).

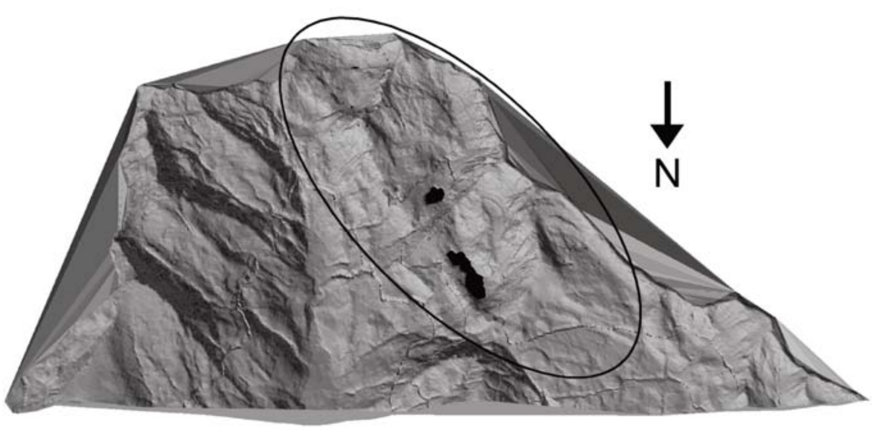

Fig. 2 – Digital Elevation Model (DEM) of the upper part of the Tagliole Valley (after Castaldini, 2003). On the left hand-side of the valley, on the northern slopes of Mts. Rondinaio (1964 m a.s.l.) and Giovo (1991 m), two well preserved twin glacial cirques have been modelled in the Macigno sandstones. At the bottom of the cirques, Lake Santo (1501 m), with its typical "bean-shaped" form, and Lake Baccio (1554 m), a sub-circular impoundment, are of particular evidence. Inside the circle, the study area.
– *Modello digitale del terreno della parte superiore della Valle delle Tagliole (da Castaldini, 2003). Sulla parte sinistra della valle, sui versanti settentrionali dei monti Rondinaio (1.964 m s.l.m.) e Giovo (1991 m), sono evidenti due coppie di circhi glaciali ben conservati modellati nelle arenarie della Formazione del Macigno. Sul fondo dei circhi, sono evidenti il L. Santo (1501 m), con la sua tipica forma a "fagiolo", e il L. Baccio (1554 m), a forma sub-circolare. Nel cerchio l'area di studio.*

Fig. 3 – The north-eastern cirque of Mt. Rondinaio shaped in arenaceous rock types of the Macigno Formation (Mid-Late Oligocene - Early Miocene?) showing a NNE trend monocline attitude, dipping 20°.
- Il circo nord-orientale del M. Rondinaio modellato nelle rocce arenacee del Macigno (Oligocene medio/superiore-Miocene inferiore?), che mostrano un'inclinazione a monoclinale verso NNE sui 20°.

The influence of the structural characteristics on slope morphology is relevant in all the study area where structural scarps are found and in the lower part of the northern slopes of Mts. Rondinaio and Giovo, where the slope inclination coincides with that of the strata, thus corresponding to structural surfaces. In addition, the higher erodibility of the clayey and silty intercalations determined the modelling of steps and reverse slopes upstream of which water-stagnation depressions and ponds were formed, afterwards filled by palustrine deposits. Also the tract of crests and watersheds have been considered as structural forms.

Faults and fractures are developed by morphological features such as alignments of trenches, saddles and altimetric discontinuities of ridges.

The head of the valley lies within the wide glacial cirques of Mts. Rondinaio and Giovo which are the most significant peaks found in the valley.

Trenches and reverse slopes occur in the upper portions of the north-western cirques of Mt. Rondinaio and Mt. Giovo. Trenches and reverse slopes were considered, for the first time, as the surface features of inactive rock slides which partially remodelled the edge of the cirques.

The favourable causes for triggering these rock slides might be:

i) Structural factors: the movements took place along layer joints, which correspond to lithological discontinuities (alternance of sandstones and pelites) or along the slope direction which coincides with the bedding of the Macigno Formation.

ii) Meteorological conditions: rainfall and water from snowmelt may lubricate the Macigno pelitic layers.

iii) Deglaciation: the withdrawal and final disappearance of glaciers, after the ice period corresponding to the Alpine Würm glaciation, determined a debutressing of the slopes which reacted in order to re-establish their pristine equilibrium conditions.

iv) High seismic activity: it is well documented by several earthquakes occurring in historical times in this sector of the Northern Apennines (e.g. BOSCHI *et alii*, 2000). Furthermore, the area investigated is next to Garfagnana, one of the most seismic areas of the whole Northern Apennines. In this context, the X degree M.C.S. scale earthquake which struck Garfagnana and Lunigiana on 7th September 1920 and the other ones exceeding the VII-VIII degree (1481, 1767, 1837, 1939) should be mentioned (see CASTALDINI *et alii*, 2002a).

Cirques and structural scarps show sheer, subvertical slopes which have undergone slope, cryogenic and running water processes. These scarps are therefore covered, in their lower part, by active or inactive scree slopes with talus cones and debris flow deposits (fig. 4). Many gullies developed along fracture lines and on these deposits. During the winter season these tracks are utilised also by avalanches which, in any case, do not leave significant traces in the landscape. In the lower part of the gullies, debris flow deposits and colluvial fans are found.

Rock steps and overdeepened hollows modelled by glaciers and filled by palustrine and/or lacustrine deposits, are found inside the cirques. Vast glacial deposits and numerous moraine ridges and arcs also occur at various altitudes, at the bottom of the cirques (fig. 5). They bear witness to the discontinuity of the glaciers' withdrawal, which occurred through some pause phases, after their Last Glacial Maximum expansion, when a glacial tongue occupied all the valley. Moraine deposits consist of heterometric clasts, locally very large boulders, with abundant matrix without depositional structures. Due to the barrage of runoff waters, the stadial moraine apparatuses have determined the formation of the perennial Lakes Santo (1501 m), Baccio (1554 m) and Turchino

Fig. 4 – Debris accumulation at the foot of the north-western slope of Mt. Rondinaio.
– Detriti al piede del versante nord-occidentale del M. Rondinaio.

Fig. 5 – Panoramic view of morainic arc and Lake Torbido (which is dry because it is an ephemeral lake) at the upper part of the north-eastern cirque of Mt. Rondinaio.
– *Panoramica dell'arco morenico e del Lago Torbido (senz'acqua in quanto temporaneo) nella parte superiore del circo glaciale nord-orientale del M. Rondinaio.*

(1613 m), plus other small lacustrine depressions which are now completely filled by palustrine deposits.

Lake Santo, with its typical "bean-shaped" form, is the largest lacustrine basin of the whole Modena Apennines; it covers an area of 58,100 m^2, a perimeter of 1259 m and a length of 550 m. Its maximum depth varies from 15 to 20 m. The lake occupies the bottom of the north-eastern cirque hollow of Mt. Giovo. The rocky threshold which contains the lake downstream is covered by moraine deposits up to 10 m thick. The glacial landscape is typical because of presence of erratic boulders and *roches moutonnées* (found near the southern sector of the lake). This lacustrine basin stretches in a NNW-SSE direction and was formed on a tectonic discontinuity. The origin of Lake Santo can therefore be considered as complex (fig. 6).

Lake Baccio is a shallow, sub-circular small lake: its diameter is about 200 m with a perimeter of about 500 m. The origin of the lake is clearly glacial since it is found at the bottom of the wide north-western cirque of Mt. Rondinaio and is barred downstream by a moraine arc cut through by its emissary stream. The shores are occupied by marshy vegetation. In its upstream part, a lacustrine delta is found. At the end of the 1980s a concrete dam was built to prevent the depletion of this small impoundment by the emissary stream.

Inside the glacial cirque on the north-eastern slope of Mt. Rondinaio, two small glacial lakes are found: Lake Torbido and Lake Turchino. Lake Torbido (1675 m) occupies a small glacial overdeepened hollow. Its shallowness and scarce water feeding condition the lake's flow regime which during the summer is often completely dry (fig. 5). Lake Turchino is a sub-circular perennial small impoundment some 1,5 m deep. It is dammed by a small moraine ridge, downstream of which a rocky threshold with *roches moutonnées* isolates an area with palustrine deposits. It is fed by small underground springs which confer it the characteristic of a permanent impoundment.

Inactive cryogenetic landforms and deposits are present, such as: several block fields present in many places in the upper part of the slopes, a block stream located inside the north-eastern cirque of Mt. Rondinaio and a well-preserved rock glacier found at the bottom of the north-western

Fig. 6 – Panoramic view of Lake Santo, the largest lacustrine basin of the Apennines of Modena. Its origin is considered complex: tectonic and glacial.
– *Panoramica del Lago Santo, il bacino lacustre più esteso dell'Appennino modenese. È di origine complessa: tettonica e glaciale.*

cirque of Mt. Giovo (fig. 7). This rock glacier (recognised for the first time by PANIZZA, 1992) is the only one in the whole study area. Therefore, these kinds of landforms are less numerous than shown by ALAGNA *et alii* (1987) and MAZZA & PANIZZA (1988).

There are no detailed studies on the snowline in the Tagliole Valley. Nevertheless, investigations conducted by CASTALDINI *et alii* (1998) in the adjacent Rio delle Pozze Valley by applying the method by HÖEFER (1922), produced the following results.

During the Last Glacial Maximum the snowline was about 1480 m a.s.l. Two stadial phases were recognised, in agreement with FEDERICI (1979) AND FEDERICI & TELLINI (1983). Two withdrawal stages were identified for the first phase (1st Apennine stage corresponding to Dryas I), with snowline at altitudes of 1611 and 1663 m, respectively.

Also for the second Apennine stage (or cirque stage corresponding to Dryas II) two withdrawal stages were identified, with snowline at altitudes of 1770 and 1836 m, respectively.

Finally, contrary to other valleys of the Apen-

Fig. 7 – The rock glacier at the bottom of the north-western cirque of Mt. Giovo.
– Il rock glacier sul fondo del circo nord-occidentale del M. Giovo.

nines, the Tagliole Valley has not undergone intense anthropogenetic practices Therefore the forms due to man's activity are irrelevant; in fact the only anthropogenetic feature is a parking area for tourists near the eastern side of Lake Santo.

5.2. – Geo-Tourist Map of the Upper Tagliole Valley

A geo-tourist map is a thematic map which combines geological-geomorphological data with basic tourist information. The geo-tourist map here illustrated was derived from the geomorphological map, with appropriate simplifications and integrations.

The goal was to make a map which could be easy to read for a tourist of average education. Since the readability of a map depends essentially on the simplicity of the symbols used (Papotti, 2002), we deliberately avoided to elaborate a legend with all information, which would have implied a long list of symbols. Considering that the more symbols are added the more is lost in clarity, the symbols were limited to the essential ones. The legend consists of two clearly distinct categories one with symbols representing the geomorphological characteristics and a second showing symbols concerning to tourist information.

As regards the geomorphological aspects, the geo-tourist map illustrates all the elements of the landscape that a tourist can observe and identify. An effort was made to use simple, clear, graphically pleasing symbols with short captions, avoiding specialised terminology (as it was used, for example, by Regione Emilia-Romagna, 2002; Angelini *et alii*, 2004). In any case, the legend adopted is scientifically correct.

From the practical viewpoint, using the geomorphological map as a starting point, the following criteria of elaboration were applied: i) the symbols of the main features were maintained (e.g. bedrock, hydrography, glacial landforms and deposits, rock-glaciers, ridges, saddles); ii) the distinction of age and activity for landforms and deposits was eliminated; iii) faults/fractures were cancelled in the geomorphological map, because they are not easily identifiable in the field; iv) the less representative forms and the most difficult to recognise were eliminated (e.g. structural surfaces, slopes affected by rill wash, V-shaped valleys, fans and cones, reverse slopes); v) the various types of deposits were simplified: single grouping for moraine deposits, deposits due to superficial waters and for deposits of various origin (which includes gravitational and cryogenetic deposits); vi) the range of colours used was reduced.

The tourist information was mainly indicated with the commonly used colour (brown) and symbols for tourist maps. They include: i) logistic information such as parking places, picnic areas, refuges, information points; ii) general information (such as footpaths, itineraries recommended by the Park, chapels, historical sites, rock sculptures, crucifixes on mountain peaks and meteorological stations).

Most of the tourism facilities (five refuges and two picnic areas) are located near Lake Santo and are easy to reach from the parking place (fig. 8).

This setting have facilitated the fruition of the study area which was visited by an average of 50.000 people during the summer season over the past years. The Upper Tagliole Valley offers many opportunities for hikers since the area is characterised by eight footpaths managed by the Italian Alpine Club (C.A.I.). Among them, two thematic Park itineraries are recommended in the map. One is a geomorphological route focusing on the land-

Fig. 8 – Tourists near Vittoria Refuge, located at the southern sector of the Lake Santo.
– Turisti presso il Rifugio Vittoria, ubicato nella parte meridionale del Lago Santo.

forms created by the glaciers which occupied the Tagliole Valley some 10.000 years ago ("In the tracks of glaciers"). The other route runs along two stretches of the ancient "Via dei Remi", a road utilised in the 18th century for the timber transport to Pisa, where the material was used for shipbuilding. The historical site, "Campi di Annibale", is located in the north-western sector of the study area. This is a rather flat area stretching over sandstone layers (corresponding to a structural surface) which, according to a legend, was used by Hannibal as a military camp.

6. – FINAL REMARKS

The study here illustrated was finalised with the implementation of a geomorphological map and a geo-tourist map of the upper part of the Tagliole Valley at the 1:10.000 scale.

The geomorphological map allows an updated and more detailed knowledge of the geomorphological features found in this sector of the Modena Apennines.

For instance, rock slide processes which have locally re-modelled the edges of the north-western cirques of Mts. Rondinaio and Giovo, were identified for the first time. Moreover, the mapping of glacial and cryogenetic landforms and deposits was revised.

The geomorphological map is common within the framework of geomorphological studies, but the geo-tourist map is an original document preceded only by another example (CASTALDINI *et alii,* 2005b) at least in Italy. The aim was to produce a map that could be easily interpreted by tourists with average education and help them to understand the surrounding landscape. Therefore, since the readability of a map depends essentially on the simplicity and significance of its symbols, the legend was subdivided into two clearly distinct sectors; the first sector shows the symbols representing the geomorphological characteristics, whereas the second shows the symbols regarding tourist information.

The geomorphological and geo-tourist maps were implemented using the ArcView GIS computer program. Therefore, since these documents are presented in the digital format, they can be easily updated and/or integrated with further data.

The geo-tourist map is the cartographic document characterising the tourist-environmental map of the Upper Tagliole Valley (CASTALDINI *et alii,* 2005a). This is a pocket foldable map printed on both sides with illustration notes both in English and Italian. In addition, the tourist-environmental map contains a synoptic description of the geological, geomorphological, botanical and zoological aspects, accompanied by photographs and information on excursion itineraries, visitor centres, norms of correct behaviour, refuges and, finally, cultural and tourism attractions in the region. The tourist-environmental map is part of the initiatives taken by the Frignano Park for improving the knowledge, utilisation and appraisal of the environment in a sector of its protected areas.

Therefore, the documents described were produced to meet the ever-growing educational needs of public boards and contribute to a transfer of information from scientific research to possible users and local communities.

In conclusion, these studies show how geomorphological investigations can effectively contribute to the production of maps which can be utilised in the field for environmental tourism.

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Analysis of landforms in geoarchaeology: Campo Lameiro, NW Iberian Peninsula

Analisi delle forme del rilievo in geoarcheologia: Campo Lameiro, Penisola Iberica nord-occidentale

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Abstract – The present work is part of an interdisciplinary project on the future Rock Art Park of Campo Lameiro (Galicia, NW Spain), in which Earth Science disciplines played a fundamental role in the development of the archaeological project. Our investigation focused on the evolution of landforms as a key factor in geoarchaeological analysis. The aim was to determine the influence and control of relief structure on the formation, distribution and genesis of soils and sediments in Campo Lameiro –which may be considered as the environmental archives. This approach is particularly important in this area, due to the scarcity of archaeological remains other than the rock art itself. Soils and sediments are unique archives that have recorded landscape transformations linked to cultural evolution. In the studied area the oldest sedimentary facies date back to the late Pleistocene – early Holocene. From the mid Holocene onwards the dominant processes are erosion and colluviation, in high and low potential energy areas respectively; which implied an intense redistribution of the soil resource through time. During the Bronze Age, when most rock art panels appear to have been made, these processes intensified and the rock surfaces were largely exposed. The environmental dynamics in the area follows a pattern already described for other sectors of NW Spain, and is therefore consistent with the regional evolution. Our results demonstrate the usefulness of paleoenvironmental analyses in building a framework for the comprehension of Galician rock art.

Key Words: Geoarchaeology, Landforms, Environmental archives, Late Pleistocene, Holocene.

Riassunto – Il presente lavoro è parte di un progetto interdisciplinare sul futuro Parco dell'arte rupestre di Campo Lameiro (Galizia, nord-ovest della Spagna), dove le discipline delle Scienze della Terra giocano un ruolo fondamentale nello sviluppo del progetto archeologico. Le ricerche sviluppate si sono concentrate sull'evoluzione delle forme del rilievo come fattore chiave nelle analisi geoarcheologiche. Lo scopo è stato quello di determinare l'influenza e il controllo dei fattori strutturali del rilievo nella formazione, distribuzione e genesi dei suoli e dei sedimenti in Campo Lameiro, che può essere considerato un archivio ambientale. Questo approccio di lavoro è particolarmente efficace ed importante in quest'area, a causa della scarsità di ritrovamenti archeologici diversi da quelli legati all'arte rupestre. Suoli e sedimenti sono archivi unici in cui sono registrate le trasformazioni del paesaggio collegate all'evoluzione culturale. Nell'area di studio la più antica facies sedimentaria risale al tardo Pleistocene – inizio Eocene. Dal medio Olocene in avanti i processi dominanti sono l'erosione e la produzione di colluvio, rispettivamente in aree ad alta e bassa energia potenziale. Questo implica un'intensa ridistribuzione della risorsa suolo nel tempo. Durante l'Età del Bronzo, quando la maggior parte delle pitture rupestri sembra siano state fatte, questi processi si intensificarono e le superfici rocciose furono ampiamente esposte. Le dinamiche ambientali nell'area seguono uno schema già descritto per altri settori della Spagna nord-occidentale e quindi conforme con l'evoluzione regionale. I risultati qui illustrati dimostrano l'utilità delle analisi paleoambientali per la comprensione dell'arte rupestre della Galizia.

Parole Chiave: Geoarcheologia, Forme del rilievo, Archivi ambientali, Tardo Pleistocene, Olocene.

1. - INTRODUCTION

Geoarchaeology is both an interdisciplinary and specialized discipline. This dichotomy does not weaken the discipline, although it does lead to de-

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bates over its boundaries and definitions (HUCKLEBERRY, 2000). BUTZER (1971, 1981, 1982) was among the first to stress the application of a geoscientific perspective in the study of human prehistory, a field that he defined at the time as prehistoric geography. In his view, humans are best understood with respect to their ecology, and Geoarchaeology could play an important role in defining the environmental context of past societies. He also alluded to the significance of such research to modern environmental issues. HUCKLEBERRY (2000) defined Geoarchaeology, slightly modifying the perspective offered by GIFFORD & RAPP (1985), as "the application of Earth Science method and theory to understanding the human past." This definition is broad enough to include experts from a range of scientific backgrounds to contribute towards the understanding of human prehistory. The archaeological record is a complex system affected by a variety of chemical, physical and biological processes, that have to be defined prior to deciphering behaviour through induction. All of these theoretical considerations, and a growing recognition of the value of interdisciplinary study, have made it possible for Geoarchaeology to become an essential component in archaeological projects (MARTÍNEZ CORTIZAS, 2000).

Regardless of the nature and rate of human disturbance on the landscape, considerable debate has surrounded the identification of climate changes and human impacts (whether direct or indirect) as driving forces of landscape change. Assessments of the geomorphic impacts of human modification to landscapes must be framed within the context of the natural range of variation, requiring solid baseline information on the long-term character and behaviour of the system in question (BRIERLEY & STANKOVIANSKY, 2002). Relief structure and its evolution govern the formation, erosion and distribution of soil and sediments. Due to the difficulties in direct dating of the panels, in rock art sites it is necessary to unveil the chronology of the processes of weathering, erosion and sedimentation to know when the exhumation of the rock outcrops occurred, and thus rock art could have been produced.

On the other hand, the distribution of archaeological sites is a function of several factors: cultural activities, taphonomic processes, geomorphic changes, and the nature and extent of the archaeological surveys themselves (SCHIFFER, 1987; Stein, 2001). The distribution of archaeological sites detected using GIS reflects patterns of discovery and documentation, which in turn are influenced by survey strategies such as the distribution of rock art, and geomorphic processes -erosion and deposition of sediments (BAUER *et alii*, 2004; GUCCIONE *et alii*, 1998). Also, the concept of landscape sensitivity is fundamental to the relationship between climate and erosion in shaping the landscape. According to KNOX (2001) "Agricultural landscapes are more sensitive to climatic variability than natural ones because tillage and grazing typically reduce water infiltration and increase rates and magnitudes of surface runoff." The effect of erosive rainfall can be amplified because bare soil accelerates surface runoff and soil erosion. Studies developed in NW Spain support the interpretation that human activities in the past led to a rapid decrease of forest cover and accelerated soil erosion, challenging the ability of cultures to adapt to new circumstances (GONZÁLEZ DÍEZ *et alii*, 1996; MARTÍNEZ CORTIZAS *et alii*, 2005).

The work presented here is part of an interdisciplinary study on the area where the future Rock Art Park of Campo Lameiro (Galicia, NW Spain) will be located. In this project Earth Sciences disciplines played a major role in complementing the archaeological research. Our paper focuses on the evolution of landforms -rocky substrate, sediments and soils - as a key factor for geoarchaeological analysis, with the objective of defining the relief units –location and timing of formation- and to relate them to the spatial distribution of the rock carvings. We aim to determine the influence and control of relief structure on the formation, distribution and evolution of soils and sediments.

This approach is particularly important in the studied area since there are few archaeological remains other than the rock art itself. Granite landforms, soils and sediments are unique archives that have recorded transformations in the landscape linked to cultural evolution.

2. – STUDY AREA AND METHODOLOGY

The future Campo Lameiro Rock Art Park is being built in southwestern Galicia (NW Spain) at an elevation of 330 m a.s.l. and 25 km from the coast (fig. 1). The area is an almost isolated hill, isolated by a series of fractures with preferential directions (N-S, E-W), which the fluvial network uses to flow through the territory. The general rolling topography, with a series of tops and troughs, is the result of a combination of granitic macro and microforms. It is an area of transition between the coast and mountain range with humid, temperate climate. Present mean annual temperature is 14.5 °C, and mean annual precipitation is 1500 mm (MARTÍNEZ CORTIZAS & PÉREZ ALBERTI, 1999).

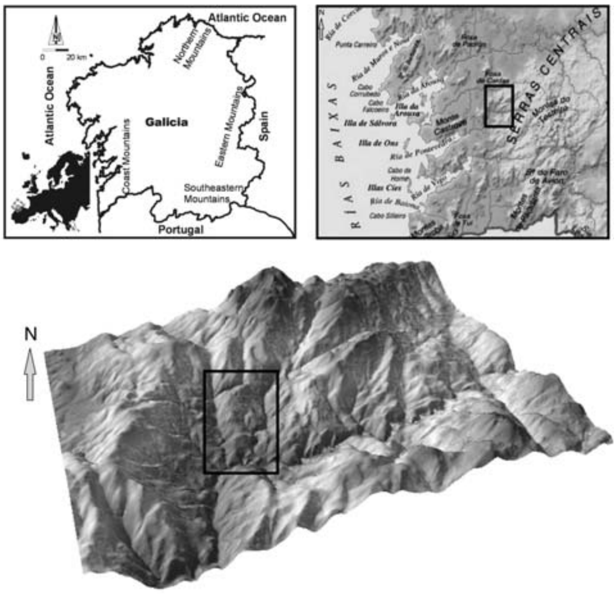


Fig. 1 – The future Campo Lameiro Rock Art Park will be located in South-Western Galicia (NW Spain) at an elevation of 330 m a.s.l. and 25 km from the Atlantic coast.
– Il futuro Parco dell'arte rupestre di Campo Lameriro sarà ubicato nel settore sud-occidentale della Galizia (Spagna NW) a 330 m s.l.m di quota e a 25 km dalla costa atlantica.

The methodology used to relate the geoarchaeological analyses and the geomorphologic context started with the interpretation of aerial photographs, in order to define the relief units and how they link to the regional geomorphologic context. In a second stage, fieldwork was carried out in order to differentiate landforms. All this information was used as a basis in order to designing and subsequent opening of 43 ditches in ten sectors, with a total length of 2.5 km (fig. 2). We followed two main criteria for its design: the variety of morphological units, their location in sectors prone for accumulation, in erosive/accumulative or erosive areas; and their proximity to the rock carvings. The aim was to obtain as extensive and varied a representation as possible of the superficial formations that fossilize the substrate, their facies and morpho-sedimentary features, and to obtain as full a stratigraphic sequence as possible.

The groups of ditches correspond to different microtopographies, each associated to rock carvings. Systematic descriptions of the sedimentary facies were made in order to define the vertical and lateral stratigraphic changes. More detailed descriptions were made for a small number of profiles in each ditch, which generally coincided with the deepest ones and showing the greatest variation of sedimentary facies.

Eleven deep soil profiles (with depths between 1,5 and 3 m) were also selected for more complete geochemical soil analyses -such as the concentration of trace elements- and pollen analyses: five representative of different sectors of the area, five in a transept perpendicular to one of the most important rock art panels, and one outside of the Park area. The locations of the trenches, the soil profiles and the rock art panels were incorporated into a digital terrain model, then combined with the information obtained from the other disciplines involved –Geomorphology, Archaeology and Pedology– to conform a GIS database (fig. 2).

3. – RESULTS

3.1. – Geological structure and bedrock lithology

The sector of Campo Lameiro was subjected to the lithostructural evolution of the northwestern Iberian Peninsula. The tectonic movements that occurred throughout the geological history of Galicia acted differentially on its lithology, and defined the main lines of the relief at regional and local scales (Parga Pondal, 1969; Pérez Alberti, 1986; 1990; 1993). The result was the for-

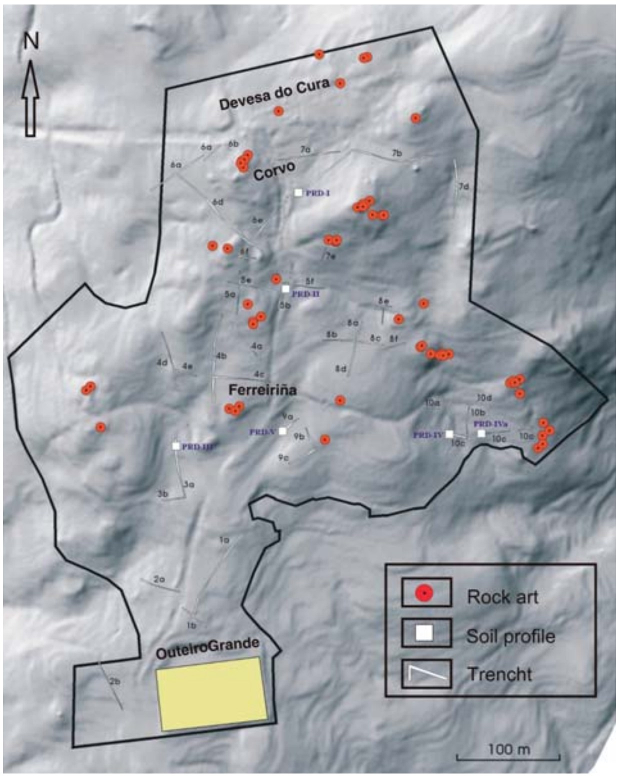


Fig. 2 – The georeferenced trenches, soil profiles and rock art panels georeferenced, were incorporated into a digital terrain model, then combined with the information obtained from the other disciplines involved – geomorphology, archaeology and pedology– to conform a GIS database.
– Le trincee georeferenziate, i profili pedologici e le pitture rupestri georeferenziate sono state aggiunti in un modello digitale del terreno e successivamente implementati con le informazioni geomorfologiche, archeologiche e pedologiche per costruire un database cartografico.

mation of a series of fractures running from NW-SE, NE-SW and N-S, which generated a relief marked by the dichotomy between the vertical shapes of the hills and mountains, and the horizontal shapes of the valleys, cut through by the fluvial network (fig. 3). Within this structural context the studied area appears as an almost isolated hill at the centre of the watershed, defined by the river network, and surrounded by the main fractures running from N-S and E-W as well as by numerous joints that break the substrate running N-S, E-W, NW-SE and NE-SW (fig. 3, fig. 4a).

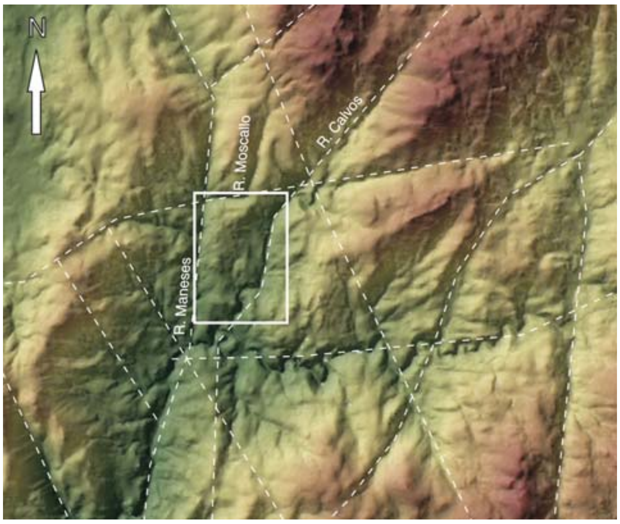


Fig. 3 – Joint system in the surrounding area to the future Campo Lameiro Park. The white box indicates the sector of study, shown with detail in figure 4.
– *Sistema di fratture nell'area circostante il futuro Parco di Campo Lameiro. Il quadrato bianco indicata l'area di studio, mostrata in dettaglio in figura 4.*

The lithology is homogenous throughout the whole of the Park. It is comprised of two mica granitic rocks with megacrystals of K-feldspars; with minerals showing a certain degree of orientation towards the north of the area (IGME, 1982 a, 1982 b). Outside the area of the Park, a small band of schists and paragneiss is found running from northwest to southeast.

3.2. – Landforms

3.2.1. – *Granite landscape*

Granitic modelling dominates the slopes of the area and the differences in altitude makes it possible to divide it into three sectors, with granitic outcrops separated by small talwegs. The tops are organized following a polygonal pattern resulting from long-term granite alteration that is controlled by a joint system running from N-S and E-W (fig. 4a). This tectonic pattern defines an alignment with a series of tops and granitic slabs interspersed

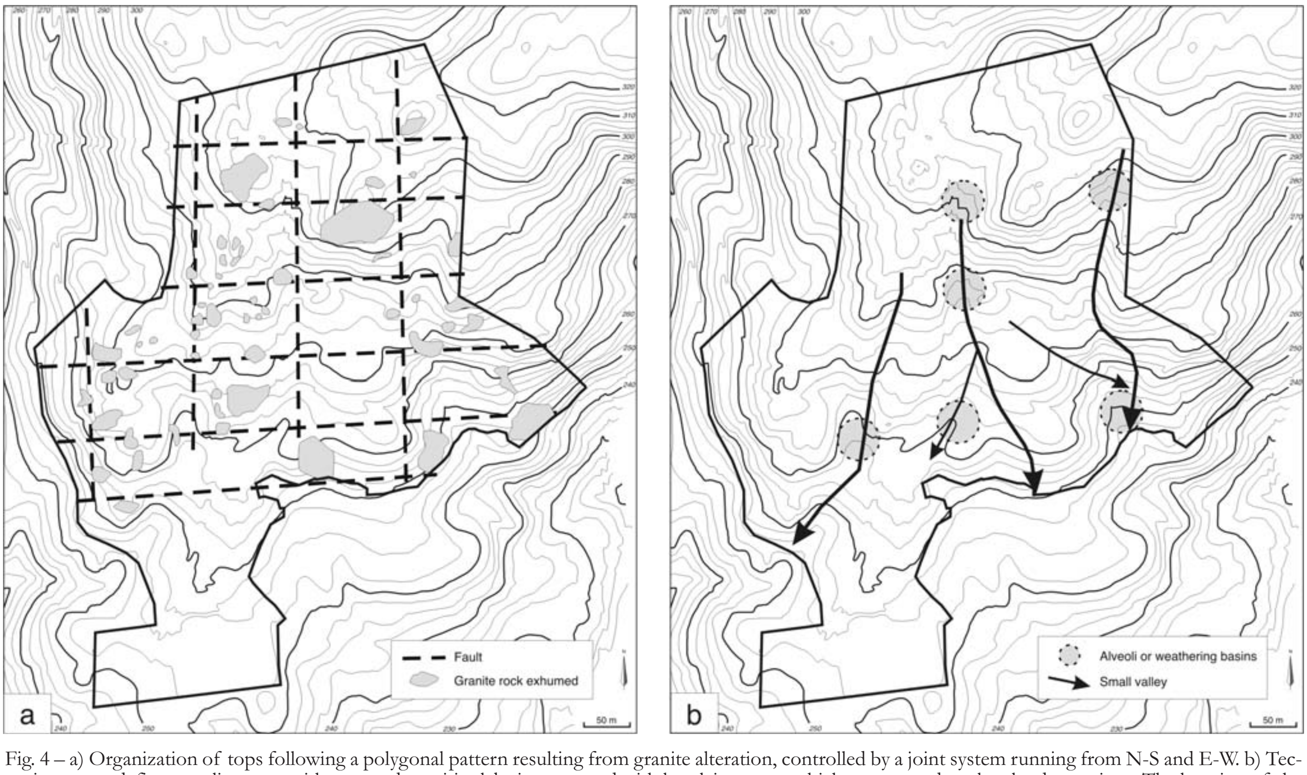
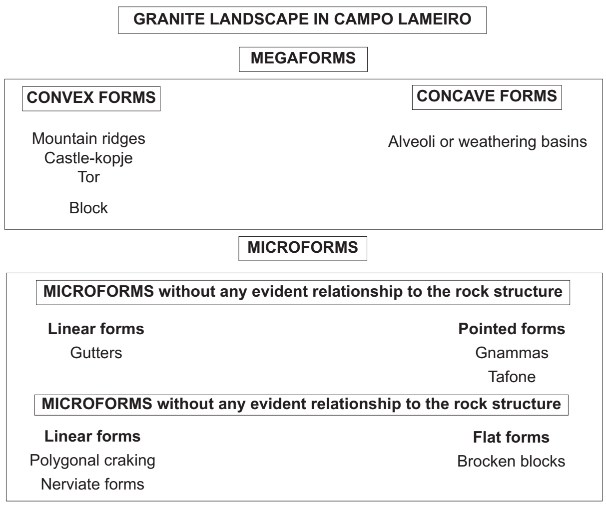


Fig. 4 – a) Organization of tops following a polygonal pattern resulting from granite alteration, controlled by a joint system running from N-S and E-W. b) Tectonic pattern defines an alignment with tops and granitic slabs interspersed with low-lying areas, which correspond to alveolar depressions. The location of the granite outcrops and the alveolar depressions defines three main flow paths within the area, that channelized the transport of water and sediments to the valleys.
– *a) Oraganizzazione delle cime secondo uno schema poligonale, risultato dell'alterazione granitica e controllato da un sistema di* joint *con direzione N-S ed E-O. b) La struttura tettonica definisce un allineamento con cime e lastre granitiche inframezzate con aree depresse, che corrispondono a depressioni alveolari. L'ubicazione dell'affioramento granitico e le depressioni alveolari definiscono tre canali di flusso principali nell'area, che trasportano acqua e sedimenti a valle.*

Tab. 1 – *The lithological, structural and geomorphological variety of granite landscape. Types of megaforms and microforms in Campo Lameiro, modified from* TWIDALE *(1992).*
- La varietà litologica, strutturale e geomorfologica del paesaggio granitico. Tipi di megaforme e microforme in Campo Lameiro, modificato da TWIDALE (1992).



with small low-lying areas, which correspond to alveolar depressions (fig. 4b).

The central sector of the area has a maximum elevation of 330 m a.s.l. and minimum one of 259 m a.s.l. Altitude decreases from north to south in a series of steps, with *Devesa do Cura* and *Corvo* tops to the north, at a elevations over 300 m a.s.l., to a central peak, *Ferreiriña*, at 289 m a.s.l., and to the south, *Outeiro Grande*, at 250 m a.s.l. (fig. 2).

The upper and lower sectors are connected through steep, deeply eroded slopes, where the rock substratum is visible at the surface -as it happens in the slopes facing towards the east of the Park. This sector is contrasting with the central and western ones, where the main shape is articulated into three levels with different altitudes and gentler slopes, dominated by alveolar depressions surrounded by crests and granitic slabs.

The lithological, structural and geomorphological variety found corresponds to that of granitic landforms (tab. 1). The latter are classified into two groups, depending on their size: megaforms or large scale forms, and microforms or smaller forms (GODARD, 1977; TWIDALE, 1986; 1989). The most important within the first group are convex megaforms, mostly granitic crests, represented by c*astle kopjes* (fig. 5) in which vertical joints predominate over horizontal joints, such as those were the petroglyphs of *As Ventaniñas* and *As Forneiriñas are located;* or *tors*, in which the main joints run horizontally, such as *Pena Furada* (fig. 6).

Recent stone quarrying works on the crests has considerably modified their initial structure, making it difficult to find them with their natural shape. As a whole they are combined with concave megaforms – *depressions or alteration alveoli* – which occupy a lower topographic position, and are surrounded by granitic tops (fig. 7).

At an intermediate topographic position are the granitic *slabs*, minor forms that are related to the structure of the rock - joints direction mainly -, flat in shape and slightly tilt down. They are associated with other smaller linear forms not related to the rock structure and usually located on vertical surfaces as *grooves* and *channels*, with small depressions as *gnamas* –found both on horizontal and vertical walls. But also to other small linear microforms related to rock structure, as narrow chan-

Fig. 5 – Dismantled castle kopje in the upper part of Campo Lameiro. In some cases fallen blocks contain rock carving.
– *Kopje smantellata nella parte superiore di Campo Lameiro. In alcuni casi i blocchi caduti contengono delle incisioni rupestri.*

Fig. 6 – Tor of Pena Furada. The main joints run horizontally. There are rock carvings on the horizontal surfaces both on the basal rock and higher surfaces.
– *Tor della Pena Furada. I* joints *principali si sviluppano orizzontalmente. Vi sono incisioni rupestri sulle superfici orizzonatli sia nella parte basale che in quella superiore.*

Fig. 7 – Dismantled castle kopjes between alveoli or weathering depression. In the front there are rock carvings represented by cup marks and rings.
– *Kopje smantellata tra alveoli o depressioni legate all'alterazione meteorica. Di fronte vi sono incisioni rappresentate da coppelle ed anelli.*

nels and *cracks*, which follow the direction of joints or the areas between the planes of a joint. The rock art panels of *Os Carballos* and *Os Cogoludos* are good examples, carved on slabs, in which the joints, narrow channels and other linear features are the result differential erosion (fig. 8).

Within the smaller forms are specific shapes that are not related to rock structure: as *gnamas* and *taffonis*. They are associated with megaforms and mainly found on tops and slabs. The first are concave in shape, and appear both on horizontal and vertical surfaces, whereas the second appear in the inner part of a wall producing a hollow structure -as in the tor of *Pena Furada* (fig. 9). In other cases gnamas at both sides of a rock connect to create a hole, as seen at the top of *Ventaniñas* (fig. 10).

Fig. 8 – Slab with joints, splits and linear branches. The rock surface is covered by rock carvings - cup marks and rings.
– *Lastra con fratture, fessure e ramificazioni lineari. La superifcie della roccia è ricoperta da incisioni, coppelle ed anelli.*

3.2.2. – *Sedimentary deposits*

The thickest sedimentary deposits with the greatest variety of stratigraphic layers are preferentially found in the alveolar depressions, where sedimentation was favoured, and their paleoform has conditioned the evolution of these surface formations over time. Nevertheless, depending on where they are located surperficial formations can be classified into four main groups: those situated in high potential energy areas prone both to erosion and sedimentation, such as the one represented by the sequence of PRD-I (fig. 2, fig. 11a); those in low energy areas where accumulation dominated, such as the channelled depressions where PRD-III (fig. 11a) and PRD-V (fig. 11b) are found; formations that fossilize alveoli found at intermediate posi-

Fig. 9 – Tafoni of Pena Furada. It appears in the inner part of a wall producing a hollow structure.
– *Tafoni a Pena Furada, presenti nella parte superiore di un muro, producono una struttura con caratteristiche conche.*

Fig. 10 – Gnamma located in Ventaniñas. Gnammas are concave in shape, and appear both in horizontal and vertical surfaces.
– *Depressioni a conca (gnammas) ubicate in Ventaniñas. I gnammas hanno forma concava e compaiono sia nelle superfici verticali che orizzontali.*

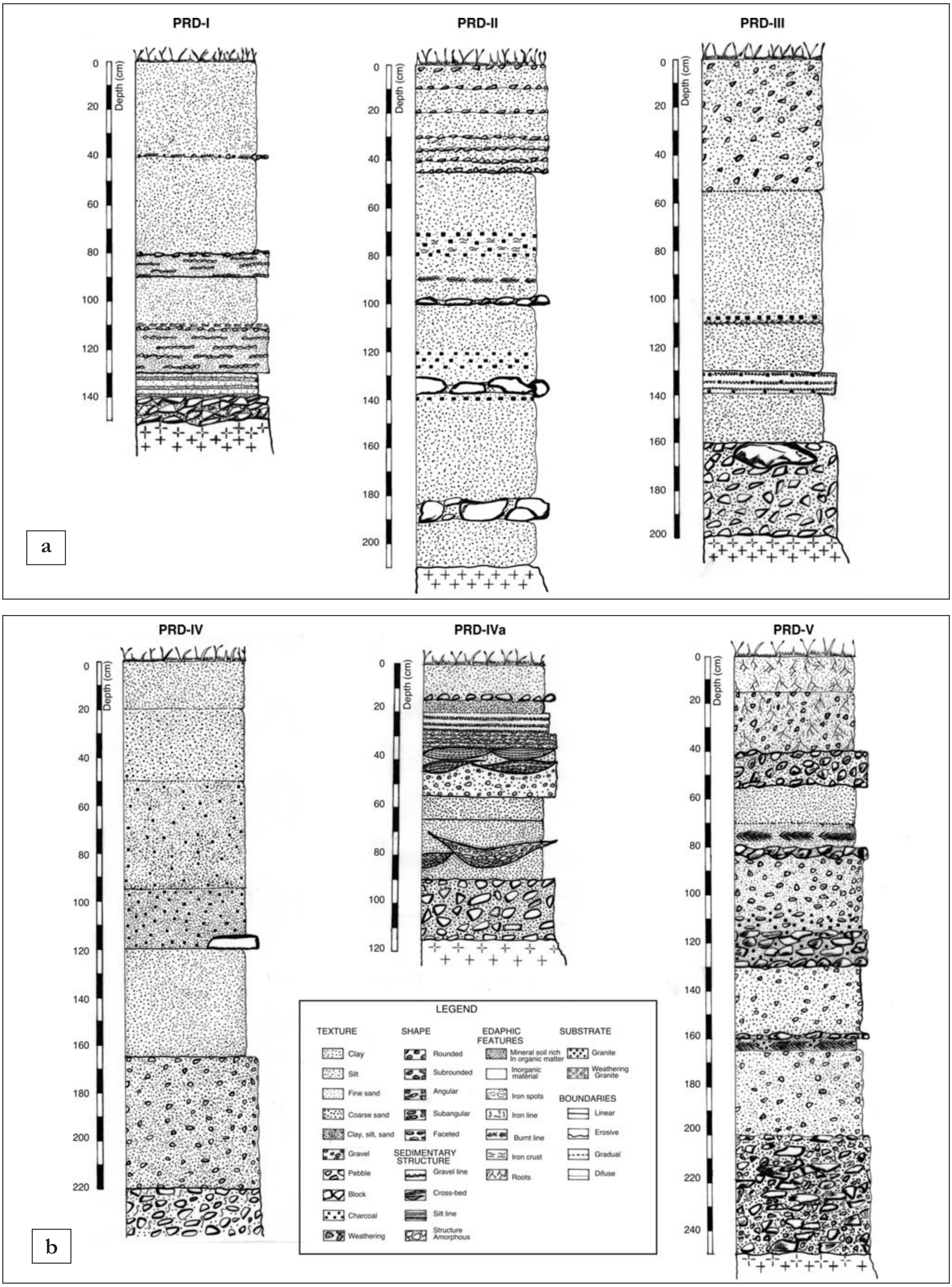


Fig. 11 – Sedimentological and stratigraphic columns: a) profiles PRD-I, II, III; b) profiles PRD-IV, IVa, V and a legend.
– Colonne sedimentologiche e stratigrafiche: a) profili PRD-I, II, III; b) profili PRD-IV, IVa, V e la legenda.

tions, located next to the base of a granite slab and with their external border eroded, as is the case of PRD-II; and those that fossilize alveoli floors, as is the case of PRD-IV, PRD-IVa (fig. 11b).

We do not make here a detailed description of each deposit, but provide a general summary of the most important morphosedimentary features (fig. 11a,b). Two types of stratigraphic units have been found: a basal inorganic sedimentary layer that covers the granitic substrate with varying thickness (50 to 100 cm); and a younger, thicker layer (up to 250 cm) represented by colluvial, polycyclic soils, rich in organic matter.

The basal unit appears over the rock or a deeply weathered saprolite, and is compossed of gravel and faceted stones with rounded edges, mostly quartz with some granite, embeded in a matrix of medium to coarse sands with abundant muscovite and usually without a clear sedimentary structure. This unit is well represented in the PRD-IVa deposit (fig. 11b), which has one of the most complete stratigraphic sequences due to its topographic position. It contains layers of gravels and faceted stones interspersed with a sandy matrix without any structure, accumulations of faceted gravels in cross beds and layers of subrounded quartz sands alternating with silt layers, in a lenticular shape. Iron coatings and discrete iron layers are also frequent.

The second unit is represented by colluvial soils that show an apparent homogeneous morphology resembling deep, black to dark brown A horizons (mineral soil rich in organic matter). They have a loamy sand to sandy loam texture, with abundant quartz and muscovite, are acidic and have high C/N ratios. Despite the apparent homogeneity in the morphology, they contain gravel and stone lines at different depths, charcoal layers and layers of burnt soil of typical red to orange colour, as it can be observed in figure 11 a, b.

4. – DISCUSSION

4.1. – Granite landscape

Granite modelling is the result of the interaction of a number of factors: rock type, tectonic, climatic changes, human activities and the associated morphogenetic systems, which either directly or indirectly have acted over time, and led to the present shapes seen in Campo Lameiro (fig. 12).

The dense joint system helped to weaken the granite and allowed alteration and weathering to proceed deeply into the rock. These processes were enhanced during periods of favourable climatic conditions, such as the tropical climate that prevailed in NW Spain during the Tertiary (Pérez Alberti, 1986). Under these wet and warm climate conditions the weathering of the granite progressed faster generating a deep mantle of saprolite. At the same time the granitic macro and microforms were predefined and later exhumated by the removal of the saprolite mantle through erosion and transport.

Alveolar depressions are the most representative major forms found in Campo Lameiro. Their formation was also controlled by the joint system that channelled both the upwards and downwards alteration processes (hydrothermal/thermal) and the downwards weathering processes (illuviation and other pedogenetic processes) (Vidal Romaní, 1989). Their final shape is also linked to fluvial and alluvial processes that gradually uncovered the megaform.

The genesis of the more localized, small scale granite forms occurred in many different ways through time. But most of them are the result of the presence discontinuity planes that favoured uneven advances of the chemical and physical alteration/weathering processes (dissolution, exfoliation, humectation-dessication and haloclastism) as well as formative features caused by concentrated loads in particular sectors of the granite body that would predetermine the existence of weak areas well before exhumantion (Twidale, 1989).

4.2. – Sedimentary deposits

Present landscape in Campo Lameiro integrates and reflects the interactions of environmental factors and human activity over time. This dynamic

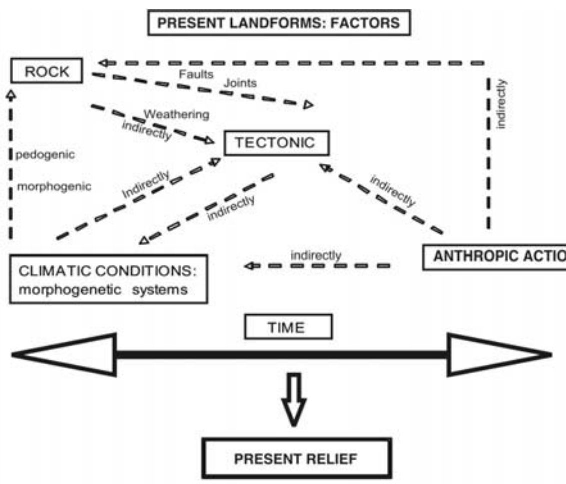


Fig. 12 – The present landforms of relief are the result of different parameters: rock, tectonic, climatic conditions, time and anthropic action. – *Le forme del rilievo attualmente presenti sono funzione di differenti parametri: litologia, tettonica, condizioni climatiche, tempo e attività antropica.*

Tab. 2 – *Bulk radiocarbon (14 C yr BP) and calibrated ages (1σ and 2σ) for different depths in two colluvial soils (PRD-I and PRD-II).*
- Datazioni al radiocarbonio (14 C yr BP) ed età calibrate (1σ e 2σ) per differenti profondità in due depositi colluviali (PRD-I e PRD-II).

Sample code	Depth (cm)	Convetional age BP	Calibrate age 1σ BP	Calibrate age 2σ BP	Laboratory
PRD-I-11	50-55	2300±40	2350-2310 BP	2360-2300 BP	Ua-21845
PRD-I-15	70-75	3055±40	3340-3280 BP	3360-3160 BP	Ua-21846
PRD-I-19	90-95	5300±50	6065-5995 BP	6200-5935 BP	Ua-21847
PRD-I-25	120-125	7610±55	8430-8355 BP	8485-8330 BP	Ua-21848
PRD-II-18	85-90	1835±40	1720-1820 BP	1695-1870 BP	Ua-22555
PRD-II-25	120-125	3055±40	3240-3340 BP	3160-3360BP	Ua-22556
PRD-II-35	170-175	3770±40	4090-4160 BP	4060-4255 BP	Ua-22557
PRD-II-39	190-195	5350±40	6020-6080 BP	5995-6155 BP	Ua-22558

evolution has been constant from the Late Pleistocene until today, as has been revealed by the palaeoenvironmental records analyzed and the chronology supported by radiocarbon datings (tab. 2). Microtopography controlled erosion and sedimentation, the first being most acute in the steepest slopes and at the foot of the tops, while the redistributed soils and sediments accumulated in the talwegs and the alveolar depressions. The shape of the studied area, a small isolated mountain with heights decreasing north to south, ensures that all sediments have an internal source and there was not significant contributions from the outside. The location of the granite outcrops and the alveolar depressions defines the existence of three main flow paths (fig. 4b) within the area, which served to channel the transport of water and sediments to Praderrei and Paredes valleys. Part of it was not carried away, but was instead captured and accumulated in the alveolar depressions.

The influence and control of the relief structure is a determining factor in the formation, distribution and evolution of the soils and sediments. Due to the lack of significant archaeological remains apart from the rock carvings, colluvial soils are the only environmental archives that preserved the record of the past changes. Colluvial soils are stratigraphically complex, differ in maximum age and phases represented, and have signficant time hiatuses (as for example PRD-I, see table 2).

Radiocarbon dating and stratigraphic correlation helped to put into context the natural and human induced changes that took place in Campo Lameiro since the late Pleistocene/beginning of Holocene. These are comparable to those occurred in other areas of the northwest of the Iberian Peninsula and the Atlantic coast of Europe during the same period, although some specific morpho-sedimentary features are related to local evolution. One of the most outstanding features provided by the morphology of the sediments is the sequence of colluvial levels, with charcoal, stone and gravel layers as well evidence of soil burning. This burnt soils would be a consequence of both natural and human provoked fires. All these features point to intense soil erosion, either as a result of environmental factors, human activity or a combination of both, as has been described for other parts of Europe (Sarmaja-Korjonen, 1992). Geomorphology, stratigraphy and chronology provided the basis to reconstruct landscape evolution in the area, which can be described in four main phases.

- Phase 1:11.000-8000 BP

The inorganic facies that evenly cover part of the rock substrate and that preserved the sedimentary structure in some places (such as PRD-IVa, figure 11b), is the result of the erosion and transport of the strongly weathered saprolite mantle, which generated a large amount of material. The mineralogical composition, shape of the clasts, degree of weathering and the type of fine matrix refers to a morphogenetic system controlled by water. This colluvio-alluvial formation is probably the result of the erosion of more ancient deposits. Its sedimentary facies are quite varied. There are heterogeneous and chaotic layers, resulting form soil flow processes; cross-bed, linear structures and lenticular sand layers, related with alluvial transport, which are only preserved in alveoli bottoms. They were formed under an alluvial morphogenetic system, probably as small alluvial fans, with three main channels following the natural talwegs.

The deepest deposit is associated with the ancient trough that runs through the eastern sector of the area from north to south.
Fans are dynamic systems that can temporarily storage sediments (Gómez Villar, 1996) as a result of a sporadic yet continuous supply, in geological terms, in a highly energetic environment. Slope angle, the ability to concentrate runnoff, the heterometry of the sediments and a low vegetation cover are all factors that help to explain the presence of this kind of formations. A decreasing slope angle and the widening of the valley decreases the energy of the runoff waters and favours the dispersion of sediments in an orderly manner. Alluvial fans depend equally on rainfall torrentiality and the ability to produce large amounts of sediments. At PRD-I (fig. 11a) this basal unit is fossilized by a paleosol that provided a radiocarbon age dating of 8,480-8,320 cal. BP, indicating that the fans are at least late Pleistocene or early Holocene in origin. Their formation in the studied area may be associated to the Younger Dryas (11.000-10.000 BP) which was characterized by a severe cooling and rainy environment, as is represented at sedimentary level by important alluvial-colluvial accumulations that are well defined in the northwestern Iberian Peninsula (Martínez Cortizas & Moares Domínguez, 1995; Valcárcel Díaz, 1998). This is consistent with recent research on fluvial activity in Spain that suggests increase activity by 11.170-10.230 and 9.630-8.785 BP (Thorndycraft & Benito, 2006).

- Phase 2: 8000-6000 BP

From 8,480-8,320 cal. BP to 6,200-5,930 cal. BP (age obtained at the top of second paleosol of PRD-I), sedimentation must have slowed and pedogenesis progressed due to landscape stability and large vegetation cover. Although not detected in Campo Lameiro, the earliest evidence of significant transformations by humans in NW Iberia date back to this period, around 7500-7000 BP (during the Epipaleolithic), and seem to have been the result of small scale impacts in the forest by means of fires (Martínez Cortizas, 2000; Martínez Cortizas *et alii*, 1999 a,b, 2000).

- Phase 3: 6000-3500 BP

The second paleosol of PRD-I shows an abrupt discontinuity with the overlying layer –a stone line- suggesting the onset of intense soil erosion. Considering the available radiocarbon dating this may have happen after 6200-5930 cal BP, an age correlated to the initiation of sedimentation in PRD-II with a basal radiocarbon dating of 6155-5990 cal BP. As a result of increased erosion the transport of soil and sediments caused a progressive accretion and infilling of the alveolar depressions and the valleys of Praderrei and Paredes. It was possibly at this time, around 6000 BP (the Mid Neolithic), when the granite outcrops started to be exhumed together with the upper part of the slabs. Studies on landscape evolution in northwestern Spain indicate that soil erosion began to be a widespread phenomenon at least from 6,000-5,500 BP (Costa *et alii*, 1996; Martínez Cortizas, 2000; Martínez Cortizas *et alii*, 2000). A decline in forest cover and the first appearance of cereal polen indicated by palynological studies (Ramil, 1993; Martínez Cortizas *et alii*, 2005), the erosive discontinuities, stone and charcoal lines in colluvial soils, as well as the start of a progressive soil acidification point to human activities as the main trigger. But this is also coincident with a climatic abrupt change in Spain and other parts of Europe (Martínez Cortizas *et alii*, 1999 b,c; Magny *et alii*, 2006) to wetter and cooler conditions, which probabily resulted in a higher landscape sensitivity to human activities.

- Phase 4. 3500- 500 BP

A relative stability of the slopes seems to have occurred at the beginning of this period, shown by the development of a new paleosol cycle which is represented in PRD-I and PRD-II (fig. 11a), and in both cases with the same age (3360-3160 cal. BP). Soil data obtained shows an increase in organic matter, which may also support a certain degree of stability in this paleosurface.
After 2000 BP a new erosive phase occurred, represented in the soils by gravel and stone lines, charcoal layers and burnt soil layers, which again seems to be the consequence of forest fires. In a study on the evolution of climate and landforms during the Upper Holocene in the Iberian Range and the Ebro and Pre-Pyrenean basins, Gutiérrez Elorza & Peña Monné (1992), focused on the role played by human activities, distinguished two periods of sediment accumulation linked to erosive processes: a generalized one that corresponds to the cold phase of the Iron Age (2900-2300 BP) and another, less significant during the Post-Medieval period corresponding to the Little Ice Age (500 BP). The dating of 2360-2300 cal BP at a depth of 50 cm in PRD-I, just above the charcoal, may be assimilated to the moment indicated for the Upper Holocene in the Iberian Range and which is also indicated by Martínez Cortizas *et alii* (2000) for the Atlantic ranker of *Coto da Fenteira* in NW Spain. Whereas the age of 1690-1870 cal. BP at 90 cm in PRD-II, over a burnt soil layers, marks an erosive episode that may be local, and perhaps related to activity that took place at the foot of the rock carving of *Os Carballos*.
By 3000 BP a critical threshold must have been

crossed in NW Spain because many indicators show an acceleration of environmental degradation. A significant forest decline coincides with an increase in soil acidification and the first detection of atmospheric and soil metal pollution (Martínez Cortizas *et alii*, 1997, 2002; Kylander *et alii*, 2005). In fact, forest evolution and atmospheric metal pollution (a proxy of mining and smelting activities) have been coupled since 3000 BP until the beginning of the industrial revolution (Martínez Cortizas *et alii*, 2005).

4.3. – Archaeological implications

In order to relate present landforms and rock art in the studied area, it is necessary to understand the processes of alteration/weathering of the granite and the structural control exerted by granite landforms on landscape evolution (i.e. erosion and sedimentation). The timing of exhumation of the rock surfaces is key in providing a useful surface for rock art expressions. The erosive processes involved in rock surfaces exhumation were driven both by natural factors –as climate changes– and human activities –mainly through impacts on the vegetation cover (Wilkinson, 2005). Apart from the direct changes on vegetation communities, human activities intensified soil erosion and led to a dramatic redistribution of the soil resource as well as to the exposure of the raw material that was used to make the carvings: the granite rock. The outcrops and the upper part of the slabs probably began to be exposed by 6000 BP (Mid Neolithic), as this was the time when soil erosion started to be widespread. At the end of the Neolithic/beginning of the Bronze age erosion accelerated, with most outcrops and the lower part of the slabs being exhumed. This may have been the time when the first carvings were made.

An iconographic study of the rock carving panels of the area represented by cup and rings and its comparison with other found in Atlantic areas ascribed them to the Late Neolithic (4800 – 4500 BP) or Early Bronze Age (4500 – 3000 BP) -such as the panel of *Os Cogoludos*, located at the foot of the highest and steepest granite outcrop in the area (Santos Estévez, 2005). According to this author, most of the carvings in the studied area -such as scenes of deer hunting or equestrian- may have been made between 3000 and 2400 BP and were therefore in use from the Late Bronze Age until the Iron Age. This provides a minimum age of some 3,000 years and a long period of time for rock exposure. Obviously, the steepest areas and those at higher elevations would have been the first to be affected by erosion, whereas those in the middle section -such as the slab of *Os Carballos*- would have been exposed later depending on the balance between erosion and accumulation in the local basin.

A dating of 960-790 cal. BP just at the base of the colluvium that covered much of the carving of O*s Carballos* prior to archaeological excavation, indicates that at that time the panel was buried. The burial of the rock slabs at the middle and lower sectors of the area may well have occurred quite quickly. For example, the top 60 cm of the PRD-II colluvium are comprised of interspersed coarse sands and gravels with indications of fast laminar transport. This structure may be indicative of the basin having been partially filled, with the material flowing over its lower edge towards one of the main basins of the area (where PRD-V is located). At the same time the slabs at higher elevation and on gentler slopes started to be buried by a shallow soil layer, depending on the evolution of the surrounding outcrops. The other sectors would have been subjected to preferential accumulation as it is the case of PRD-IV, PRD-III and PRD-V.

Although the upper layers of the last two deposits possibly show a more local evolution. Both sectors, situated in troughs, are currently enclosed by stonewalls. This was possibly done in order to protect them from erosion, and to use these wet areas for pasture. Both the slopes in the eastern and western sector are predominately erosive, with the only exception of few locations with small alveolar depressions.

Although human activities seem to have been involved in the landscape evolution of the area since at least 6000 years ago, enviromental changes (natural and human induced) have also challenged human societies which responded to perceived changes adapting to the new conditions in a feedback loop so that landscape and human groups coevolved interacting in a complex way.

The result of this interaction expressed as modifications in the vegetation cover, the elimination of the soil resources in many areas and its concentration in more localized, control-demanding sectors, and a progressive acidification and contamination. These transformations may have affected ecological diversity in ways we still have to uncover, that subtetly modified the services offered by biodiversity to human societies. To a great extent, present landscape is the product of these interactions.

5. – CONCLUSIONS

This study demonstrates the usefulness of interdisciplinary palaeoenvironmental analysis in building up an integrated framework for the understanding of rock art in NW Spain. The distribution of archaeological sites in the studied area is a function of various factors including cultural activities, geomorphic changes, taphonomic processes, and the nature and extent of the archaeological surveys themselves. The chronology of environmental changes is consistent with studies developed in other areas of NW Spain but also in other parts of Spain and Europe. Both climate changes and human activities were the driving forces of an evolution that is strongly conditioned by the local lithology.

The onset of widespread erosion occurred at the Mid Holocene under increasing human pressure and climate deterioration. As a result many areas were denudated and the soil resource redistributed into more localized sectors. These processes accelerated during the Bronze Age, when most of the rock art panels seem to have been made, as the rock was exposed due to the exhumation of granite landforms. The combined effect of climatic changes and disturbances from human activity had a major impact on local vegetation communities and soil cover, thereby increasing soil erosion and contributing to a more degraded environment. The sensitivity of landscape to human pressures seems to have changed coupled to climate deterioration.

A proper understanding of landscape evolution, and particularly of present cultural landscape, needs the integration of cultural and environmental records in order to obtain a more in depth view of human eco-dynamics than by simply analyzing environmental variables alone.

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figg. 12 - tabb. 2

The Rupe Tarpea: the role of the geology in one of the most important monuments of Rome

La Rupe Tarpea: il ruolo della geologia in uno dei più importanti monumenti di Roma

DE RITA D. (*), FABBRI M. (*)

ABSTRACT – The Rupe Tarpea is one of the most significant monuments of the Roman time. The Campidoglio is built up on this cliff. The legend says that during the wars of the Romans against the Sabins (IV-III centuries BC), a young lady named Tarpea, while Roman soldiers were sleeping, opened the city doors to the enemy who could enter undisturbed. When the Romans, made save the city, knew about the betrayal, killed the girl pushing her down from the cliff. Since that time, the cliff was named Tarpea. The Rupe Tarpea itself records the geological evolution of the area: it is constituted by ignimbrite deposits erupted from the Colli Albani volcano, immediately south of Roma. Erosion processes during quiescence periods of the volcano and after the end of the volcanic activity, are responsible for the dissection of the ignimbrite plateau forming the rupe and the famous seven hills of Roma. In this study, we indicate the need to include the Rupe Tarpea in global sites of geological interest to promote a discerning for a different type of tourism which basically takes into account people's culture. The Romans, in fact, recognize the Rupe as part of their cultural heritage.

KEY WORDS: Cultural heritage, Geosite, Rome, Capitoline Hill.

RIASSUNTO – La Rupe Tarpea è uno dei più significativi monumenti del periodo Romano e il Campidoglio sorge su questa rupe. La legenda racconta che durante le guerre dei Romani contro i Sabini (IV-III secolo a.C.), una giovane donna di nome Tarpea, mentre i soldati romani stavano riposando, aprì le porte della città al nemico che poté entrare indisturbato. Quando il tradimento fu scoperto i Romani scaraventarono la fanciulla giù dalla rupe che da allora portò il suo nome. Da un punto di vista geologico la Rupe Tarpea registra l'evoluzione geologica dell'area: è costituita da depositi ignimbritici del vulcano dei Colli Albani, immediatamente a sud di Roma. I processi erosivi attivi nei periodi di quiescenza del vulcano e alla fine dell'attività vulcanica sono responsabili dell'incisione del plateau ignimbritico e della formazione dei sette famosi colli romani. Nel presente studio, è stata evidenziata la necessità di includere la Rupe Tarpea nei siti mondiali di interesse geologico al fine di favorire una distinzione per un diverso tipo di turismo che essenzialmente tenga in considerazione la cultura. I romani infatti riconoscono la Rupe Tarpea come parte del loro patrimonio culturale.

PAROLE CHIAVE: Patrimonio culturale, Geositi, Roma, Colle Capitolino.

1. – INTRODUCTION

Landscape is a sort of natural archive that shows the route of the natural evolution of the territory. The ability to read it is a useful tool to understand how to use our land and to live with harmony without destruction and degradation. Landforms often provide continuity, in term of processes, between the distant and recent past and present (WIMBLEDON *et alii,* 1999). The Rupe Tarpea represents an important archive including both the key to read the evolution of the roman territory and the primordial legend of the birth of the Urbe (ARNOLDUS HUYZEDVELD *et alii*, 1997a,b).

The history of Roma, in fact, for many aspects, is strictly connected to the presence of the Rupe.

The Rupe is the most southern cliff of the Capitol Hill (Capitoline) which dominates westward the alluvial plain of the Tiber River, in the point

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where the Isola Tiberina (Tiber's island) is almost at the centre of the river valley (fig. 1). Landscape was an important factor inducing Romans to develop on this hill the political and social life of the new city. The steep limit of the cliff allowed an easy defence, whereas the proximity to the other six small hills (Palatine, Viminal, Quirinal, Aventine, Celian and Esquiline) facilitated the continuity of the business in the hinterland. The presence of the Isola Tiberina was critical, and from the Capitol Hill the control of the mercantile business was very easy. Marketplaces and small urban areas developed on the hill very soon.

It was an ideal position and a lucky landscape, but also a large quantity of natural resources due to the geological characteristics of the territory: the Capitol Hill, as the others roman hills, is made of volcanic rocks mainly deposited by the explosive activity of the Alban Hills volcano, few kilometres southeast of Roma. They are made of pyroclastic flow deposits that, being the deposit of topographically controlled median or large volume ignimbrites, originated the flat topography (plateau) of the roman land. Fluvial erosion, particularly active close to the river Tiber delta, dissected the plateau forming the famous seven hills (fig. 1, 5b). Details of this history will be given in the next paragraph. The deposits of the Alban Hills ignimbrites show special lithification, besides to be heavy and porous, which made them easy to work.

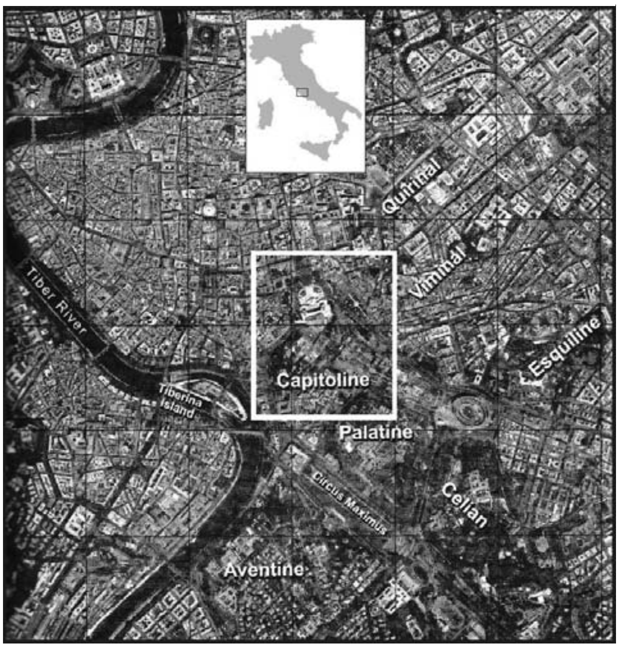

Fig. 1 – Aerial photograph of central Rome. White square indicates the location of the Capitol Hill (Capitoline). The Rupe Tarpea is the most southern cliff of the Capitol Hill (Capitoline) which dominates westward the alluvial plain of the Tiber River, in the point where the Isola Tiberina (Tiber's island) is almost at the centre of the river valley. The "seven hills" are visible, including the Quirinal, Viminal, Aventine, Esquiline, Celian, Palatine and the Capitoline. All these hills are erosion segments of a wide volcanic plateau. On the left, the flat floodplain of the Tiber and several of its meanders are recognizable.

– Fotografia aerea del centro di Roma. Il quadrato bianco indica l'ubicazione del Colle Capitolino. La Rupe Tarpea è il colle più a sud del Capitolino che domina verso ovest la pianura alluvionale del Fiume Tevere, nel punto dove l'Isola Tiberina è al centro della valle fluviale. Sono ben visibili anche i sette colli, Quirinale, Viminale, Aventino, Esquilino, Celio, Palatino e Campidoglio. Tutti questi colli sono il risultato dell'erosione che ha interessato il vasto plateau vulcanico. A sinistra nell'immagine è ben riconoscibile la pianura alluvionale del Tevere e svariati meandri.

They are good building materials and, in fact, were largely used by Romans to build up their houses (DE RITA & GIAMPAOLO, 2005). Even today it is still possible to see the scratched marks on the cliff made by the tools of the quarrymen.

Ignimbrites deposits, which are permeable, lie on impermeable clay sediments due to the Tiber floodings, creating ideal conditions for the development of local aquifers feeding several small but fresh and clean springs. These springs guaranteed the hydric resource for the city (CORAZZA, 1999; HEIKEN *et alii*, 2005).

Finally, the roman volcanic deposits are particularly enriched of Si, Na and K, enormously enriching local soils. All these advantages caused the fate of Roma: they contributed to make Roma, between all the developing cities, the most important and powerful city of the known world.

The long and fascinating history of the Capitol Hill and of the Rupe Tarpea could only be possible for the geological nature of the territory that makes them so special. In this note, illustrating as the history and the legends of the Rupe Tarpea are strictly dependent by the geology of the roman area, we want to suggest to consider the Rupe Tarpea is an important urban geosite: in the symbol of the cliff, the geological and morphological characteristics of the roman territory are harmoniously blended with the reasons of the legends and with the history of the Roman people.

2. – HISTORY AND LEGENDS OF THE CAPITOL HILL AND OF THE RUPE TARPEA

The Capitol Hill is the smallest of Rome's seven hills but it was and still is the most important. It has been considered the religious and political centre of the city since its foundation more than 2500 years ago. Even today it is considered the navel of Roma: in fact, all distances from and to Roma, as an example, are calculated starting from it.

Several important temples were built on the Capitol Hill: the Temple of Juno Moneta, the Temple of Virtus and the Temple of Jupiter Optimus Maximus Capitolinus, this latter considered the most important temple in ancient Rome. The latter was built in 509 B.C. and was almost as large as the Parthenon in "Athens". With the edification of these buildings the Capitol Hill became, besides that political, the most significant religious site of the city. Later on, in 79 B.C., on the hill was built the Tabularium, used as the empire's main archive. The hill, and the temple of Jupiter in particular were the symbols of Rome as Caput Mundi, capital of the world. Even after the decline of the Emperor capitol, during the Medieval Age, when the Capitol Hill was the site for the cattle fair, Romans considered the hill the Augustus Hill, the symbol of the Romanity. When in 1143, the Roman people rose up against the Pope, the Capitol Hill became the site of the new municipality and the Romans had there their political and social assemblies (meetings). It is a matter of fact that just above the ruins of the Tabularium the Senate building was built up. After a long period of crisis, in 1538, Pope Paolo III committed Michelangelo the project to restore the Campidoglio square. The new project was scheduled to be as the first step to locate at the centre of the square the Marco Aurelio equestrian statue. To realize the new square a huge quantity of material was used to soil the Asylum, the topographic low separating the two small hill tops of Capitol Hill: the Arch to the north, where is presently the S.Maria d'Aracoeli church, and the Capitolium to the south.

Such a special site could only be a symbol and in fact the Rupe Tarpea is widely considered the symbol of the Romanity. Several ancient legends refer to the Rupe Tarpea. The name itself comes from an ancient fascinating history. Tarpea is the name of a legendary young woman, daughter of Tarpeo defender of the Capitol Hill. She loved the Sabins' king, but at that time there was the war between the Sabins and the Romans. The legend tells that after Roma was built up (VII century B.C.), Romans realized they needed women to originate their progeny. They organized a big party inviting the Sabins, their neighbours. Taking advantage because of the Sabins distraction, Romans kidnapped those women which were close to in the buildings of the Capitol Hill. One night the Sabins' king convinced Tarpea to open the doors of the Capitol. When the Romans knew about her betrayal, she was immediately executed by being thrown down from this same cliff. The hill was since then called Rupe Tarpea (Tarpeian Rock). Since that moment any traitor suffered the same treatment in the same place.

The suggestion of this history is so strong to last up to us and to inspire several tragedies: among them we can remember the tragedy of Cristoph Kuffiner for which Beethoven orchestrated the Triumphal March.

The Capitol Hill falls back again into a well known legend related to the famous Capitol gooses that, in 390 B.C., awaked the Romans with their calls avoiding the Gauls invasion.

3. – GEOLOGICAL EVOLUTION OF THE ROMAN AREA

The geological history of the Capitol Hill is very long. It started almost one million years ago (Lower-Middle Pleistocene) when the roman area was subjected to a regional uplift, emerging from the sea. The clay and sandy-clay sediments constituting the bedrock of the area are the marks of that period during which the roman area was occupied by the sea. Monte Vaticano Formation made of Pliocene blue clays overlaid in succession by the Formations of Monte Mario and Monte delle Piche (etheropic to Monte Ciocci) Formations, from Lower to Middle Pleistocene (FUNICIELLO & GIORDANO, 2005). These formations are made of sandy sediments which show shallower sea water, suggesting the uprising of the area.

These deposits are still visible in the highest portion of the roman area (Monte Mario, Gianicolo). On the young land, the erosion processes immediately started, determining the organization of a fluvial drainage network (DE RITA *et alii*, 1992). The presence of pebbles and sandy-clay sediments of fluvial environment locally present on the Pliocene clays, makes possible to reconstruct the course of an ancient Tiber river (Paleotiber) that organized its valley in proximity of the Apennine chain and had its delta in the Ponte Galeria area (Ponte Galeria Formation; MILLI, 1997; MARRA & ROSA, 1995; figure 2a). Between 0.7-0.6 Ma, this area was subjected to an important extensional tectonic phase which caused the uplifting of the NW oriented Monte Mario ridge (GIORDANO *et alii*, 2003; DE RITA *et alii,* 2004). The Monte Mario ridge together with the pre-existing Pomezia rise created a topographic barrier that forced the Paleotiber River to move its course eastward, and its delta in that period moved near the present Anzio village (fig. 2b). At the same time, the area was interested by volcanic events. Two important volcanic districts, the Sabatini volcanic District, almost 20 km NE of the present Roma, and the Colli Albani volcanic District less than 20 km SE (fig. 2c), started their activity mainly characterized by violent explosions of ignimbrites and fall of pyroclastics covering the area with a thickness of several hundred of meters. The first explosions from the Colli Albani volcanic District were particularly important for the geological character of the area. In fact, the very huge quantity of water

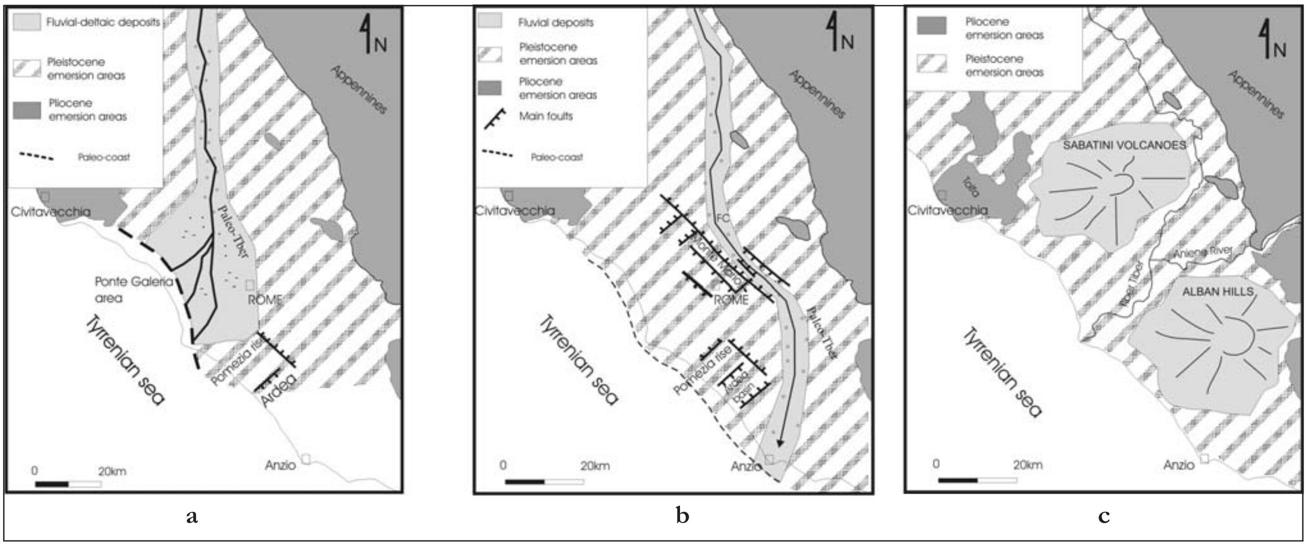

Fig. 2 – Geological evolution of the Roman area. a) One million years ago (Lower-Middle Pleistocene) the roman area was subjected to a regional uplift, emerging from the sea. On the young land, the erosion processes immediately started, determining the organization of a fluvial drainage network. An ancient Tiber river (Paleotiber) organized its valley in proximity of the Apennine chain and had its delta in the Ponte Galeria area. b) Between 0.7-0.6 Ma, the area was subjected to an important extensional tectonic phase which caused the uplifting of the NW oriented Monte Mario ridge. The Mount Mario ridge together with the pre-existing Pomezia rise caused a continuous topographic barrier that forced the Paleotiber River to move its course eastward, and its delta in that period moved near the present Anzio village. c) At the same time, the area was interested by volcanic events. Two important volcanic districts, the Sabatini volcanic District, almost 20 km NE of the present Roma, and the Colli Albani volcanic District less than 20 km SE, started their activity mainly characterized by violent explosions of ignimbrites and fall pyroclastics covering the area with a thickness of several hundred of meters (modified after GIORDANO *et alii*, 2002).

– Evoluzione geologica dell'area romana. a) Un milione di anni fa (Pleistocene inferiore-medio) l'area romana è stata soggetta ad un sollevamento regionale, emergendo dal mare. Sulla terra emersa i processi erosivi si instaurarono immediatamente determinando l'organizzazione del reticolo di drenaggio. L'antico Tevere (Paleotevere) sviluppò la sua valle in prossimità della catena appenninica e il suo delta nell'area di Ponte Galeria. b) Tra 0.7 e 0.6 milioni di anni, l'area è stata soggetta ad una importante fase tettonica di tipo estensionale che ha causato il sollevamento della dorsale nordoccidentale di Monte Mario. La dorsale di Monte Mario insieme con il preesistente sollevamento di Pomezia hanno causato una barriera topografica continua che ha determinato lo spostamento del corso del Paleotevere verso est e del suo delta vicino all'attuale abitato di Anzio. c) Nello stesso periodo l'area è stata interessata da eventi vulcanici. Due importanti distretti vulcanici, il distretto dei Sabatini, circa 20 km a nord-est dell'attuale Roma, e il distretto dei Colli Albani, a meno di 20 km a sud-est, incominciarono la loro attività, prevalentemente caratterizzata da violente esplosioni ignimbritiche e piroclastiche che hanno ricoperto l'area con uno spessore di varie centinaia di metri (modificato da GIORDANO et alii, 2002).

stagnating in the low topographic area limited by the Monte Mario-Pomezia ridge and the Apennine chain, coming in contact with the rising magma, determined violent phreatoplinian explosions (fig. 3; DE RITA *et alii,* 2002). The ignimbrites (four successive units separated by paleosoils: Trigoria, Tor de Cenci, Palatino and Cavaliere units) expanded several kilometres from the crater reaching the sea westward and climbing the Apennine eastward.

After these volcanic events the morphology of the roman area was completely flattened, assuming the aspect of a large and flat plateau dissected by the course of the Tiber river which had moved again westward, close to its actual position. A similar history was repeated every time that new violent ignimbrite explosions occurred during the Tuscolano-Artemisio Epoch (from 600 ka to 300 ka; DE RITA *et alii,* 1995; 2005) (fig. 4) and filled the valleys newly created by the erosive processes occurring after each eruptive phase. The thickness lateral variation of the ignimbrite deposits indicate the shifting of the paleo-valleys of the roman land after each eruption. The erosive processes were particularly active for two reasons: (i) for the quaternary wide sea level oscillations which characterized the climate during this period and (ii) for the enormous amount of new material added to the topography by the volcanism. Obviously, if the sea level was lowering during or after the eruptions, the cut of the valleys was particularly efficient. This is the reason of the seven hills of Roma due to the development of deep valleys on the ignimbrite plateau close to the delta of the Tiber river during the last glacial period, when the sea level was more than 100 m lower than at the present (fig. 5a). During the last interglacial period, still in course, these valleys come to be progressively filled by thick piles of fluvial sediments (more than 60 meters, in some cases) (fig. 5b).

4.– THE GEOLOGY OF THE CAPITOL HILL

The Capitol Hill, even today, shows its original geological characteristics and can be used as a lecture key to understand the geological evolution of the Roman area. The NW-trending hill has a very flat summit and steep cliffs with elevations between 40 and 45 m asl. The geology of the area of the Capitol Hill is summarized in figure 6a, whereas figure 6b shows a NNE-trending schematic cross section trough the Capitol Hill.

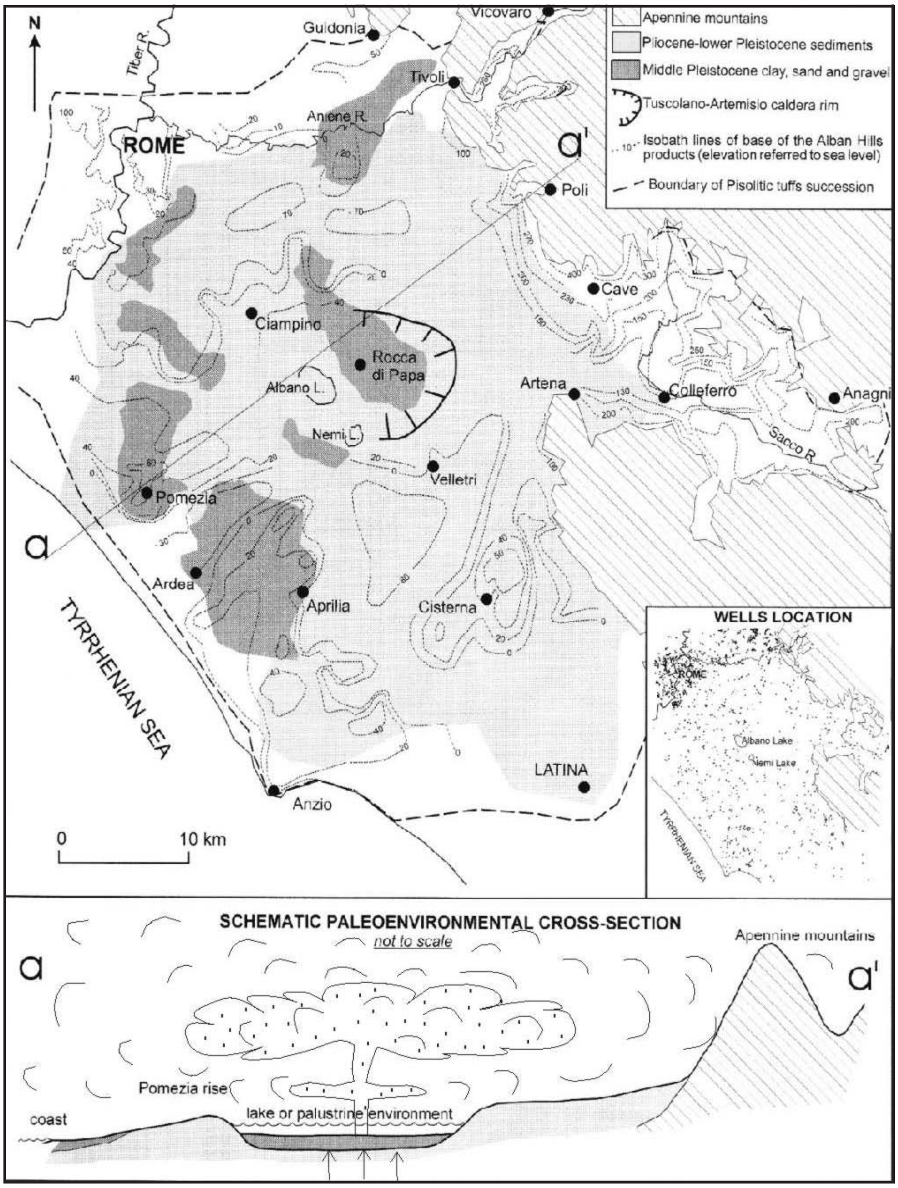

Fig. 3 – Schematic map showing the paleomorphology of the Alban Hills area at the beginning of the volcanism. The map has been constructed interpreting the data of several shallow wells, usually done for water supply (small square, down right of the map). Below is a schematic interpretation of the phreatomagmatic character of the first explosions from the Colli Albani volcanic District. The huge quantity of water stagnating in the low topographic area limited by the Pomezia rise and the Apennine chain, coming in contact with the rising magma, determined particularly violent explosions. The ignimbrites (almost four successive units separated by paleosoils: Trigoria, Tor de Cenci, Palatino and Cavaliere units) expanded several kilometres from the crater reaching the sea westward and climbing the Apennine eastward (modified after De Rita *et alii*, 2002)
– *Carta schematica che illustra la paleogeomorfologia dell'area dei Colli Albani all'inizio del vulcanesimo. La carta è stata costruita interpretando i dati di numerose sorgenti poco profonde, generalmente utilizzate per l'approvvigionamento d'acqua (piccoli punti in basso a destra della carta). In basso un'interpretazione schematica del carattere freatomagmatico delle prime esplosioni del distretto vulcanico dei Colli Albani. La grande quantità d'acqua accumulatasi nell'area compresa tra la dorsale di Pomezia e la catena appenninica, venendo in contatto con il magma in salita, determinò esplosioni particolarmente violente. Le ignimbriti (per lo più quattro unità successive separate da paleo suoli: unità di Trigoria, Tor de Cenci, Palatino and Cavaliere) si espansero per diversi kilometri dal cratere raggiungendo il mare ad ovest e salendo verso l'Appennino verso est (modificato da* De Rita et alii*, 2002)*

The most ancient deposits outcropping in the Campidoglio are made of an aggradational and fining upward succession of fluvial to lacustrine sediments. The succession, named S. Cecilia (cf. Marra & Rosa, 1995; Funiciello & Giordano, 2005; Giordano *et alii*, 2003) was deposited between 700 and 550 ka, by the activity of the PaleoTiber River that from lower Pleistocene to the beginning of Middle Pleistocene was flowing in a position more eastward, having its delta in the area of Ponte Galeria (Marra & Rosa, 1995; Milli, 1997). On this succession, volcanic deposits from the Colli Albani volcano lie. At the base of the Rupe there is the deposit of the third (named Palatino unit) of the four largest magnitudo eruptions occurred between 570 and 530 ka from the Alban Hill volcanic area (Karner & Renne, 1998; Karner *et alii*, 2001). This event is separated by a paleosoil from the subsequent Casale del Cavaliere unit (fig. 7). These eruptions were particularly violent (phreatoplinian type; De Rita *et alii,* 2002) because the rising magma encountered surficial waters related to a large costal lake or to a palustrine environment developed between 700 and 600 ka, when the uplift of the NW trending Mt. Mario ridge caused the diversion of the paleo-Tiber river toward southeast. The ignimbrite deposits are generally known in literature as "Pisolitic tuffs" (Fornaseri *et alii*, 1963) for the presence in the ashy matrix of accretionary-lapilli. In the Campidoglio area the ignimbrite deposits seem to be confined within a NW-trending paleo-valley that may be the course of the ancient Tiber or a secondary valley of it.

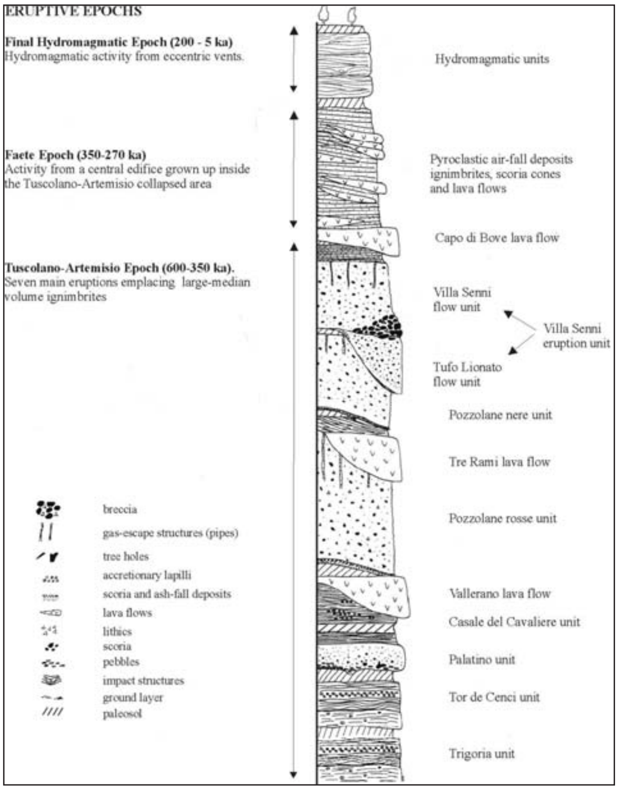

Fig. 4 – Up to date schematic stratigraphy of the Alban Hills volcanic activity (modified after ROSA, 1995).
– *Schema stratigrafico aggiornato dell'attività vulcanica dei Colli Albani (modificato da ROSA, 1995).*

Outcrops along Via della Consolazione allow to recognize a massive and poorly sorted deposit, made by 90% coarse ash-sized matrix composed of juvenile shards and fragments of analcime, clinopyroxene and mica crystals. Lava lithics and vescicular scoria lapilli are dispersed in the matrix. At the base of the unit it is possible to observe wood remains, density structures and calcareous and siliceous fluvial clasts ripped up by the pyroclastic flow (fig. 8).

Thin deposits of clastic and volcaniclastic fluvial materials lie on the Casale del Cavaliere unit and are visible along Via della Consolazione. They are the record of fluvial processes occurred immediately after the eruption to restore the normal sedimentary conditions. The two phreatoplinian deposits in the Campidoglio area are deeply eroded. On the erosive westward dipping surface is the deposit of the Villa Senni unit whose thickness increases westward (fig. 9). This suggests that significant modification of the drainage network occurred between the deposition of the phreatoplinian units and the subsequent Villa Senni volcanic unit occurred at about 350 ka. During this interval of time a new important valley, northwest of the ancient one, in the area where now is Via del Teatro Marcello, was eroded. This event probably occurred because of the subsequent deposition of ignimbrites (Pozzolane rosse and Pozzolane nere units dated at 430 ka; KARNER *et alii*, 2001) from the Alban Hills volcano whose emplacements forced the Tiber river course westward. None of these ignimbrites is present in the Campidoglio area.

The Villa Senni unit is composed of two different deposits: (i) the Tufo Lionato and (ii) the Villa Senni units which are the lower and upper flow units respectively of the same eruption. These eruption-units have been dated several times with different techniques at ca. 350 ka (BERNARDI *et alii*, 1982; RADICATI DI BROZOLO *et alii*, 1981; KARNER & RENNE, 1998; KARNER *et alii*, 2001). The Rupe Tarpea is made of the Tufo Lionato deposit (fig. 10) whereas the Villa Senni unit is not present. It has very limited and thin exposures in the Campidoglio area.

The Tufo Lionato eruption-unit is characterized by yellowy-reddish ashy matrix composed of juvenile shards and fragments of analcime, clinopyroxene and mica crystals. Yellow pumices, black scoria, lava and holocrystalline (leucite + pyroxene) lithics may be found dispersed in the matrix. The name Tufo Lionato comes from the yellow colour of the ashy matrix resembling that of the lion head of hair and from the lithification of the tuff due to intense processes of zeolitization of the ashy matrix that give to the tuff its particular resistance.

On top of the Tufo Lionato eruption-unit, the Aurelia unit is present (MARRA & ROSA, 1995, GIORDANO *et alii*, 2003; FUNICIELLO & GIORDANO, 2005). The Aurelia unit is made of pebbles, clays, sands and volcaniclastic sediments on a flat morphology representing the remain of a previous fluvial terrace (fig. 10). The altitude of the Aurelia deposits indicates the level of the river after the Villa Senni eruption. The last marine low standing at about 18 ka caused the intense fluvial erosion that has determined the steep cliffs of the hill. The present day morphology of the Capitol Hill is also partially due to the man action. The most important modifications of the morphology of the hill due to the action of the man are the separation of Capitol Hill from the Quirinal Hill wanted by Julius Caesar between the 108 and 113 B.C. to make space for the Roman Foro and the realization of the Campidoglio square that included the partial filling up of the threshold (*Asylum*) separating the two small tops of the hill, the Arx and the Capitolium. In urban areas the man actions may be considered as a geological factor strongly modifying the natural environment.

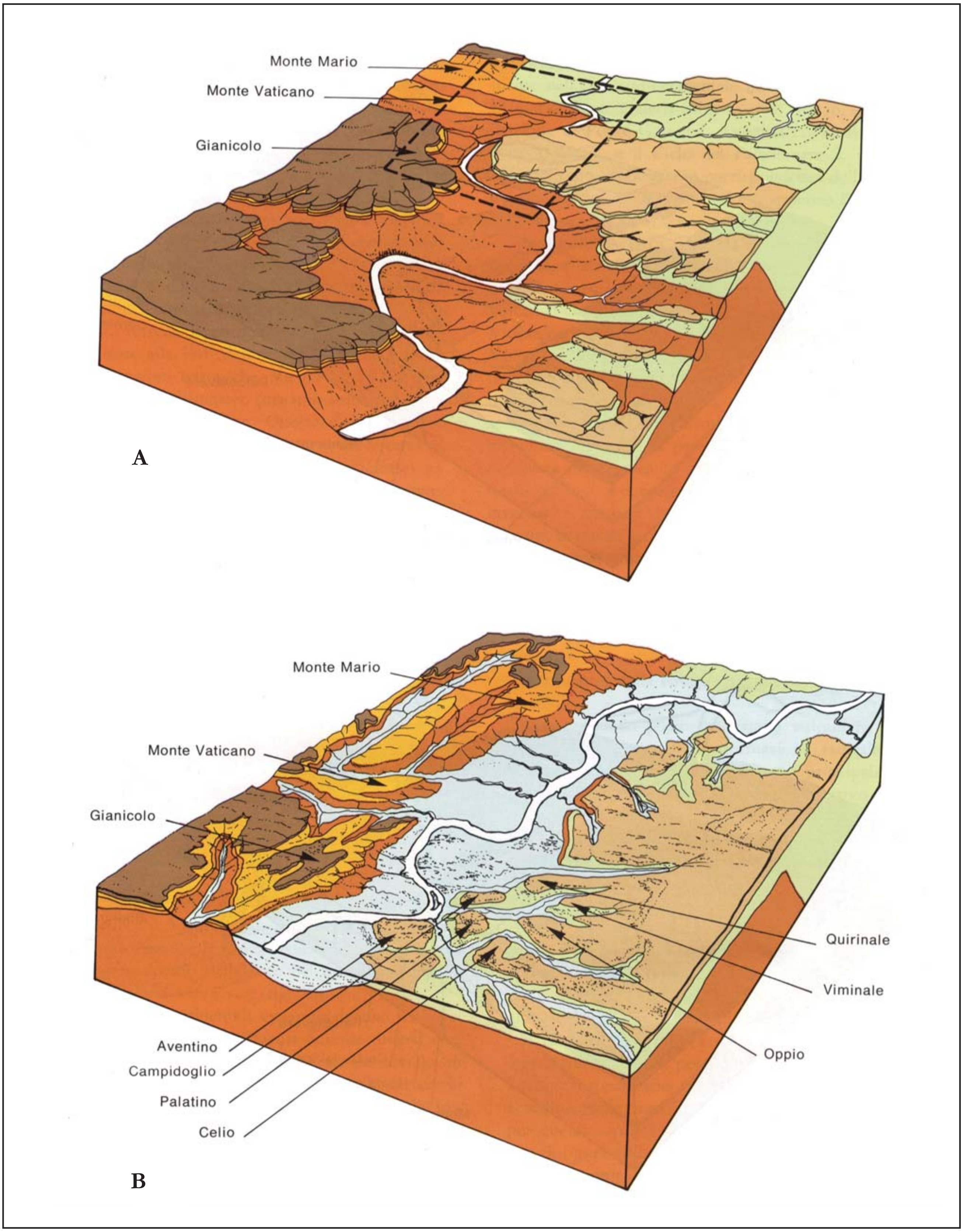

Fig. 5 – Block diagrams illustrating the recent geological evolution of the Roman area. 5A) Erosion processes related to the Wurm glacial period caused the excavation of deep valleys in the volcanic products. 5B) The erosion processes caused the formation of the seven hills upon which Rome grew up (from Funiciello, 1995).

— Il diagramma a blocchi illustra la recente evoluzione geologica dell'area romana. 5A) I processi erosivi correlati al periodo glaciale würmiano hanno causato l'escavazione di profonde valli nei prodotti vulcanici. 5B) I processi erosivi hanno causato la formazione dei sette colli sui quali Roma si è sviluppata (da Funiciello, 1995).

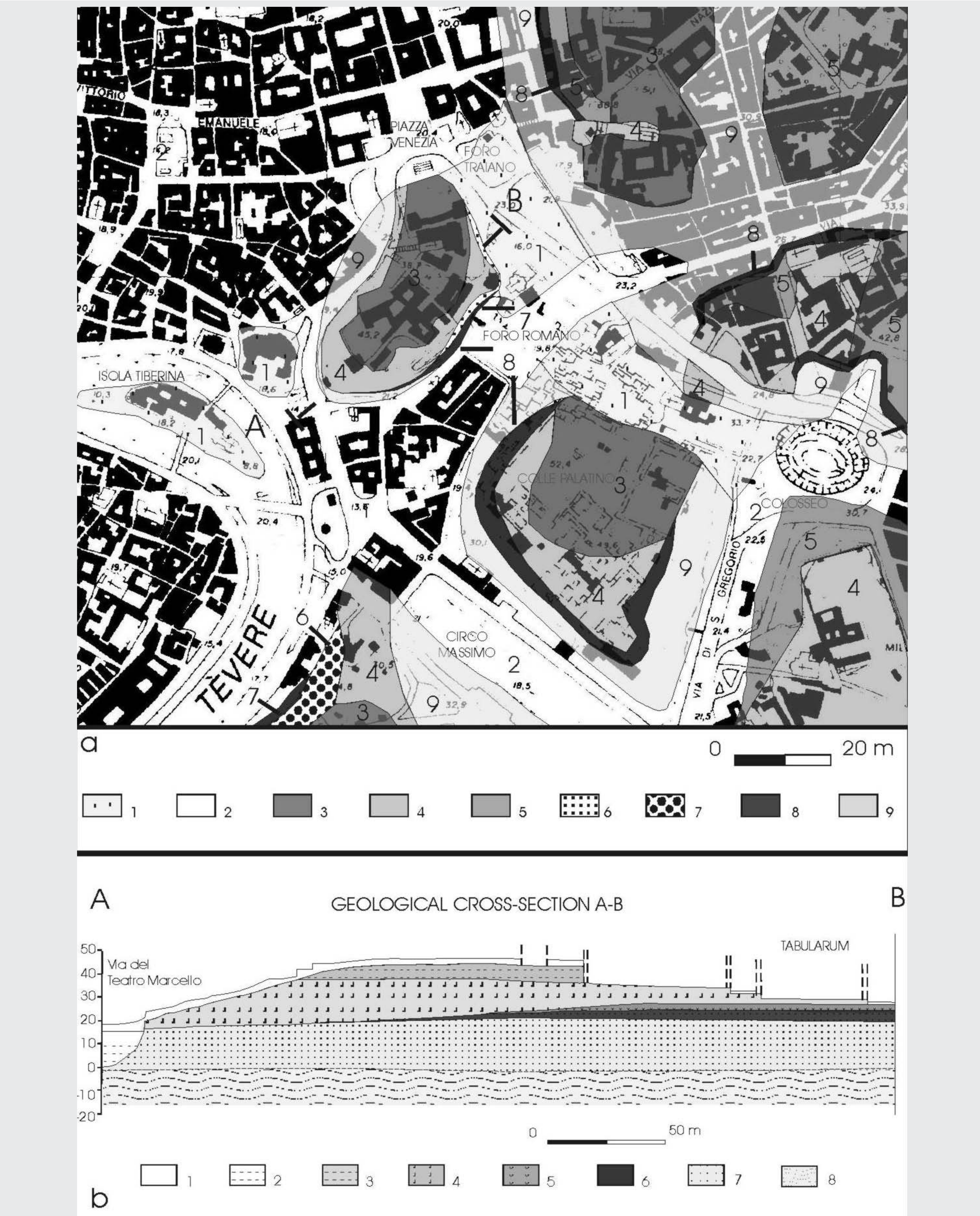

Fig. 6 – a) Schematic geological map of the Campidoglio area. Legend: 1. Urbanized areas. 2. Alluvial deposits. 3. Aurelia unit. 4. Villa Senni eruption deposits. 5. Sacrofano succession. 6. Valle Giulia unit. 7. Casale del Cavaliere unit. 8. Palatino unit. 9. Santa Cecilia unit. b) NE-trending cross section trough the Capitol Hill. 1. Antropic materials and buildings. 2. Alluvial deposits 3. Aurelia unit. 4. Tufo Lionato flow unit deposits. 5. Casale del Cavaliere unit. 6. Palatino unit. 7. Santa Cecilia unit. 8. Monte Vaticano Formation.

– a) Carta geologica schematica dell'area del Campidoglio. Legenda: 1. Aree urbanizzate. 2. Depositi alluvionali. 3. Unità Aurelia. 4. Depositi dell'eruzione Villa Senni. 5. Successione di Sacrofano. 6. Unità di Valle Giulia. 7. Unità di Casale del Cavaliere. 8. Unità di Palatino. 9. Unità Santa Cecilia. b) Sezione del Campidoglio con direzione NE. Legenda: 1. Materiali antropici ed edifici. 2. Depositi alluvionali 3. Unità Aurelia. 4. Depositi dell'unità di Tufo Lionato. 5. Unità Casale del Cavaliere. 6. Unità Palatino. 7. Unità Santa Cecilia. 8. Formazione di Monte Vaticano.

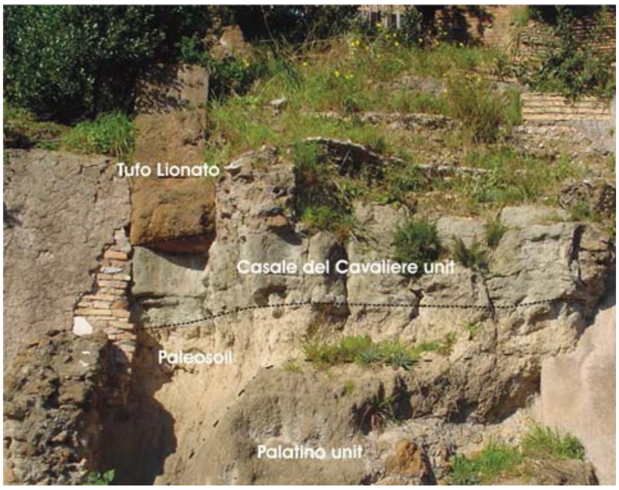

Fig. 7 – The Rupe Tarpea from Via della Consolazione. On top of the volcanic deposits (Palatino, Casale del Cavaliere and Tufo Lionato units) the sandy-clay sediments of the Aurelia formations are visible.
– *La Rupe Tarpea vista da Via della Consolazione. Al di sopra dei depositi vulcanici (unità del Palatino, unità Casale del Cavaliere e unità Tufo Lionato) sono visibili i depositi sabbioso-argillosi della Formazione Aurelia.*

Fig. 8 – Density structures at the base of the Palatino unit.
– *Strutture di densità alla base dell'unità Palatino.*

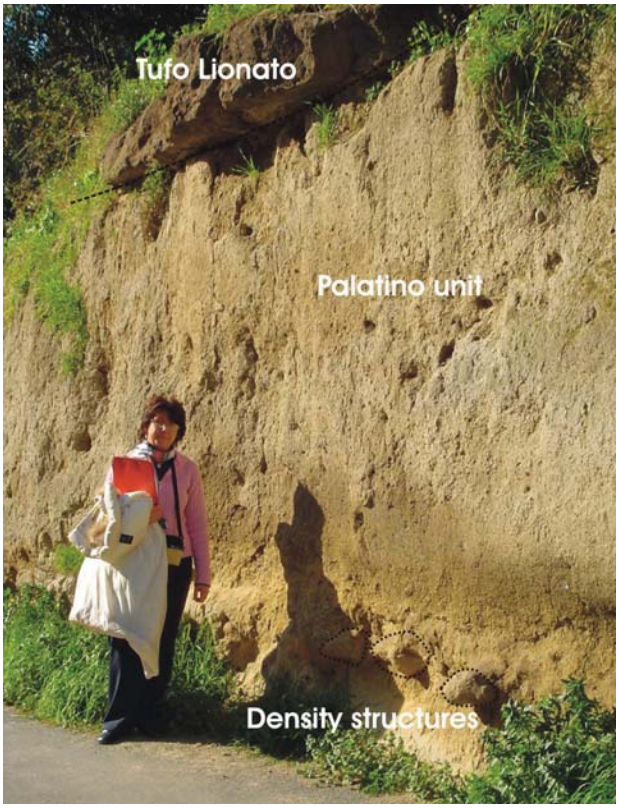

Fig. 9 – Outcrop on the south-eastern side of the Capitol Hill, showing the volcanic and volcaniclastic succession constituting the Rupe Tarpea. This outcrop represents the mark of the geological evolution of the area. At the base is the Palatino unit that a paleosoil separates by the overlying Casale del Cavaliere unit. This last unit appears deeply eroded by an erosion NW dipping surface forming a fluvial channel. The channel is filled up by the volcanic deposits of the Tufo Lionato eruption unit.
– *Affioramenti del settore sud-est del Campidoglio che mostrano la successione vulcanica e vulcano-clastica che costituisce la Rupe Tarpea. Questo affioramento rappresenta il segno dell'evoluzione geologica dell'area. Alla base affiora l'unità del Palatino che è separata dalla successiva unità di Casale del Cavaliere da un paleo suolo. Quest'ultima unità appare profondamente erosa da una superficie erosiva con immersione con direzione nord-ovest a formare un canale fluviale. Il canale è stato riempito da depositi vulcanici dell'unità eruttiva di Tufo Lionato.*

5. - CONCLUSIONS

In the Capitol Hill, the ruins of the roman monuments, the architecture of the historical buildings and the landscape constitute an inseparable whole: all these aspects are, in fact, closely interconnected. The landscape assumes an archaeological relevance as much as it perpetuates the morphological and landscape conditions which permitted the establishment and development of man's activity. The Rupe Tarpea reflects the concept that a landscape that has remained intact trough the millennia offers a key to the interpretation of ancient civilizations and acquires consequently an archaeological value (ANZIDEI, 1999).

The geology and the geomorphology of the Capitol Hill and the steep cliffs of the Rupe Tarpea represent cultural heritages of the Roman area. In this small but representative area of Roma city the relationships among geology, geomorphology, archaeology, history and architecture are evident and significant and strongly suggest to include the Rupe Tarpea in the global sites to promote a discerning type of tourism that takes note of people's culture. The Romans, in fact, recognize the Rupe as part of their cultural heritage. The symbol of the cliff, the geological and morphological characteristics of the roman territory are harmoniously blended with the reasons of the legends and with the history of the Roman people.

The original geological characteristics of the site are well preserved and may be indicated to illustrate the regional geological characteristics of this area even constituting an irreplaceable witness of the history of the Roman area.

Fig. 10 – View of the Rupe Tarpea from southwest. The altitude of the Aurelia deposits indicates the level of the river after the Villa Senni eruption. – *Vista della Rupe Tarpea da sud-ovest. La quota dei depositi dell'Aurelia indica il livello del fiume dopo l'eruzione di Villa Senni.*

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Landscape units, Geomorphosites and Geodiversity of the Ifrane-Azrou region (Middle Atlas, Morocco)

Unità di paesaggio, Geomorfositi e Geodiversità della regione Ifrane-Azrou (Medio Atlante, Marocco)

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ABSTRACT – The concept of geomorphosites is relatively recent (PANIZZA, 2001), finding application in many European nations, but in Africa much research on geomorphological heritage has still to be done. The research group has started studying landscape units, geomorphology, geomorphosites and geological heritage in different North-African regions, with the aim of drawing thematic geomorphological maps. The choice of these arguments as main objectives of this research is determined by the absolute lack of specific researches on these topics in Morocco. Furthermore, the very interesting landscapes, very rich in geological and geomorphological sites, deserve to be better known, safeguarded and valorised. This research has allowed to realise the first example of Landscape and Geomorphosites Map in Morocco, compiled for the area of Ifrane and Azrou in the Middle Atlas (Central Morocco).
This region is already inserted in the classical tourist routes that connect Fes and Meknès with the South of Morocco and this fact, together with its geological and geomorphological variety, has suggested its selection for this type of applied research. The research carried out by means of the analysis of airborne- and satellite images and direct field observations have brought to the recognition of 14 landscape units in which 42 geomorphosites have been selected. These geomorphosites comprise springs, karst landforms (polje, dolines, caves, sinkholes, stone forests, cryptokarstic dolines), carbonate depositional landforms (travertines and waterfalls), fluvial landforms (meanders, canyons, palaeo-valleys, etc.), structural landforms (triangular facets, hogbacks, cuestas, residual outcrops, etc.), volcanic landforms (volcanoes, caldeira, pyroclastic cones, lava tube) and two geo-botanical sites. The results of this research have been summarised in a geomorphological map, representing the various landscape units and the geomorphosites, and comprises a proposal for the valorisation of the geomorphological heritage by means of six itineraries. The Map, constructed upon a Landsat ETM+ image, is completed with some geological sketch maps and sections and several photographs of the geomorphosites with their scientific explanation.

KEY WORDS: Geomorphosites, Karst, Geotourism, Mapping, Middle Atlas, Morocco.

RIASSUNTO – Il concetto di geomorfosito è relativamente recente (PANIZZA, 2001) ed ha trovato applicazione in molti paesi europei, ma quasi tutto resta da fare sulla ricerca sui geomorfositi nel continente africano. Il Gruppo di Ricerca ha iniziato a studiare le unità di paesaggio, la geomorfologia, i geomorfositi e il patrimonio geologico in alcune regioni del Nord Africa, con lo scopo di redigere delle Carte Geomorfologiche tematiche. La scelta di questi argomenti come principali obiettivi delle ricerche fu determinata dalla quasi completa assenza di tali studi in Marocco. Inoltre, i paesaggi molto interessanti, in cui abbondano siti di interesse sia geologico sia geomorfologico, meritano di essere meglio conosciuti, salvaguardati e valorizzati. Questa ricerca ha consentito di realizzare il primo esempio di Carta dei Paesaggi e dei Geomorfositi per il Marocco, comprendendo l'area di Ifrane ed Azrou nel Medio Atlante (Marocco centrale).
Questa regione si trova attualmente già inserita in uno dei classici itinerari che collegano le città imperiali di Fès e Meknès con il Sud del Marocco. È proprio questa sua caratteristica, insieme all'abbondanza di siti di interesse geologico e geomorfologico, ad averne determinato la selezione per questo tipo di ricerca applicata.
La ricerca, svolta attraverso l'uso di immagini aeree e satellitari ed alcune campagne geologiche sul terreno, ha portato all'individuazione di 14 unità di paesaggio in cui 42 geomorfositi sono stati descritti e catalogati. Questi siti comprendono sorgenti, morfologie carsiche (polje, doline, inghiottitoi, paesaggi ruiniformi, doline criptocarsiche), morfologie carbonatiche di deposizione (travertini e cascate), forme fluviali (meandri, gole, paleovalli, ecc.), forme strutturali (facette triangolari, hogbacks, cuestas, forme residuali, ecc.), forme vulcaniche (coni vulcanici, caldeira, coni piroclastici, grotte di lava) e due località di interesse geobotanico.

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I risultati di questa ricerca sono stati riassunti in una Carta geomorfologica che rappresenta le varie unità di paesaggio ed i geomorfositi, e comprende una proposta di valorizzazione di questo patrimonio geomorfologico attraverso sei itinerari tematici. La Carta ha come base un'immagine Landsat ETM+, ed è completata da alcuni schemi geologici e diverse fotografie dei geomorfositi con loro spiegazione scientifica.

PAROLE CHIAVE: Geomorfositi, Carsismo, Geoturismo, Cartografia, Medio Atlante, Marocco.

1. – INTRODUCTION

Geoconservation and Geological Heritage are well-known in Europe since the first debates held in the late 80's and especially since the birth in 1993 of ProGEO (European Association for the Conservation of the Geological Heritage) from the previously instituted European Working Group for Earth Science Conservation. The European Project GEOSITES, promoted by the International Union of Geological Sciences (IUGS) has induced many European countries and regions to evaluate their geological heritage (AA.VV., 1998; WIMBLEDON *et alii*, 1995).

Also the term Geomorphological heritage or Geomorphological asset, even though much less common in scientific literature, has also been used since about ten years (BARCA & DI GREGORIO, 1999; CARTON *et alii*, 1994; PANIZZA & PIACENTE, 1993), while the term "Geomorphosite" has been coined only recently as "a landform with attributes which qualify it as a component of the cultural heritage" (PANIZZA, 2001; PANIZZA & PIACENTE, 2003). In practice, however, many previously described Geosites can often also be defined as Geological Monuments or Geomorphosites.

The whole of this cultural geological revolution has lead to the introduction of the term "Geodiversity" defined as "the range (or diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes" (GRAY, 2003; SHARPLES, 1995).

Geoconservation, Geological Heritage, Geosites, Geomorphosites and Geodiversity, however, are terms that are not yet properly developed in the African continent, although the first attempts are starting to obtain some preliminary results especially in South Africa (REIMOLD, 1999) and much more recently in some North African countries (DE WAELE *et alii*, 2005a; DE WAELE *et alii*, 2005b; OUANAIMI *et alii*, 2005).

One of the most interesting North-African countries from this point of view is Morocco, a country with a very rich geology, studied by several generations of earth scientists and recognised as one of the most interesting geological regions of the Mediterranean area by most of the modern geological scientific communities. The extraordinary geological succession, characterised by rocks of all sorts of types (igneous, sedimentary and metamorphic) dating from Precambrian up to Holocene, spread over a latitude range of 22-36° North and altitudes from sea level up to 4165 m a.s.l. at Mount Toubkal, have lead to a very rich geomorphological and geological landscape and a very high degree in geodiversity.

For this reason our research team has decided to start a scientific campaign on the Geomorphosites and the Geodiversity of Morocco choosing as a first test site the Middle Atlas of Ifrane-Azrou (EL WARTITI *et alii*, 2008; DE WAELE & MELIS, 2009) (fig. 1). This research has been carried out by the Laboratories of Environmental Geology and of Remote Sensing (TeleGis) of the Department of Earth Sciences (Cagliari University - Italy) in collaboration with the Laboratory of Applied Geology of the Science Faculty of the University Mohammed V-Agdal of Rabat (Morocco). This Project has benefited of the financial aid of the Sardinian Government (Regional Law 19/1996, cooperation with developing countries).

2. – GEOGRAPHICAL AND GEOLOGICAL SETTING

The Middle Atlas is a SW-NE elongated mountainous chain located between the Atlantic Morocco to the West and the Moulouya plains to the East and forming a physical barrier that separates the Atlantic regions from the eastern parts of Morocco. Towards the South it is bordered by the high mountain ranges of the High Atlas, while to the

Fig 1 – Geographical location of the study area.
– *Ubicazione dell'area di studio.*

North it passes to the Saïss plain and the Rif mountains. From a morphological point of view the Middle Atlas can be subdivided in two main sectors: the northern and western parts are called the Middle Atlas *Causses*, while in the South and Southwest the "*Atlas Moyen Plissé*" (or Folded Middle Atlas) is located.

The Middle Atlas *Causses* are characterised by a series of high plains at altitudes ranging from 1800 m a.s.l. North of Oum Er Rbia to little over 1000 close to El Hajeb, more or less cut by valleys. In the Folded Middle Atlas the landscape is controlled by more or less broad synclines bordered by narrow ridges that can reach altitudes of more than 2000 meters, with a maximum of 2794 at Jbel Tichoukt. The study area is almost entirely located in the Middle Atlas *Causses* and comprises the villages of Ifrane, El Hajeb, Ain Leuh, Timahdite and Azrou.

This area is located not far South of the imperial cities of Fès and Meknès and covers a surface of more than 3500 square km. It is crossed by the national roads P21 connecting Meknès to Midelt and Ar-Rachidia and the P24 that links Fès to Beni Mellal and Marrakech and is thus one of the cross-roads used by foreign visitors to go from North to South Morocco. Furthermore, the area is already well-known for its Cedar forests and ski stations close to the tourist resort of Ifrane.

Climate is of Mediterranean type and is characterised by rainy winters and springs and a long period of drought with intense precipitation during late summer storms. Mean annual rainfall exceeds 900 mm (from 655 mm at El Hajeb – 1050 m a.s.l., over 827 mm at Azrou – 1250 m a.s.l. up to 1122 mm at Ifrane at 1635 m a.s.l.) and mean annual temperature is about 12 °C with very great differences between winter and summer (Ifrane: -4 - 30 °C, El Hajeb: 3-32 °C). Snow is present above 1500 meters of altitude during winter giving sometimes possibility of skiing (stations of Mischliffen and Jbel Hebri).

From a geological viewpoint the outcropping rocks are of metamorphic, sedimentary and volcanic origin and cover a lapse of time ranging from Silurian to Holocene (MARTIN, 1981; MICHARD, 1976; PIQUÉ, 1994) (fig. 2). The oldest rocks of the area crop out in a vast territory West of the national road P21 between El Hajeb and Azrou in an erosion window. This interesting and scenographic

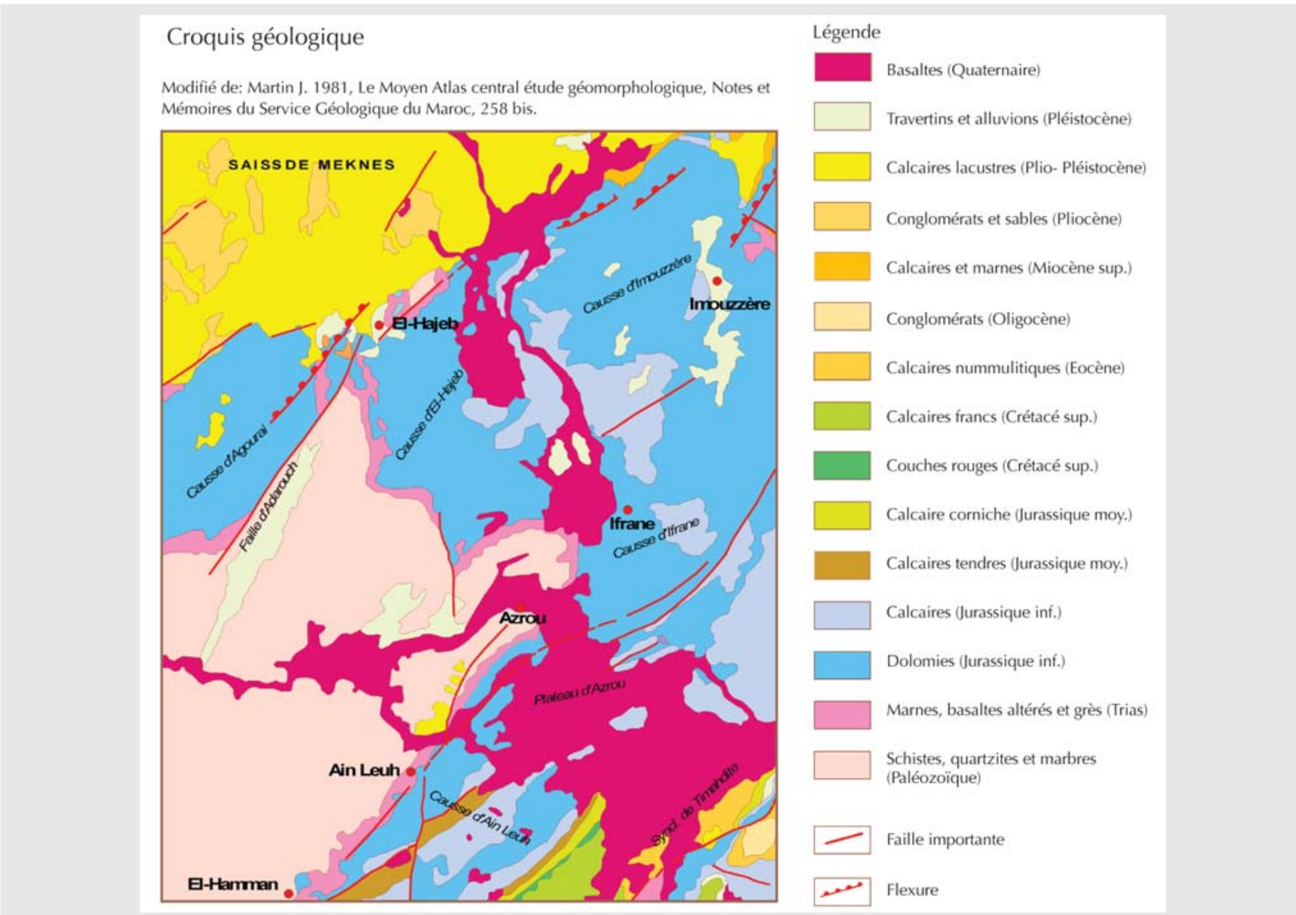

Fig. 2 – Geological sketch map of the study area (modified from MARTIN J., 1981).
– *Carta geologica semplificata dell'area di studio (modificata da MARTIN J., 1981).*

panorama on Palaeozoic rocks can be observed from the well-known *Balcon d'Ito*, one of the famous tourist stops of this part of Morocco. The Palaeozoic sequences are characterised by an alternation of soft (shales and phyllites) and hard rocks (marbles, sandstones and quartzites) intensively folded in typical Variscan NE-SW directions and ranging in age from Ordovician to Lower Permian. The structural control is clearly visible in the landscape with sharp and long rectilinear ridges and a subdendritic drainage pattern with valleys mainly directed NE-SW (AA.VV., 1975).

The first sediments deposited upon this basement complex are Triassic sandstones and red clays followed by weathered doleritic basalts that can be traced along the entire western margin of the *Causses* (PIQUÉ & LAVILLE, 1993). These outcrops, clearly recognisable by their colours, from the reddish of the clays to the dark brownish of the volcanic rocks, have been eroded by surface drainage forming a concave and gentle slope towards the underlying Palaeozoic rocks (MARTIN, 1981). But the most important rock types that characterise more than 50 % of the study area are the Jurassic carbonate rocks of the *Causses*. These are composed of dolostones, calcareous dolostones and limestones that have been deposited in a more or less shallow sea from Sinemurian up to Bathonian (COLO, 1964; MARTIN, 1981). The entire series is easily distinguishable in two major facies: a lower dolomitic one easily recognisable for its greyish colour and ruin-like morphologies, and an upper facies where limestone is predominant.

Towards the end of the Middle Jurassic the whole area emerged from the sea giving rise to a long and intense erosion period that lasted from Upper Jurassic until part of Lower Cretaceous. The first post-Jurassic sediments are composed of red marls and clays with conglomerate intercalations attributed with some doubts to the Cenomanian. These sediments crop out on the border of the large syncline of Bekrite-Timahdite. These are followed by pure and marly limestones of Upper Cretaceous, followed by a thick sequence of sandstones, gypsum and claystones of Palaeocene and ending with the fossiliferous limestones of Eocene age that form a platform and cliffs near the village of Timahdite (RAHHALI, 1970).

The sedimentary sequence of the study area ends with the lacustrine limestones, sands and conglomerates of Plio-Quaternary age that have infilled the Saïss plain and travertines that locally crop out along the border of the *Causses* (e.g. El Hajeb).

During Pleistocene also an important alkaline volcanic phase has taken place leaving over 400 square km of basalts with beautiful cones and calderas on the plateau d'Azrou (HARMAND & CANTAGREL, 1984; HARMAND & MOUKADIRI, 1986). K-Ar Age of these basalts ranges between 0.6 and 1.8 Ma (EL AZZAB & EL WARTITI, 1998), but the fresh landforms suggest an even younger age for some of these volcanoes.

3. – GEOMORPHOLOGY

The overall geomorphology of the Middle Atlas Causses is the product of a combination of mostly inherited and some active landforms.

The topography of the summits of the *Causses* designates an important palaeo-surface (denudation plain) that has been dated back to Eocene. This testifies a long period of tectonic stability, with the Eocene sea submerging most of the Mesozoic carbonates. Subsequently tectonic activity reactivated during Oligocene and dislocated the different plateaus of the *Causses*. Another period of tectonic stability occurred during Middle Miocene producing another denudation plain that did however leave the higher summits and the Eocene palaeo-surface in place (MARTIN, 1981). During this continental period karst corrosion processes begin to play an important role.

During Late Miocene-Pliocene erosion processes start building up the present landscapes, with the slow uplift of the *Causses* and the formation of the Northern and Western tectonic escarpments: the first clearly divides the Saïss plain and Rif from the Middle Atlas *Causses* while the second separates the *Causses* from the Palaeozoic outcrops (BEAUDET & MARTIN, 1967). The presence of important deposits of travertines in the Saïss plain and along the north-western border of the *Causses* testifies important karst corrosion of the Liassic dolo- and limestones during this period. Erosion processes accelerate with the rapid incision of the Oued Sebou gorge on the Pliocene-Quaternary boundary leading to the final shaping of the present landforms and landscapes.

During Quaternary this landscape is disrupted by volcanic activity that give rise to several edifices and lava flows. The volcanic landforms appear very fresh and unaltered, especially on the Azrou plain, and comprise lava flows (pahoehoe lava), lava tubes, hornitos, spatter cones, caldera, explosion craters etc. The fact that these lava flows cover a karst topography has led to a convergence of forms with big collapse cryptokarstic dolines sometimes due to the presence of underlying lava tubes, but generally related to the collapse in depth of karst tunnels in limestones of Lias (MARTIN, 1981).

The present landscape of the *Causses* is disseminated with more or less active karst landforms, mainly present on the dolo- and limestone outcrops at different altitudes, but minor forms have also been observed in the Palaeozoic marbles of the Tizra hogback. Many of the bigger landforms, such as poljes, macrodolines and uvalas, are related to the intense karst phases of Mio-Pliocene and are now almost completely inactive. They are generally located in structurally favourable areas such as intersection of faults or synclines. Some of these (Dayet Ifrah, Aguelmam Azigza etc.) still contain temporary lakes but lack springs and ponors. Their base level, very close to the aquifer, is slowly filling up with sediments and corrosion is no more active on their bottoms and their flanks.

The very large macrodolines such as Moutferraoun (1.5 km wide and 110 m deep) and Trou de la Panthère are big collapse structures in the Lower Lias dolostones that do not appear to be related to faults. Their origin is most probably due to the dissolution of salt in the underlying Trias, leading to relatively fast collapse (El Khalki & Akdim, 2001; Martin, 1981).

The same dolostones display a wide variety of ruin-like forms, creating strange landscapes of rocky mushrooms, pinnacles and towers of several meters high, cut by rectilinear troughs and trenches. Very beautiful examples are located at Tidrine, near Ifrane, and at Tisfoula, along the road to the springs of Oum-Er-Rbia.

Karren landforms are widely represented especially in the dolostone facies in association with these ruin like landforms, but also occur in limestones of the *Causses* and in the marbles of Tizra. In some places, at high altitudes and on the northern slopes, their rounded forms probably reflect their corrosion under snow or beneath a soil cover. Besides all kinds of normal and rounded clints also solution pans (*kamenitze*) are well represented.

The influence of snow on the karst forms is also well displayed above 1,700 m of altitude in the asymmetric shape of the dolines, with a preferential dissolution of their protected inner slopes. A similar phenomenon also occurs in the High Atlas karst of Ait Abdi (Perritaz, 1996).

Despite the well developed surface karst only few caves are known in the Middle Atlas mountains. This is due to the scarceness of thick pure limestone beds, often intercalated with marly limestones, and the abundance of highly fractured dolostones that convey surface waters directly to the underlying Trias through cracks and fissures (Martin, 1981). One of the best examples of true karst caves is Ifri-ou-Berrid, a sinkhole located at the end of a blind valley and with an underground development of approximately 100 meters, ending in a drowned passage.

Landscape development during Quaternary is characterised by the mechanical and chemical cutting of valleys during the wetter periods and the deposition of travertines and alluvial sediments during periods with diminished flow rate and higher temperatures. Now these valleys are mostly dry, except from the ones fed by springs (e.g. Oum-Er-Rbia) and are the relict of the drainage network of the pluvial periods.

Present morphodynamics is mainly correlated to karst denudation processes, weathering of the alkaline basalts and slope dynamics (especially on soft rock-types, e.g. Triassic marls and altered dolerites), enhanced by heavy sheep-breeding activities, with formation of badlands, gullies, creep and solifluction phenomena etc.

4. – METHODS

The adopted methodology is based on the experience acquired during the past couple of years in two National Research Projects (PRIN 2001-2003 on Geosites in the Italian Landscape and PRIN 2004-2006 on Geotourism in Italy) and especially during a Co-operation Project, financed by the Sardinian Regional Government, in which our team has collaborated with the Institute des Regions Arides of Medenine (Tunisia) aiming to define the geological heritage of the region of Tozeur in South Tunisia (De Waele *et alii*, 2005b; Di Gregorio *et alii*, 2002). This method is based on the preliminary consultation of scientific and geographic literature and topographical, geological and tourist maps that have lead to a first selection of sites and landscapes of geological and geomorphological interest. For this purpose the detailed and magnificent PhD work of Jacques Martin, presented in 1977 at the Université de Paris VII (Martin, 1981), has been of enormous value, giving lots of suggestions on sites and landscapes of possible geo-tourist attraction.

Several field campaigns have been organised to study more in detail the selected geosites and geomorphosites, to verify the collected bibliographical data and to make detailed observations and gather further documentation (e.g. geological sketches, geomorphological processes, photographs). During these trips several other geomorphosites, previously ignored, have been added to the list and have also been studied in detail.

For the description of these sites in the field a sheet file has been compiled in which, together with the data of identification of the site (e.g. commune, locality, co-ordinates, altitude) also data on accessibility, visibility, geology and geomorphology, use and state of conservation are reported. Contents of such a sheet file, similar to the one adopted by our research team in Tunisia, is reported in figure 3.

Nom du Géosite: **Numéro**

1. IDENTIFICATION
- *Gouvernorat*:
- *Commune*:
- *Localité*:
- *Références cartographiques* (1:50.000 ou 1:100.000):
- *Coordonnées métriques centrales* (U.T.M.):

Localisation (sur une carte du Maroc) *Itinéraire (sur Carte routière 1.1.000.000)*	*Extrait de la Carte topographique et localisation (échelle 1:100.000 ou 1:50.000)*

Description géométrique *(Surface, Longueur, Profondeur, Largeur, Hauteur, Epaisseur, etc.)*
- Longueur : - Largeur : - Epaisseur :

Accessibilité *Facile (proche d'une route)* ☐ *Difficile (loin de la route)* ☐ *Très difficile* ☐

Point panoramique Qui ☐ Non ☐

Visibilité de loin Qui ☐ Non ☐

Saison conseillée pour la visite | *H* | *P* | *E* | *A* | *T* |

2. DESCRIPTION
Géologie-stratigraphie
Géomorphologie, genèse et évolution

3. CLASSIFICATION GENETIQUE
Processus génétique principal **Processus génétique secondaire**

Actif ☐ Inactif ☐ Actif ☐ Inactif ☐

Définition de la Forme

4. UTILISATION ET CONSERVATION
Utilisation actuelle du monument et du territoire limitrophe
Etat de conservation
Mesures de conservation existante (Lois, Parcs, etc.)
Menaces et/ou perturbations au paysage
Propositions de conservation et de valorisation

5. REFERENCES BIBLIOGRAPHIQUES

6. CARTOGRAPHIE GEOLOGIQUE, GEOMORPHOLOGIQUE ET ESQUISSES DU SITE

7. REFERENCES PHOTOGRAPHIQUES

Fig. 3 – Example of the sheet file, in French, used in the field for the cataloguing of the Geomorphosites.
– *Esempio di una scheda da rilevamento, in lingua francese, utilizzata in campagna per l'inventariazione dei geomorfositi.*

For the identification, classification and the graphical representation of the geomorphosites a Landsat ETM+ Image has been used. The different lithological units outcropping in the area have been recognised by means of the creation of interpretation keys based on field surveys using the medium-infrared band combinations. Lithology, tectonics, drainage pattern, land cover and topography have then been analysed to characterise the general morphology of the study area. The use of satellite images has proven to be an ideal instrument for the recognition of the main landforms, guiding the field campaigns in a remarkable way. Where the vegetation is lacking or relatively scarce the spectral response of the different lithologies can easily be observed, while the distinction of topography has been enhanced introducing shadow analysis. Directional filters associated with spectral analysis have allowed to recognise the general structure of the area and the most important faults and alignments.

All the bibliographical, field and remote sensing data have been summarised in a geomorphological map superimposed on the satellite image (fig. 4).

The next step was to define the different landscape units based on a complex geomorphological and environmental analysis of the different parts of the study area. This landscape analysis allows to subdivide the territory in homogeneous units, differing in morphology, lithology or land-use and classified according to a hierarchic scheme.

Subsequently, the singles sites have been positioned on the satellite image and the links between the single geomorphosites and geosites (intrinsic values) and the surrounding landscape (overall value) have been defined in order to have a complete perception of the importance of geological heritage in the region.

This applied geomorphological interpretation of the Middle Atlas of Ifrane-Azrou allows to summarise the geological and geomorphological heritage of the area in which the single sites, because of their easy perception (recognisability), their characteristic form (completeness), their state of conservation (exemplarity) and their effective possibility of visit (accessibility) (Poli, 2003), are integrated in a global landscape and constitute the foundation for a sustainable geotouristic development. For a more direct understanding of this geomorphological heritage the geomorphosites and geosites are grouped in networks, according to similar geomorphological processes and differentiated by colours. This distinction in thematic networks of geosites and geomorphosites makes it also easier to define coherent actions of planning, valorisation and conservation.

5. – LANDSCAPE UNITS

Landscape units are territorial ambits with specific, distinctive and homogeneous characteristics regarding their genesis, constitution and evolution due to both natural and human interactions (Bertrand, 1970; Di Gregorio, 1987; Romani, 1986). In general a Landscape Unit is a geographically distinct portion of an area that has a particular visual character.

The identification of the single Landscape Units has been carried out by means of the analysis and the classification of a complex series of characterising and significant elements (geological constitution, geomorphological elements, altitude, climate and microclimate and other physical and geographical elements, vegetation, material expressions of the human presence etc.). These elements also allow to define the originality, the scientific interest and the perceptive quality of the landscape according to the European Landscape Convention (ECC Treaty n° 176, October 20th 2000) (Di Gregorio, 2003).

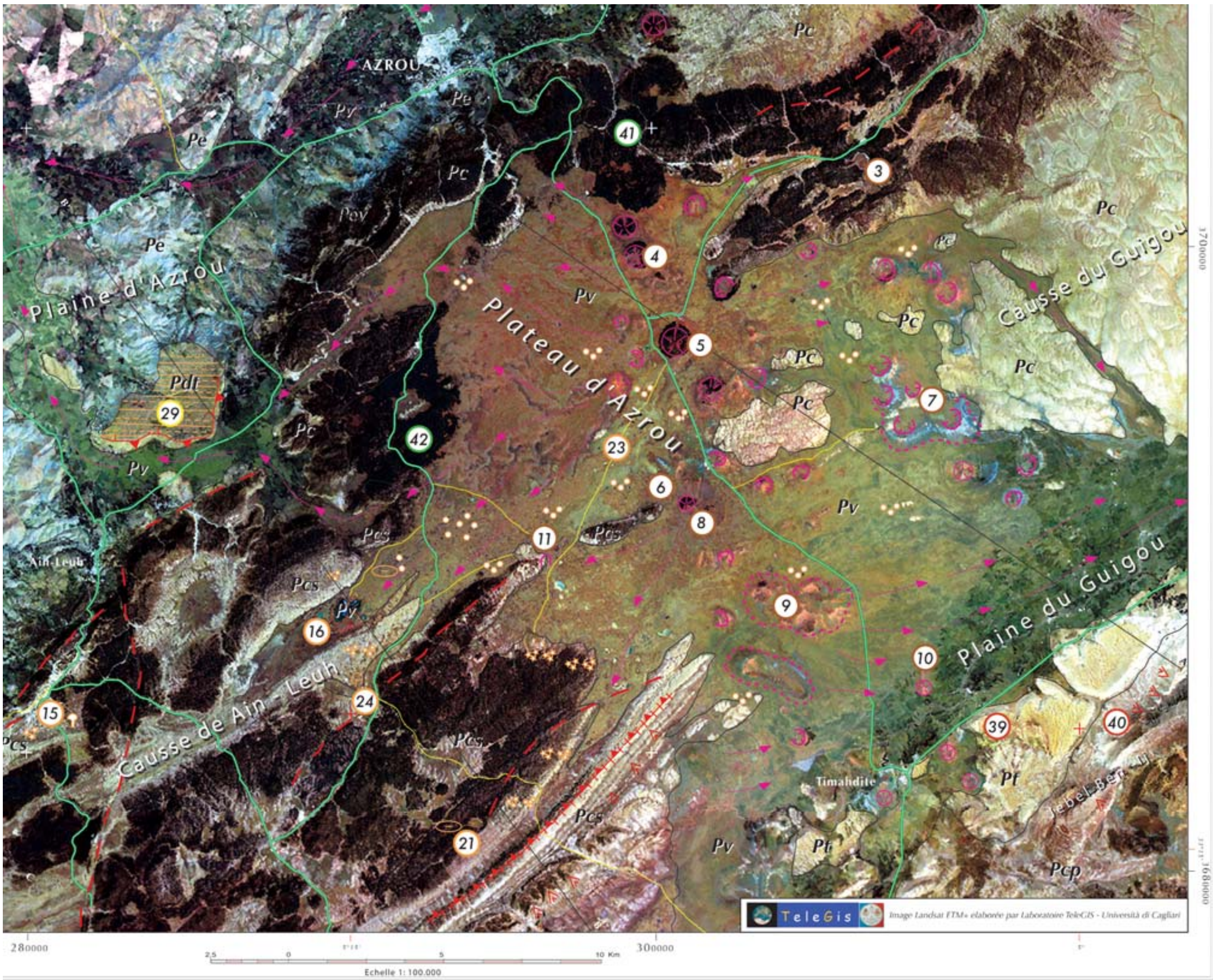

Fig. 4 – Extract of the map of Landscape Units and Geomorphosites of the Ifrane-Azrou region. The represented area is the basaltic plateau of Azrou, one of the landscape units with the highest geodiversity. For the legend see attached Map.
– *Stralcio della Carta delle Unità di Paesaggio e dei Geomorfositi della Regione di Ifrane-Azrou. L'area rappresentata è l'altopiano basaltico di Azrou, una delle unità di paesaggio con la più alta geodiversità. Per la legenda si rimanda alla Carta allegata in tasca di copertina.*

This subdivision of the study area in Landscape Units allows to:

- construct a territorial matrix useful as a spatial reference for the identified elements (natural sites, cultural heritage, human settlements and infrastructures, vegetation etc.);
- to interconnect in an organic way the different components in categories, classes and types and to better understand the relationships between the single sites and the surrounding landscape;
- to describe the determinant characters of more or less extensive homogeneous areas;
- to classify, plan and manage together the single components of the landscape, orienting the actions and interventions towards a shared goal – conservation or transformation – respecting the principles of sustainability.

The subdivision of the Ifrane-Azrou region in Landscape Units has been carried out using several types of thematic maps (topographical, geological, geomorphological) at different scales (from 1:50.000 to 1:250.000), interpreting aerial photographs and satellite images (Landsat ETM+) and carrying out surveys and controls in the field. Landscape units differ in terms of geomorphology, with different landforms in relation with the geological and structural settings, and land-use. Sheep-breeding is abundant on the steep slopes, on the *Causses* and on the basaltic plateaus while agriculture characterises the lower plains where irrigation is practiced since a long time. The recognised Landscape Units could be subdivided in smaller landscape facies with a detailed analysis at larger scales (TRICART & KILIAN, 1985), according to different natural and/or human components. Several Landscape Units can also be grouped together to form Landscape Systems that describe the territory in a much more general but nevertheless characterising way. In the study area a total of five Landscape Systems have been recognised: the carbonatic *Causses*, the sedimentary and agricultural Lower Plains, the Plio-Quaternary Volcanic landscape system, the Palaeozoic Central Massif and the Transitional systems. The landscape has then further been subdivided in fourteen easily recognisable different Landscape Units. The main characteristics of the Landscape Systems and Units are resumed in table 1.

6. - GEOSITES, GEOMORPHOSITES, LANDSCAPES AND ITINERARIES

A total of 42 sites of geological and/or geomorphological interest have been identified, studied and classified and represent the essential reference for the construction of the thematic itineraries (tab. 2). Geomorphosites have been classified according to their genesis in volcanic, dissolution karst, deposition karst, fluvial, structural and polygenetic landforms, at which two geobotanical sites have been added. The same genetic

Tab. 1 – *Landscape systems and units of the Azrou-Ifrane area and their main characteristics.*
– Sistemi ed Unità di Paesaggio dell'area di Ifrane-Azrou e loro principali caratteristiche.

Landscape System (LS)	**Acronym**	**Landscape Unit**	**Description (main characteristics)**	**General morphology**	**Main lithologies**
Causses	Pc	Tabular *Causses*	Tabular carbonate plateaus (*Causses*) of El Hajeb, Immouzer, Ifrane, Guigou, Ain-Leuh	Sub-horizontal bedded dolo- and limestone plateaus with typical karst features	Liassic dolostones, dolomitic limestones & limestones
	Pcp	Slightly folded *Causses*	Folded Middle Atlas SE of Timahdite	Folded dolo- and limestones with karst features and cuestas	Liassic dolostones & limestones
	Pca	*Causse* d'Agourai	*Causse* d'Agourai	Slightly NW-tilted carbonate plateau	Liassic dolostones & limestones
	Ps	Timahdite (Bekrite) Syncline	Syncline W of Timahdite	Large syncline with Cretaceous core and basalt infilling	Cretaceous limestones and Plio-Pleist. basalts
	Pt	Timahdite balcony	Eocene limestone plateau of Timahdite	Eocene limestone balcony eroded by Oued	Eocene limestones
Lower Plains	Ptq	Saïss plain	Low plains N of Middle Atlas *Causses*	Agricultural plains and human landscape with the cities of Fès and Meknès	Plio-Quat. lacustrine sediments
Volcanic	Pv	Lavaflows	Plio-Pleistocene lava flows	Lava flows up to 40 km long	Plio.Quaternary basalts
	Pv	Volcanic plateau	Plateau d'Azrou	Plateau basalt with various types of volcanoes	Plio.Quaternary basalts
	Pv	Single volcanoes	El Koudiate, Jbel Outgui	Single volcanoes	Plio.Quaternary basalts
Central Massif	Pes	Structural landscape	Wide lower complex plain W of *Causses* d'El Hajeb	Hogbacks and syncline valleys	Palaeozoic marbles and quartzites
	Ped	Hills with dentritic drainage	Azrou plain	Smooth and rounded hills in mostly tender rocks	Palaeozoic shales and phyllites
	Pev	Reddish altered slopes	Western border of the *Causses* d'Agourai, El Hajeb & Ain-Leuh	Concave slopes in tender rocktypes	Triassic sandstones, clays & altered basalts
Transitional systems	Pd	Piedmonts	Slope deposits	More or less steep slopes	Plio-Quaternary slope debris
	Pdt	Travertines	Travertine terraces and balconies along the borders of the *Causses*	Step-like travertine terraces or plateaus	Plio-Quaternary travertines

Tab. 2 – *Geosites, geomorphosites and geological landscapes of the Azrou-Ifrane area.*
– Geositi, geomorfositi e paesaggi geologici della area di Ifrane-Azrou.

N°	Nom Géosite	Commune	Typologie	Lithologie	Age
1	Jbel Outgui	El Hajeb	Cône Volcanique	Basaltes	Plio-Pleistocène
2	El Koudiate	Ifrane	Cône Volcanique	Basaltes	Plio-Pleistocène
3	Mischliffen	Azrou	Cratère d'explosion	Basaltes	Plio-Pleistocène
4	Jbel Habri	Azrou	Cône Volcanique	Basaltes	Plio-Pleistocène
5	Jbel Hebri	Azrou	Cône Volcanique	Basaltes	Plio-Pleistocène
6	Tit Ouagmar	Azrou	Volcan complexe	Basaltes	Plio-Pleistocène
7	Bou Ibalrhatene	Azrou	Cratère d'explosion	Basaltes	Plio-Pleistocène
8	Chedifat-Tit Ouagma	Azrou	Volcan complexe	Basaltes	Plio-Pleistocène
9	Bou Teguerouine	Azrou	Volcan complexe	Basaltes	Plio-Pleistocène
10	Sidi Aziz	Azrou	Cône Volcanique	Basaltes (pyrocl.)	Plio-Pleistocène
11	Trou de Ifri-Ouska	Azrou	Tunnel de lave	Basaltes	Plio-Pleistocène
12	Dayet Aoua	Ifrane	Lac et Barrage tectonique	Calcaires dolom.	Lias inf.
13	Tidrine	Ifrane	Paysage ruiniforme	Dol. + Calcaires	Lias moyen
14	Dayet Hachlaff	Ifrane	Paysage ruiniforme	Dolomies	Lias inf.
15	Tisfoula	Ifrane	Paysage ruiniforme	Dolomies	Lias inf.
16	Afennourir	Ifrane	Synclinale + lac + dolines	Dol. + calcaires	Lias
17	Dayet Ifrah	Azrou	Polje + lac karstique	Dol. + Calcaires	Lias
18	Polje de Ouiouane	El Hammam	Polje, hum et lacs	Calcaires	Lias
19	Bassin de Agoulmam	Sefrou	Macrodoline + lac	Calcaires dolom.	Lias inf.
20	Doline de Moutferraoun	Sefrou	Macrodoline d'effondrement	Dolomies	Lias inf.
21	Trou de la Panthère	Azrou	Doline d'effondrement	Dolomies	Lias
22	Aguelmam Azigza	El Hammam	Doline avec lac	Calcaires	Lias
23	Tichilite	Azrou	Dolines Cryptokarstiques	Calc. + Basalts	Lias + Quat.
24	Ifri-ou-Berid	Azrou	Ponor + vallée aveugle	Calcaires	Lias
25	Sources Oum- Er- Rbia	Khenifra	Sources + Cascades	Dol. + travertins	Lias + Quat.
26	Cascades des Vierges	Ifrane	Cascades	Travertins	Quaternaire
27	Ifrane Zaouia	Ifrane	Cascades	Travertins	Plio-Pleistocène
28	Terrasses d'El Hajeb	El Hajeb	Dépots de travertins	Travertins	Pleist. inf-moy.
29	Jbel Irhoud	Azrou	Plateau de Travertins	Travertins	Pliocène
30	Source Vittel	Ifrane	Sources karstiques	Calcaires + travertins	Lias + Quat.
31	Gorge de l'Oued Tizguite	El Hajeb	Gorge fluviale	Calcaires + basaltes	Lias + Plio-Quat.
32	Méandre Oued Akkous	El Hajeb	Méandre fluvial	Basalts + trav.	Pleist. inf-moy.
33	Gorge de l'Oued Defali	El Hajeb	Gorge fluviale	Dolomies	Lias
34	Village perché Bou Youssef	El Hajeb	Village sur travertins témoins	Travertins	Plio-Pleistocène
35	Mohamed ou Messaoud	El Hajeb	Paysage plurigénétique	Scistes+ marbres	Paléozoïque
36	Paysage d'Ito	El Hajeb	Paysage plurigénétique	Scistes + Arenites	Paléozoïque
37	Crête de Tizra	El Hajeb	Hogback	Marbre	Ordovicien
38	Tammeroit	Ifrane	Butte	Conglomerates	Pliocène ?
39	Balcon de Timahdite	Timahdite	Synclinale	Calcaires	Eocène
40	Chevrons de Timahdite	Timahdite	Chevrons	Calc. + dolomies	Lias
41	Cèdre Gouraud	Azrou	Site géobotanique	Calcaires	Lias
42	Paysage des Cèdres	Azrou	Paysage géobotanique	Calcaires + basaltes	Lias + Plio-Quat.

relationships have lead to the definition of the six itineraries that are based on genetic relationships between the different geomorphosites and exemplify the major genetic concepts of the landscape: volcanic, karst (dissolution and deposition), fluvial, structural and geobotanical.

The geomorphosites, in different colours according to their genetic relationships, the networks (grouping the geomorphosites of the same colours) and the landscape units are represented in the Geomorphosites Map of the region of Ifrane-Azrou, in scale 1:100.000. This map is the graphical summary and is the final product of this research. An extract of the Map is shown in figure 4.

This thematic map has been designed upon a Landsat ETM+ image and also reports infrastructural information (roads, villages etc.) and the main landforms and morphologies.

The geographical distribution of the geomorphosites in this map shows a greater concentration of sites of geomorphological and/or geological interest in the Landscape Units of the Tabular *Causses* (Pc) and on the volcanic Plateau d'Azrou (Pv). These

Landscape Units are the ones with the greatest degree in Geodiversity (GRAY, 2003).

The six itineraries, reported in different colours, group the geomorphosites with similar genetic characteristics and have been given the following names: *La petite Auvergne* (small Auvergne), connecting 11 volcanic sites and named after the famous French volcanic region, *L'eau qui dissoud les roches* (the water that dissolves the rocks) grouping the 14 karst sites, *L'eau constructrice des roches* (the water that builds the rocks) comprising the 4 travertine sites, *L'eau constructrice des paysages* (the water that sculpts the landscapes) comprising 4 fluvial geomorphosites, La Terre vivante (the Living Earth) connecting 7 structural and tectonic landscapes and, finally, the 2 geobotanic sites. These networks have been reported in a miniature extract of the Map (bottom left) and reports, besides the geomorphosites (in different colours) also the landscape units and the road network. This extract is shown in figure 5.

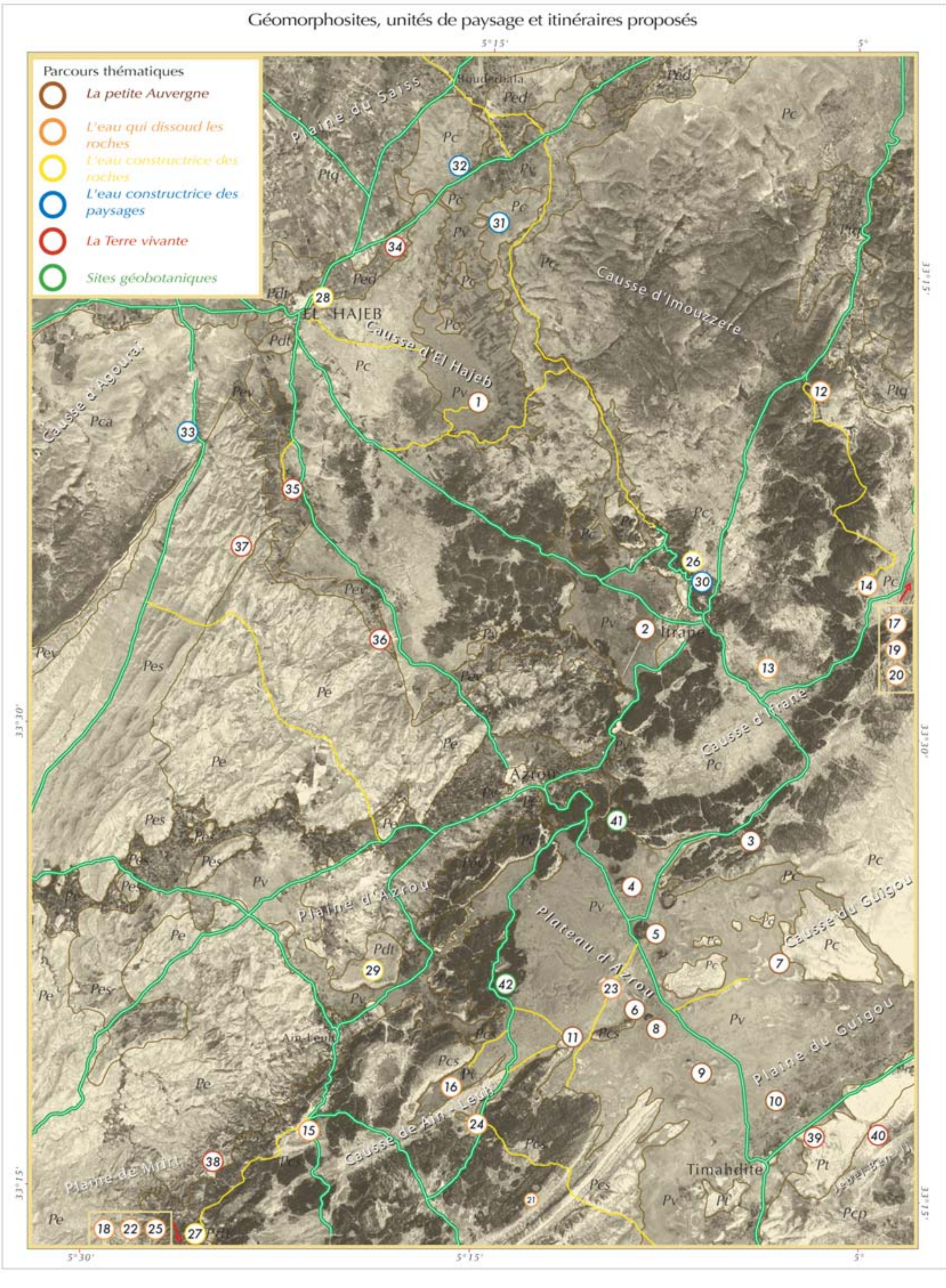

Fig. 5 – The itinerary map, in French, with the proposal of six thematic itineraries (left upper corner). In this miniature map all geomorphosites (circled numbers), the landscape units (in black italic letters) and the main roads are also summarised.
– *La Carta degli Itinerari, in lingua francese, con la proposta di sei itinerari tematici (angolo superiore sinistro). In questa piccola mappa sono segnalati tutti i geomorfositi (numeri cerchiati), le unità di paesaggio (in lettere nere corsive) e le strade principali.*

For every itinerary a series of photographs of the most important geomorphosites with exhaustive explanations are given on the right side of the Map, two examples of which is given in figures 6 and 7.

7. - CONCLUSIONS

Research on geological and geomorphological sites is a completely new branch of earth science in Morocco, despite the fact that it is one of the most important North African countries for what concerns geology, geomorphology and landscape. Morocco, in fact, has both Atlantic and Mediterranean coastlines, several mountain chains (Rif, Middle Atlas, High Atlas, Anti-Atlas), a wide variety of ecosystems ranging from Mediterranean forests over high mountain meadows to plain deserts and plenty of other geo-ecosystems.

This paper is one of the first attempts of popularising geology and geomorphology to the local communities by means of a Geo-tourist Map that reports the essential sites of geomorphological sites and landscapes and also gives information on geology, geomorphology and geodiversity of the region of Ifrane and Azrou in the Middle Atlas. The Map, designed on a Landsat ETM+ image and written in French, describes this region in a scientific way but in the meantime uses a simple and direct language that has the purpose of bring-

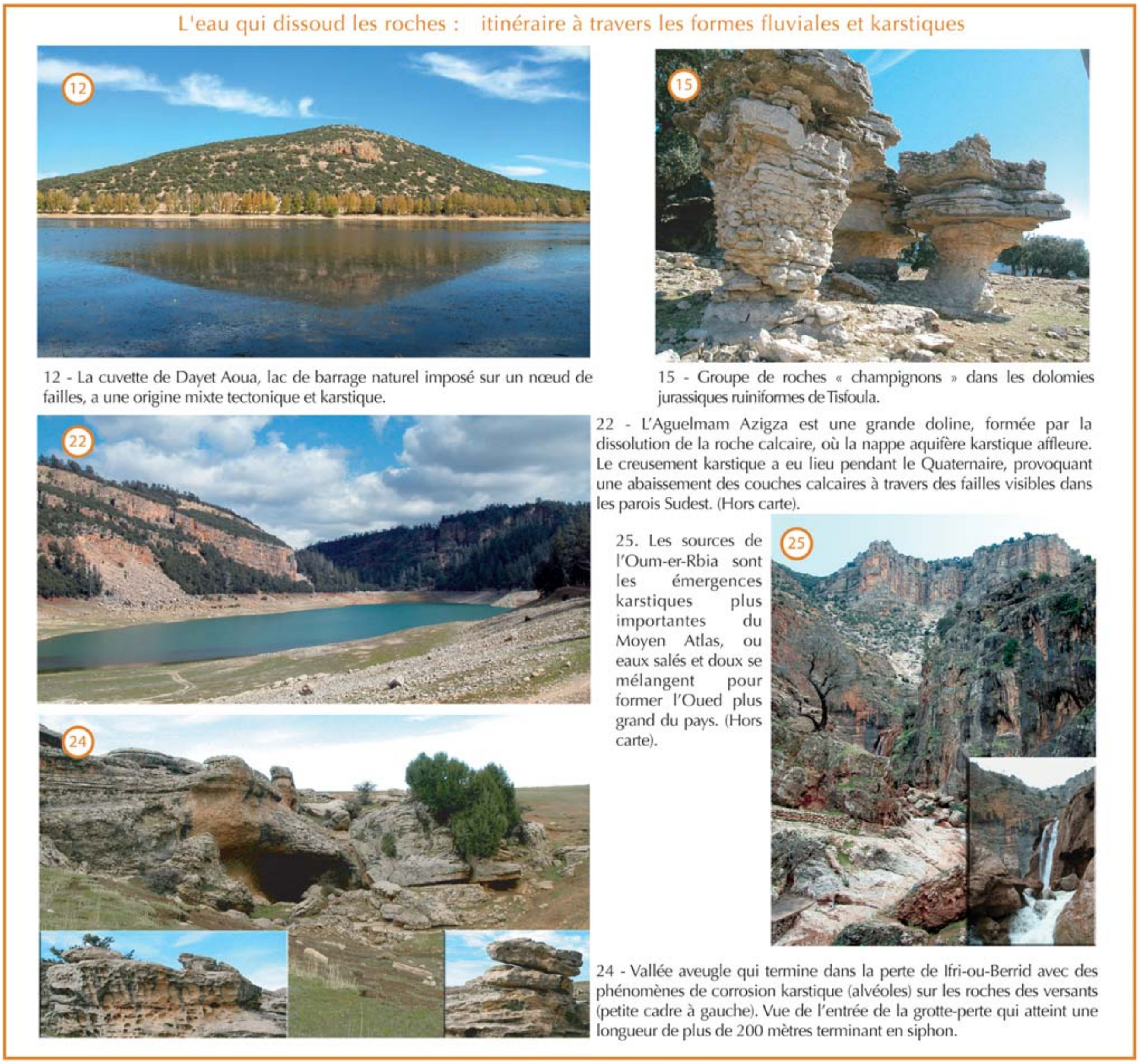

Fig. 6 – The "Water that dissolves the rocks" itinerary, in original French language, shows 5 of the most important karstic geomorphosites of the *Causses* region.
– L'itinerario "L'acqua che dissolve le rocce", in lingua originale francese, comprende 5 dei più importanti geomorfositi carsici della regione dei Causses.

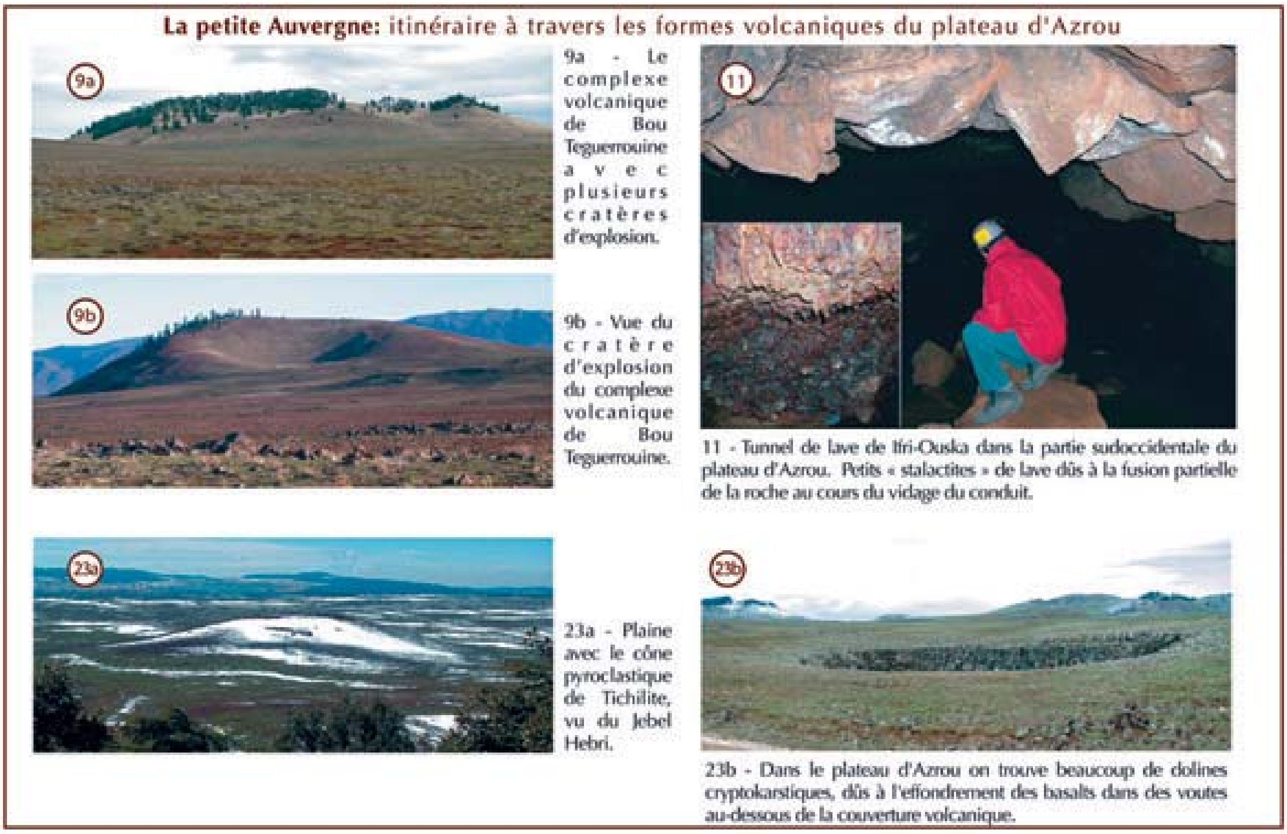

Fig. 7 – The "Small Auvergne" itinerary, in original French language, illustrates typical landforms related to volcanic processes of the Azrou Plateau.
– L'itinerario "Piccola Alvergna", in lingua originale francese, illustra alcuni dei più tipici geomorfositi legati all'attività vulcanica dell'Altopiano di Azrou.

ing also local people, unfamiliar with science, closer to the geological and geomorphological significance of the landscape in which they live. The Map is particularly designed for tourists, that often rush through this area in their travel to South Morocco, in the hope that they will decide to stay a while in the region to visit the geomorphosites suggested and described in the map. The use of photographs, showing the remarkable geological and geomorphological heritage of this region, is aimed to attract people to visit these sites.

The quantitative evaluation of the geological and geomorphological heritage of the region, following the guidelines proposed by several authors (Barca & Di Gregorio, 1991; Bruschi & Cendrero, 2005; Coratza & Giusti, 2005), in order to give a valuable tool for Environmental Impact Assessment studies (Bonachea *et alii*, 2005) could be a further development of this research.

Finally, it must be stressed that the implementation of tourist pressure on some of these geomorphosites, representing a logical consequence of the publication of geo-tourist maps such as the one presented in this paper, could compromise their integrity. Therefore it is becoming increasingly important to inform the local population and especially the local stakeholders that manage the geomorphological heritage in order to raise awareness on the uniqueness of their landscape and the geosites and geomorphosites contained in it. The understanding that this heritage is an important part of the cultural identity of their territory (Panizza, 2003) should make conservation and valorisation much easier.

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figg. 16

Petra and Beida (Jordan): two adjacent archaeological sites up to an exploitation of geomorphology-related topics for a cultural and touristic development

Petra e Beida (Giordania): due siti archeologici confinanti idonei per una valorizzazione di temi connessi con la geomorfologia nel quadro di un loro potenziamento turistico - culturale

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ABSTRACT – Petra and Beida are two adjacent archaeological sites in southern Jordan characterised by both a striking monumental heritage, and an imposing geomorphologic landscape. These sites, besides preserving important remainders of protohistorical cultures, contain the most important Nabatean vestiges of the entire Middle-East and have more recent, Roman, Crusade and Islamic, significant remains as well. On account of the importance of their archaeological and monumental heritage, the two sites are included in the UNESCO's World Heritage list and are the heart sites of a National Archaeologic Park. Less known, yet not less interesting, is the rich and striking geomorphologic heritage of the Petra-Beida area, characterised by tectonic troughs alternating with steep mountains riddled by canyons and passages to form a town of rocks. The intrinsic beauty and significance of landforms and landscapes could be the driving elements for touristic and educational aims, towards an integration of the geomorphologic heritage with the archaeological-monumental one. In this connection, both Nabatean water management systems and historical burials of monumental areas by flood events are primary links to an integrated approach, suitable for being exploited for tourism and cultural goals. Ongoing researches by means of GPS systems and laser scanning allowed us the detailed reconstruction of both parts of the Nabatean water systems and historical alluvial fills. The digital elaboration and modellisation, as well as computer simulations and reconstructions, besides their intrinsic scientific meaning, can be powerful tools for tourism improvement and educational work.

KEY WORDS: Geoarchaeology, Geotourism, Hydraulic System, Alluvial fill, Petra, Jordan.

RIASSUNTO – Petra e Beida sono due siti archeologici adiacenti del sud della Giordania caratterizzati da uno straordinario patrimonio monumentale e da uno straordinario paesaggio geomorfologico. Questi siti, oltre a conservare importanti resti delle culture protostoriche, includono le più importanti vestigia dei Nabatei dell'intero Medio Oriente. Comprendendo inoltre significativi resti crociati romani e islamici. In considerazione dell'importanza del loro patrimonio archeologico e monumentale, i due siti sono stati inclusi nella Word Heritage List dell'UESCO e sono i siti principali del Parco Archeologico Nazionale giordano. Meno conosciuto, ma certo non meno interessante, è il ricco e straordinario patrimonio geomorfologico dell'area di Petra-Beida, caratterizzato da valli tettoniche alternate a ripide montagne intagliate da un intrico di stretti canyon e fenditure a formare città di roccia. La bellezza intrinseca e l'importanza delle forme del rilievo e del paesaggio possono rappresentare elementi trainanti ai fini turistici e didattici verso un integrazione del patrimonio geomorfologico con quello

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archeologico-monumentale. In tale contesto, sia i sistemi Nabatei di gestione delle acque sia le testimonianze storiche di aree monumentali seppellite da eventi di piena sono elementi chiave per un approccio integrato archeo-geomorfologico adatto anche a scopi turistici e culturali. Ricerche tuttora in corso con sistemi GPS e laser scanner hanno permesso di ottenere una dettagliata ricostruzione sia dei sistemi di approvigionamento idrico dei nabatei, sia delle colmate alluvionali. L'eleborazione digitale e la modelizzazione, così come simulazioni virtuali e ricostruzioni al computer, accanto al loro significato scientifico intrinseco, possono rappresentare anche efficaci strumenti per la valorizzazione turistica e per la didattica.

PAROLE CHIAVE: Geoarcheologicia, Geoturismo, Sistemi Idraulici, Riempimenti alluvionali, Petra, Giordania.

1. – INTRODUCTION

Petra - UNESCO World Heritage Site since 1985, National Archaeological Park established in 1993 by the Jordanian Department of Antiquity and the District of Ma'an under the UNESCO's auspices (UNESCO, 1991) - is a unique place for the splendid blend of landforms and architectural elements evocatively complementing one another. On a smaller scale, the same elements characterise the near Beida -not by chance known with the telling name of "*Little Petra*"- which, besides being an important protohistorical site (COMER, 2003), is part of the same World Heritage Site of Petra itself.

Being it the destination of a crowd of tourists, the Petra-Beida site is justly famous all over the world: nevertheless, only the aesthetic beauty rather than the intrinsic significance of its notable geologic-geomorphologic heritage is well known and exploited. Indeed quite every touristic guide or leaflet reports about issues as the impressive physical landscape, the astonishing chromatism of Petra and Beida sandstones, the imposing Nabatean water system, the deviation of the Siq in order to prevent flooding and, not least, the serious problem of monument weathering. The geomorphologic importance of this site is somehow implicit in the first denomination of "*Naturalistic and Archaeological Park*" already given by Jordan authorities to the initial protected area. Indeed, the importance –also for cultural and touristic purposes- of geologic-geomorphologic features is substantiated by several papers both by earth scientists (*e.g.* PANIZZA & PIACENTE, 2003; FRANCHI *et alii*, 2004 and 2005) and archaeologists (*e.g.* LUBICK, 2004 ZAYADINE, 1992; PALUMBO *et alii*, 1995). Specifically, several places in the Petra-Beida territory could be regarded as sites of specific geologic and geomorphologic interest (*i.e.* geosites or geomorphosites): namely, the Siq (*cf.* PANIZZA & PIACENTE, 2003, p. 289) and the canyon housing the monumental area of Beida are both suitable for being improved as geomorphosites (*sensu* PANIZZA, 2001). Nevertheless, being the area included in an already formalized (year 1985) UNESCO site of major monumental, archaeological and historical value, the geologic-geomorphologic elements are suitable for being improved and exploited as primary value-added components in an integrated cultural and touristic framework. A key to such integration is how the Nabatean and Roman cultures adapted to a hard physical environment, a topic already known to and attractive for many visitors. Indeed, a first major issue is the impressive Nabatean-Roman water-system, consisting of thousands of channels chiselled into the rocky slopes and flowing to cisterns and fountains. A further attractive issue is concerned with historical flood-evidence throughout the entire Petra-Beida territory and the impressive Nabatean works addressed to flooding prevention.

The aim of this paper is a concise description of the geologic and geomorphologic framework of the Petra-Beida area (fig. 1) in connection with both the exploitation of the physical environment by the ancient cultures and the modern weathering and conservation problems. Ongoing surveys and 3-D modelling of both the Petra-Beida hydraulic system and the alluvial fill in the Siq, performed in the framework of an international co-operation between Urbino University, Italian CNR and French CNRS, are also briefly reported. Actually, the results of such studies, besides their intrinsic scientific meaning, could give an innovative impulse to a better popularisation –for tourism purposes as well- of both the fascinating topic of skilful water exploitation by the inhabitants of Petra and Beida, and the flooding impact on this territory during historical times (HENRY, 1985; RAIKES, 1985).

2. – GEOLOGIC AND GEOMORPHOLOGIC OUTLINE

Petra and Beida (fig. 1) are situated on the eastern side of the Dead Sea-Wadi Araba tectonic depression (Dead Sea rift, according to BENDER, 1968; MART, 1991 *cum bibl.*; a transform valley, according to GARFUNKEL & BEN AVRAHAM, 1996), a *c.ca* 15 km-wide topographic low formed by shearing along the transform separating the Arabian and Sinai plates (*cf.* SNEH, 1996; GINAT *et alii*, 1998, *cum bibl*). Petra and Beida are placed in a rugged mountain area, characterised by heights ranging from c.ca 850 m to over 1.000 m a.s.l. Such mountain

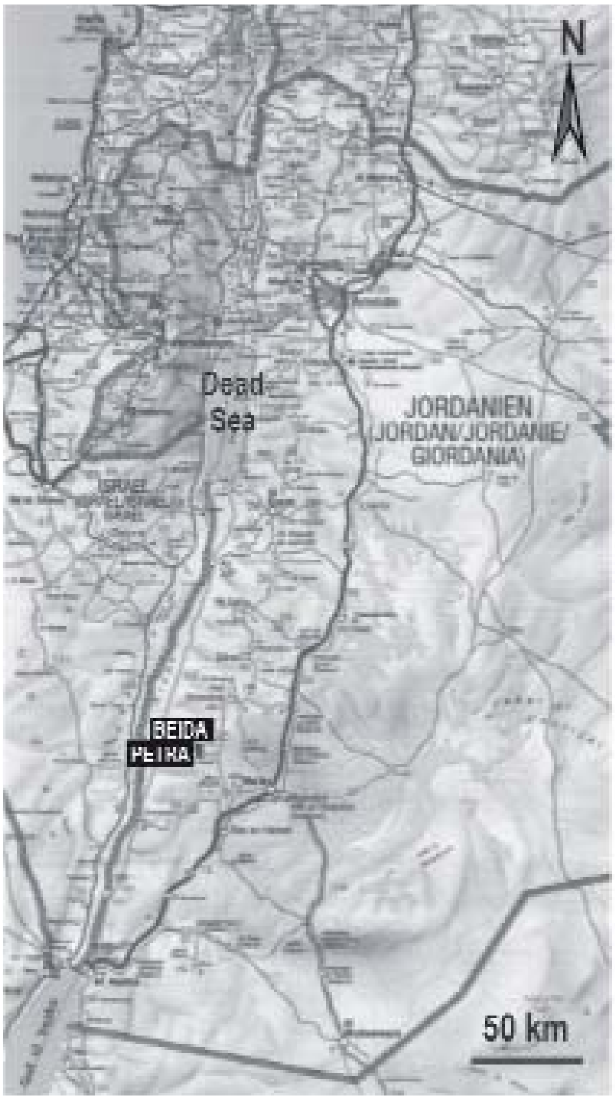

Fig. 1 – Location map.
– *Inquadramento dell'area.*

territory corresponds to the regional escarpment separating the Wadi Araba tectonic trough (south of the Dead Sea, Raikes, 1985) from a regionally-extended high carbonate *plateau* (Qa' Al Jafr, to the East). The Petra-Beida area as a whole is part of the Seil Wadi Musa hydrographic basin, which drains from the eastern margin of the carbonate *plateau* to Wadi Araba with an overall E-W stream flow-direction. The main stream (*i.e.* Seil Wadi Musa) results from the junction of two main tributaries -namely Wadi es Siq and Wadi Siq el Ghurab-Wadi Beida- flowing across Petra and Beida, respectively.

In the Petra-Beida area, the Precambrian crystalline rocks of the Arabian-Nubian shield are cut by an almost flat late precambrian–early Cambrian peneplain unconformably overlain (fig. 2) by Cambro-Ordovician, mostly quartz-rich arenitic, terrains (Bender, 1974) accounting for the weathering and erosion of the basement itself (*cf.* Avigad *et alii*, 2005 *cum bibl.*). The local stratigraphic succession (*cf.* Quennel, 1951; Bender, 1974) starts (fig 2) with the thin (locally less than 50 m in thickness) *Salib Arkose* arenitic formation, overlain by a thick (locally more than 500 m in thickness) suite of both paralic and shallow-water (*e.g.* Selley, 1972; Amireh *et alii*, 1994), massive and/or poorly stratified Cambrian-Ordovician quartzarenites belonging to the *Umm Ishrin* and *Disi* formations (Bender, 1974 *cum bibl.*; Franchi, 2002). An important -although hardly detectable at the outcrop in the Petra-Beida area - regional unconformity separates the latter from the overlying, entirely fluvial (Amireh, 1997), quartzarenites of the Early Cretaceous *Kurnub* formation. The local succession is closed by the *Ajlun Group* (Quennel, 1951), consisting of marly-calcareous platform formations (Schulze *et alii*, 2005 *cum bibl.*) over 500 m thick.

The hand-carved rock monuments of Petra and Beida (*cf.* figures 6B, 10, 16) are entirely cut in the sandstones of *Umm Ishrin* and *Disi* formations (Amireh *et alii*, 2001; Franchi, 2002); moreover, many quarries in use in different historical period attest to the fact that the same sandstones were employed as construction material (Franchi, 2002). Since the rock characters largely account for weathering-related conservation problems, it is worth emphasizing some lithologic and petrographic attributes of the two formations above (fig. 2). The *Umm Ishrin* formation is mostly composed of medium-coarse grained, well-sorted quartz (in percentage as high as 80%) combined with highly variable proportions of cements consisting (*cf.* Amireh, 1991) of authigenic kaolinite, hematite, goethite and subordinate poikilotopic calcite (Franchi & Pallecchi, 1995). Cementation by both quartz overgrowths and pressure solutions is rather frequent. Quite common are needle-shaped, not always identifiable, mineral inclusions. The most common detrital grains recognised under optical microscope are zircon, tourmaline, titanite and occasional crandallite (Franchi & Pallecchi,1995). The occurrence of several 10-15 cm-tick arenaceous lenses/layers with amounts of hematite cement as high as 50%, is a peculiarity of the *Umm Ishrin* formation. Diaclases filled with fibrous-radial hematite have also been observed. The first occurrence of whitish, thin-bedded arenites marks the rather uncertain boundary between the sandstones of the *Umm Ishirin* formation and those of the overlying *Disi* formation. This latter consists entirely of light grey, fine to medium-coarse grained quartzarenites, characterised by recurrent lenses of well

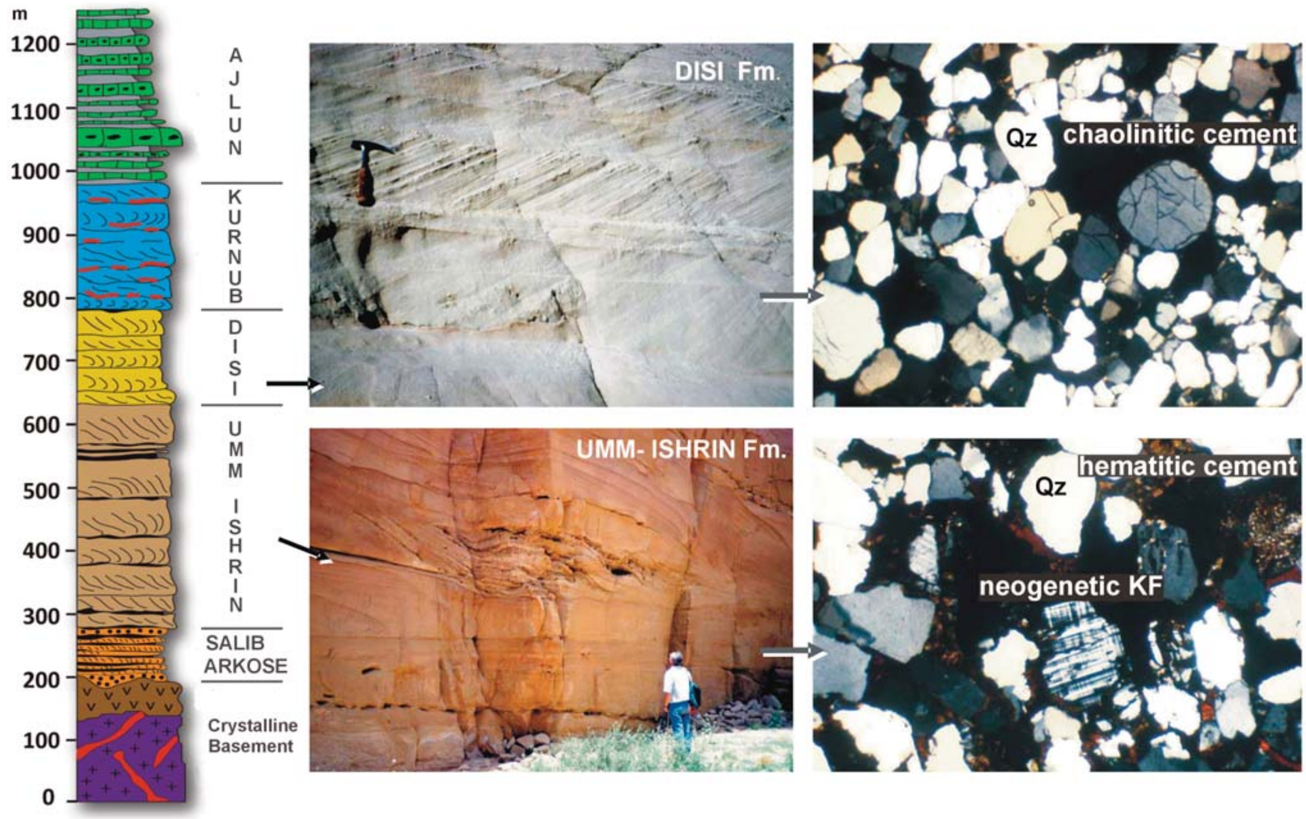

Fig 2 – Lithostratigraphy of the Petra-Beida area and view at the outcrop and in thin section of typical sandstones from the *Umm Ishrin* and *Disi* formation in which main part of the rock monuments are carved.
– *Colonna litostratigrafica dell'area di Petra-Beida e immagini degli affioramento e delle sezioni sottili delle arenarie delle formazioni dell'Umm Ishrin e del Disi. In queste rocce sono scavati i principali monumenti.*

rounded centimetric quartz pebbles. From a petrographic standpoint, the sandstones of the *Umm Ishrin* and *Disi* formations are quite similar, except for a considerable decrease of both iron oxides and hydroxides cements. The *Disi* accessory minerals are the same as for the *Umm Ishrin* and are generally found with the same frequency.

The geomorphology of the Petra and Beida territory strongly reflects both differential erosion and recent tectonics. Several distinct landforms, such as sharp stream deflections and alignments of scarps, canyons and ridges, account for recent displacement along the structural fault-system affecting the area. On the contrary, a large number of examples in which the control on landforms by the tectonic structures must be regarded as passive -*i.e.* simply produced by differential erosion processes independent (or quite independent) from the recent deformation history of the region- are apparent. At a large scale, a *c.ca* N-S trending, high escarpment (fig. 3) accounts for a marked eastward erosional retreat of the western margin of the carbonate *plateau*, favoured by the thick weak layer represented by the arenites of the *Kurnub* formation and the marls of the *Naur* formation (base of the *Ajlun Group*, figures 2, 3). The escarpment faces a wide terrace-like area accounting for the resistant top of the Palaeozoic quartzarenites (*i.*e. *Umm Ishrin* and *Disi* formations), deeply dissected by an complex net of canyons and narrow throughs concealing the sites of Petra and Beida. Indeed, in such rocks the tectonics related to the Dead Sea-Wadi Araba transform system has produced steep, high rock-relieves, spaced out by fault-bordered narrow troughs as the "*Petra Valley*" (fig. 4) (*cf.* BARJOUS & MIKBEL, 1990; FRANCHI, 2002). Since the arenites are always intensely faulted and fractured (*cf.* figs. 3, 4), streams entrenching in deep, narrow gorges as well as weathering, aeolian, and runoff processes shaped such area in a tangle of cliffs, pillars and passages to form an imposing "*town of rocks*" (FRANCHI *et alii*, 2004). The intricate system of canyons and passages that characterise the area includes both the Siq, the c.ca 4-km narrow (in places less than 4 m wide and more than 60 m high), hidden way to Petra (*cf.* PANIZZA & PIACENTE, 2003; FRANCHI *et alii*, 2004) and the cramped canyon where the

Fig. 3 – Panoramic view of the Petra-Beida territory. Please note the dissected structural bench (t) corresponding to the top-surface of the Palaeozoic sandstones and the retreating escarpment (s) at the base of the Meso-Cenozoic terrains.
– *Panoramica del territorio di Petra-Beida. Da notare il terrazzo strutturale (t) corrispondente alla superficie superiore delle arenarie del Paleozoico e la scarpata in arretramento (s) alla base dei terreni del Mesozioico-Cenozoico.*

Fig. 4 – Panoramic view of the Petra Valley; dotted lines = principal fault traces.
– *Panoramica della Valle di Petra; le linee tratteggiate indicano le principali tracce di faglia.*

monumental area of Beida is placed (fig. 5). Such canyons belong to a riddled minor stream-net, controlled by the complex fault-fracture systems affecting the Palaeozoic quartzarenites and joining the Seil Wadi Musa main stream.

Weathering is certainly one of the most effective processes in the Petra-Beida area, able both to mould landforms and to deteriorate the monumental heritage (fig. 6). The weathering effectiveness on natural landforms is underlined by a large abundance of niches, honeycomb-structures and tafoni, and by rounded and spheroidal rock-surfaces as well (*cf.* figs. 3, 6A). On both monuments and natural surfaces, hardening of external rock-surfaces is a usual phenomenon. Liken generated oxalates, at least in the documented examples (*case hardening*, DORN, 2004) are responsible for such weathering-related biological action, able to exert a partial protection of the rock-surface itself from further degradation,

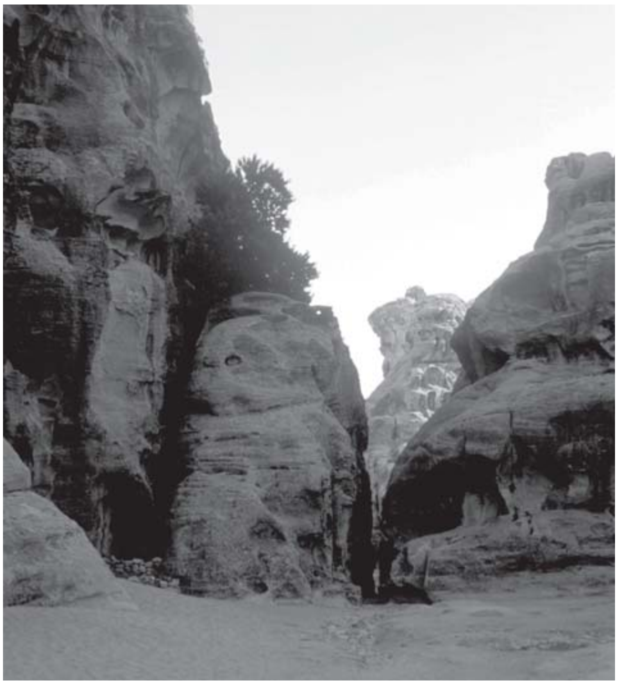

Fig. 5 – The entrance of the Beida canyon.
– *L'entrata al canyon di Beida.*

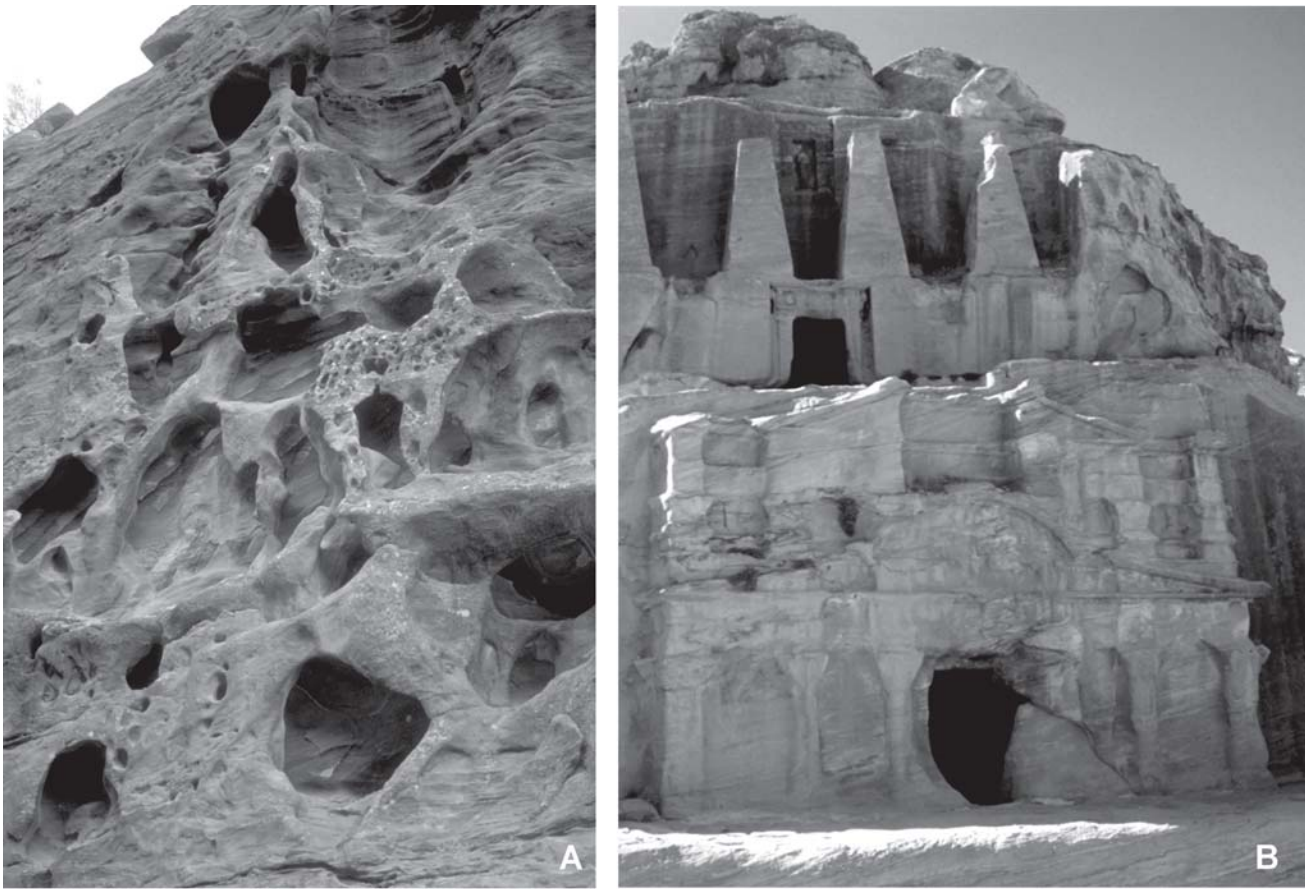

Fig. 6 – Weathering effects on the Paleozoic sandstones: A – tafoni, *Umm Ishrin* formation, Petra; B – facade of the Obelisk Tomb, *Disi* formation, Petra.
– *Effetti dell'alterazione delle arenarie paleozoiche: A – tafoni, Formazione dell'Umm Ishrin, Petra; B – facciata della Tomba degli Obelischi, Formazione del Disi, Petra.*

so often allowing tafoni-like forms to develop. With respect to the historical and artistic heritage conservation, the principal causes of degradation depend on complex interactions of mechanical, chemical, and in part anthropical processes (*cf.* ALBOUY *et alii*, 1993; FRANCHI & PALLECCHI, 1995; FRANCHI *et alii*, 1999; PARADISE, 2005). Indeed, the principal –or in any case a primary- mechanism of weathering depends on the thermal stresses (*i.e.* thermoclastism) suffered by sandstone grains (quartz above all) for insolation changes, night drops in temperature, etc. The loosened grains can be removed from the rock-surface by gravity, wind, rain-splash, runoff etc. In this concern, it is worth emphasizing that both in Petra and Baida, running waters coming from higher areas usually flow all over the facades of the monuments, largely contributing to the decaying of the architectural elements (*e.g.* FRANCHI, 2002; WEDEKIND, 2005). A second important cause of weathering processes/monument decay peculiar to the area of Petra-Baida (*e.g.* Ed Dehir, Petra) is related to salts of varying chemism, abundant all along sandstone fractures and/or faults, and the origin of which is still matter of working hypothesis. Such salts, besides producing –also owing to the presence of iron sulphate hydrate (acid hydrolisis with pH 2)- a chemical corrosion on many sandstone cements, are responsible for mechanical aloclastic processes related to cycles of salt dissolution-precipitation (fig. 7). Chemical and mineralogical analyses carried out

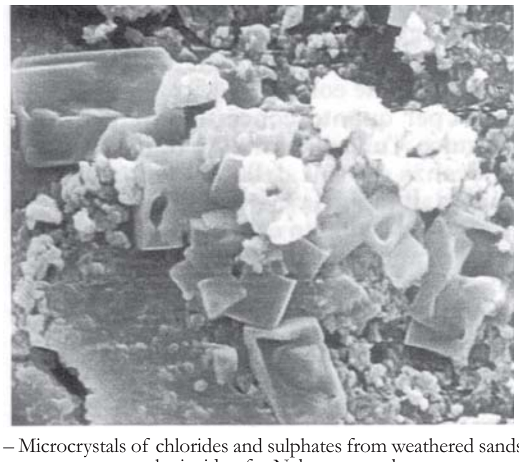

Fig. 7 – Microcrystals of chlorides and sulphates from weathered sandstones on the inside of a Nabatean tomb.
– *Microcristalli di cloruri e di solfati prodotti dal'alterazione delle arenarie nella parte interna di una tomba Nabatea.*

on a large number of samples has established (FRANCHI *et alii*, 1999) the presence in varying proportions of sodium chloride (predominant) together with potassium chloride, nitrates (deriving from the anthropisation of the tombs) and calcium sulphate.

Although largely controlled by the tectonic structure and lithology, the Petra-Beida area also shows a significant association of landforms (mainly depositional ones) related to climatic causes. The occurrence of aeolian products and landforms deriving from weathering processes typical of arid and semi-arid regions is rather obvious. Nevertheless, less obvious depositional landforms -often relic and related to past climatic conditions- are recognisable all over the Petra-Beida territory. In this connection, it is worth reporting several terrace-alluvium patches scattered on the hilltops and along the hillsides of the Petra Valley tectonic depression and partially correlatable with the remnants of ancient pedimentary surfaces. These latter are covered by more or less thick alluvial-fan deposits, sometimes deeply dissected and terraced, sometimes well preserved or only partially dissected (*e.g.* the piedmont area of Beida), anyhow likely to be related to upper Pleistocene relatively cold and humid depositional stages (FRANCHI, 2002).

3. – PHYSICAL ENVIRONMENT CONSTRAINTS AND CULTURAL OUTCOMES

The territory of Petra and Beida bears the remainders of very ancient cultures (*cf.* CLARK, 1987), every so often substantiated by important archaeological remains. Here, the remains of archaic cultures definitely co-exist and overlap with relatively recent vestiges, *e.g.* Crusader and Islamic. Petra is the crucial site of the Nabatean culture, known above all for a huge concentration of monumental tombs of Hellenistic inspiration (*cf.* fig. 16). Beida, in turn, is well known among archaeologists for its masonry architecture and other attributes of agricultural-farming settled village (fig. 8) dating back as long as the 9th millennium B.C., with older hunting occupations from about the 12th millennium B.C. (COMER, 2003).

The geomorphologic setting of the Petra-Beida territory has acted as an ideal background for the inhabitants to evolve from nomadic to resident conditions (*e.g.* BIENKUWSKI, 1995). This very change brought about the deep anthropogenic modifications which made this site unique. As a matter of fact, the prehistorical-protohistorical cultures –including the Edomite one– took advantage of landforms without significantly modifying them (*e.g.* KIRKBRIDE, 1985). Indeed, their settlement, mainly on the foothills, has been probably favoured by the vicinity of wadies and springs, although other morphologic factors such as good drainage conditions, positions out of both flash flooding and rock fall hazard must have been important in the ultimate settlement choice (*cf.* COMER, 2003). In this concern, it is worth emphasizing that Baida protohistorical settlement exploits an alluvial terrace (fig. 8), and still in its zenith (7th-6th millennium B.C.), the nearby stream has been its major water source. The Nabateans themselves –who gradually supplanted the Edomites between the 6th and the 4th century B.C.- got an undoubted advantage from the tangled geomorphology of the Petra-Beida area (*e.g.* PANIZZA AND PIACENTE, 2003; FRANCHI *et alii*, 2004). Indeed, the built Petra town is placed into a deep tectonic depression, out-of-the-way and easy to defend because flanked by cliffs (fig. 4) and reachable without difficulty only through a narrow and

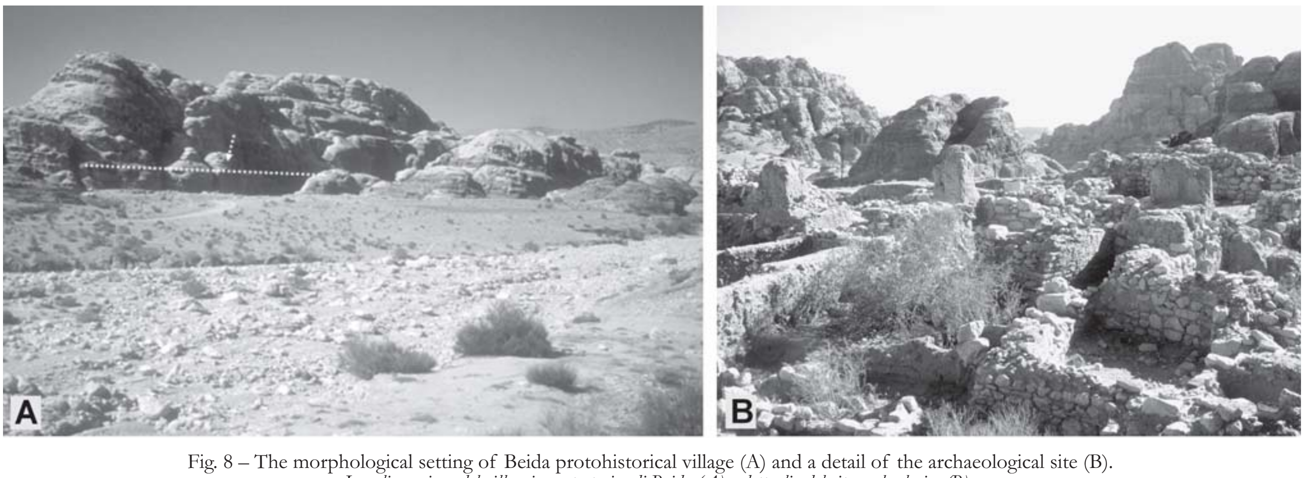

Fig. 8 – The morphological setting of Beida protohistorical village (A) and a detail of the archaeological site (B).
– *Localizzazione del villaggio protostorico di Beida (A) e dettaglio del sito archeologico (B).*

hidden passage through the mountain (the "*Siq*", i.e. *crack in the rock*): it is worth emphasizing that the geomorphology of the area hindered in some degree also the Roman conquest of the town (*cf.* PARKER, 1987), dating to 106 A.D. The monumental Nabatean Beida, in turn, is set in a narrow, hidden canyon (fig. 5) cutting a steep rock relief riddled by canyons and crevices. Besides being an ideal place to live in because of its geomorphologic setting, the Petra-Beida area benefits from a favourable climate, since its mountains protect it from both north-eastern cold winds and south-western warm ones. Being water the primary need, both the first Nabatean settlement and the earlier stages of town development, were certainly favoured by springs fit to supply water to both the local community and caravans. The growth of Petra as a big caravan town (*e.g.* ZAYADINE, 1985) got the Nabateans, innately skilled at water exploitation (they came from the arid Arabian lands), to achieve an impressive system of watering, suitable for over 30.000 inhabitants living there in the 1st century B.C.-2nd century A.D. On the contrary, the neighbouring Beida valley, reproducing and emphasizing Petra's geomorphologic characteristics on a small scale, became the heartland of both Nabatean religion and politics.

The watering-system construction, the necessity to maintain the *Siq* passage free from debris as well as the development of a monumental "*town of deads*" obtained by chiselling a multitude of tombs out of the maze of rock walls all around the built-up town, are just the main reasons for the manifold landscape modifications which make the Petra-Beida site such an unique place. Nevertheless, the necessity to prevent natural hazards, as floods or the decay of in-use architectonic elements, compelled the Nabateans to implement flood-control works as well as to equip the majority of architectural structures with drainage systems (*e.g.* FRANCHI, 2002; WEDEKIND, 2005). In conclusion, although different geomorphologic processes (*e.g.* mass movements, weathering, aeolian activity) and tectonic factors (earthquakes) influenced the Nabatean culture, water was the primary one. Hence, the fascinating subject of water exploitation and water related hazard –an issue still today able to exert a great appeal on both scholars and tourists- is what we will focus on in the next pages.

4. – THE ANCIENT WATER SYSTEM OF PETRA AND BEIDA: THE AL HABIS SITE

Umm al Biyara – the name of which means "*Mother of the Cisterns*"– is the first example (probably Edomite) of large cisterns chiselled out of rock to collect rain water. Later on, Nabateans developed impressive water supply systems based on channels and cisterns. Specifically, the Nabatean water-system, inherited in a second time by Romans, consists of imposing cisterns, dams and hierarchized channel nets (figs. 9, 10). Indeed, taking advantage from both the topographic and lithologic characteristics of the area, the construction of a dense net of channels has delivered the scarce rainfall water into a multitude of cisterns chiselled

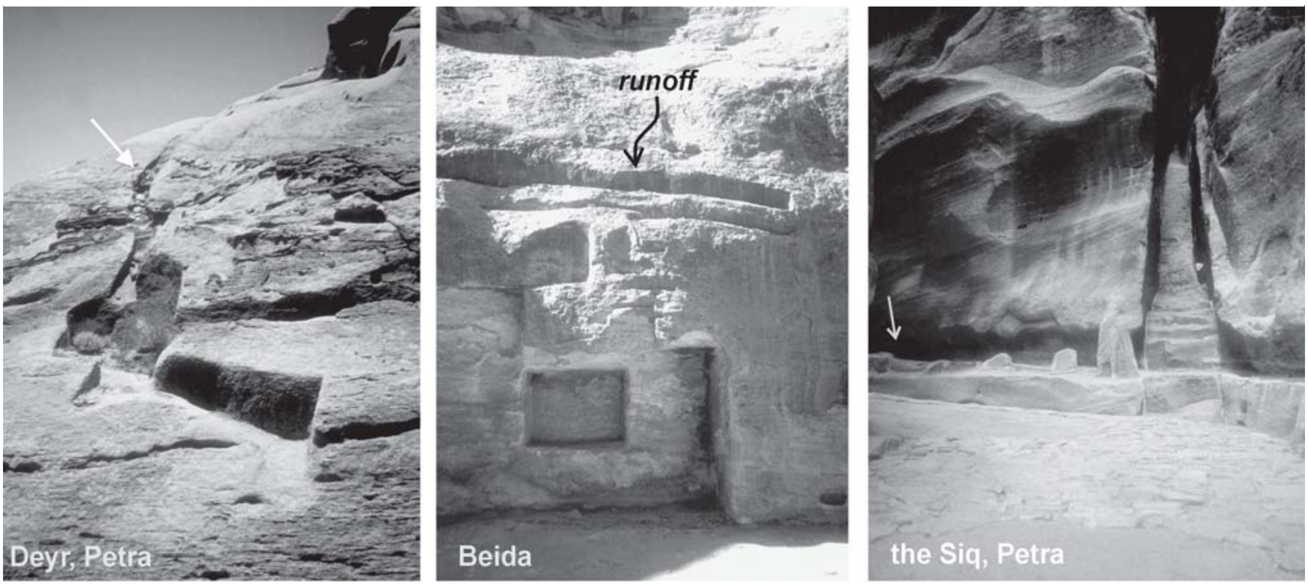

Fig. 9 – Examples of water channels and water collecting systems.
– *Esempi di canali e altri sistemi di raccolta delle acque.*

Fig. 10 – A cistern connected with a Nabatean sacral building in Beida.
– *Cisterna sottastante un edificio sacro Nabateo a Beida.*

out of sandstone slopes. Such complex hydraulic engineering works both ensured an adequate water supply for the local population and mitigated the effects of monument degradation produced by rainwater runoff down their facades (FRANCHI, 2002; LUBICK, 2004; WEDEKIND, 2005). Today, the drainage system is no longer operational, as it has been filled up with debris and broken up by landslides. Nevertheless, the elements constituting the water-supply system, often carved in rock, maintain even nowadays monumental characteristics and display an unquestionable skill both in hydraulics and in exploiting an unfavourable environment.

Taken into account the importance of the water providing system in both archaeological and geologic-geomorphologic studies, a detailed survey of the water collection system of Petra and Beida archaeological sites has been started in 2004 in order to ascertain the precise function of each single part of the system. Field work has been started in the sample-site of Al Habis (fig. 11), the choice of which accounts for both its small size and its effectiveness as a model system for testing an appropriate field surveying method. The most important water collection channels -chiselled out of the rocky slopes (*Umm-Ishrin* sandstones) and still visible today- run all around the Al Habis site, along the so-called "third bench" (fig. 11). Since the inaccessible nature of the site prevents the use of a GPS system, to rapidly acquire a cinematic view of the points, measurements were made using the Total Station Trimble 5600 (FRANCHI *et alii*, 2005). The employment of this equipment allowed both a quick survey of their course and mapping of their position on a 3-D model of the Al Habis rock-spur. 3-D reconstructions of the geometric shape of each single section of the channels was instead obtained by photogrammetry (DRAP *et alii*, 2001). The result of this operation is an extremely detailed and measurable 3-D model of the channels (fig. 12) that can be used both for classification and study purposes as well as for virtual tests and simulations on the flow of the waters.

The creation of such a detailed model allowed us to extract information on sections along the course of a channel and to estimate the degree of deterioration of the side walls of the water channel. A forthcoming development of this analyses is the spatial and functional survey of the water channeling system in order to gain an correct un-

Fig. 11 – The site of Al Habis where the water collection channels have been studied in detail. A: view from the south-east; the main water channel is found on the "third bench" (arrows). B: a detail of a channel.
– *Il sito di Al Habis dove i canali per la raccolta d'acqua sono stati studiati in dettaglio. A: panoramica da sud-est; il canale principale si trova sul "terzo gradino" (frecce). B: un dettaglio del canale.*

derstanding of the complex network of cisterns and channels. The model can be used for channel classification, flow simulation, virtual tests, and other scientific objectives as well as for to develop projects of restoration of parts of the water providing system with a consequent mitigation of runoff damages to the facades of the monuments. An exploitation in touristic and educational frameworks is also a natural development of scientific results and flow simulations.

5. – EVIDENCE OF HISTORICAL ALLUVIAL EVENTS IN PETRA

The Nabatean dependence on water is sanctioned in their rituals, thus mirroring its sacredness; such cultural trait is testified by the large number and size of cisterns and pools connected with sanctuaries and sacred places (fig. 10). Neither the more ephemeral and aesthetic forms of water employment were disregarded by the Nabateans; indeed they built up pools, fountains and gardens both in the urban area and in its neighbourhood (an aspect emphasised after 106 A.D. by the Romans). However, to Petra, water didn't mean just survival, aesthetics and rituality: it represented a natural hazard as well. It is well known how the Nabateans were obliged to divert the course of Wadi Musa stream (fig. 13), in order to prevent the recurrent flooding of the Siq, their main way to Petra (*e.g.* AL-WESHAH & EL-KHOURY, 1999; LUBICK, 2004; PANIZZA & PIACENTE, 2003, p. 289). A dam was built by Nabateans just downstream the deviation to prevent flood overflow (fig. 13); later, not only the Romans maintained the dam and the same tunnel, but they also enlarged this latter, 88 m long and 6 m wide at present time.

Since Pleistocene times, the Petra Valley and the topographically low areas around Beida underwent repeated stages of alluvial accumulation and dissection because of climatic and perhaps tectonic control (FRANCHI, 2002). Nevertheless, also in historical times, when such areas experimented a generalised downcutting –or at least a vertical stability-stage of streams, several alluvial events occurred, perhaps in connection with late Holocene climatic fluctuations (*cf.* ENZEl *et alii*, 2003, *cum bibl.*) and/or

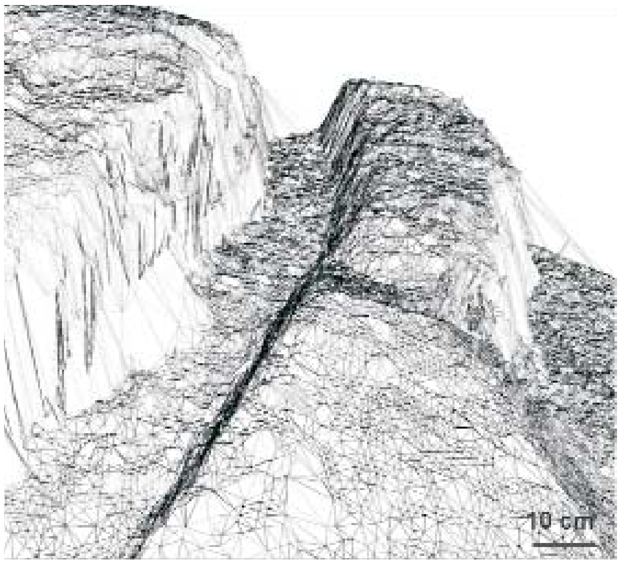

Fig. 12 – 3-D modelling of a water-channel.
– *Modellizzazione 3D di un canale.*

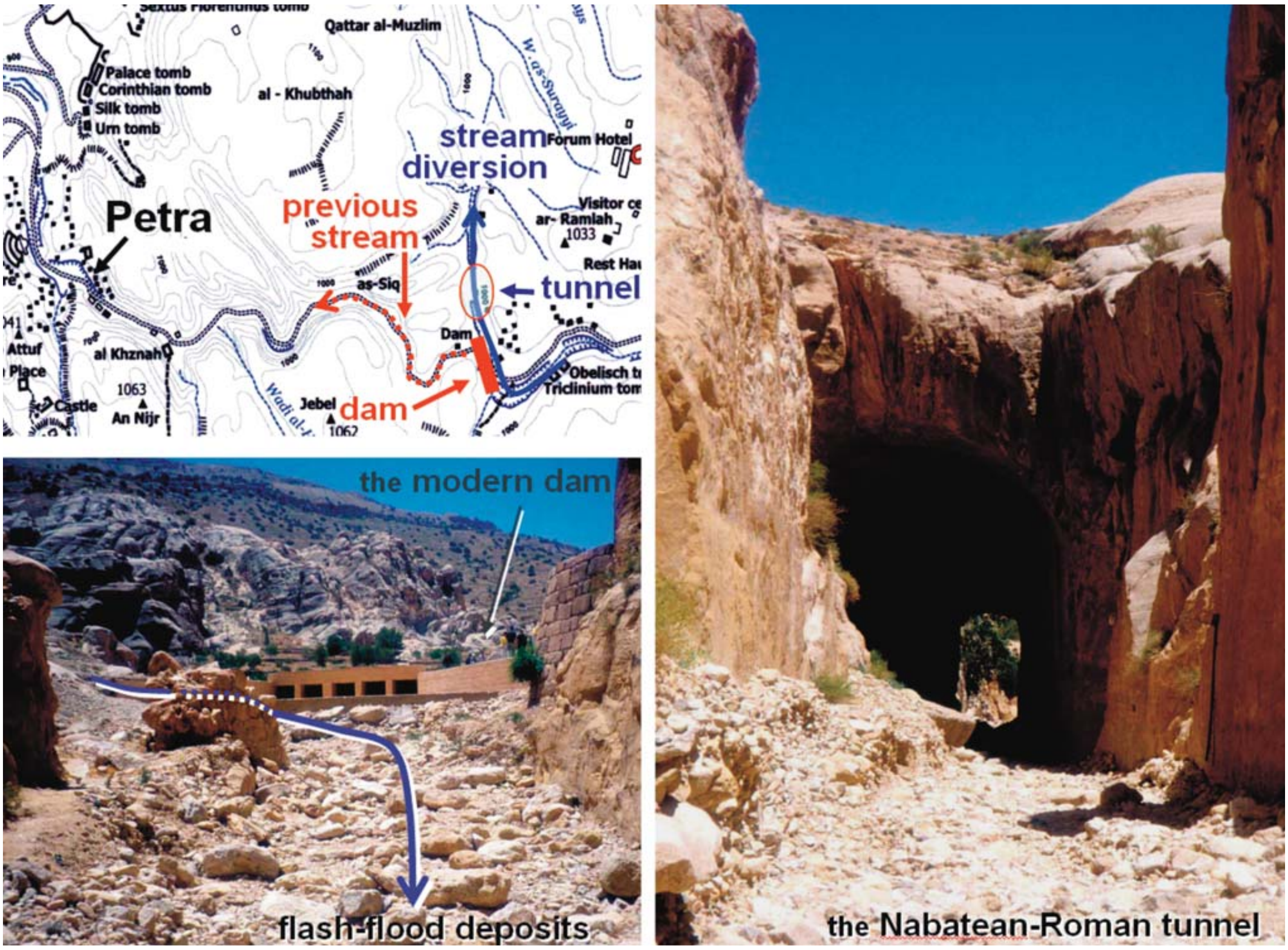

Fig. 13 – The diversion of Wadi Musa.
– *La deviazione del Wadi Musa.*

exceptional meteorological events (*cf.* AL-WESHAH & EL-KHOURY, 1999). Actually, terrace alluvium containing fragments of pottery, monuments completely or partly buried by alluvium as well as alluvial patches on the canyon rock-walls of the Siq (fig. 14), highlight flooding events spanning from Nabatean to post-Roman age. Several architectural elements (*i.e.* tombs) have been probably buried before the construction of the dam: in this respect, some of the highest alluvial patches in the Siq (*c.ca* 3.5-4 m above the Roman paving), although "Nabatean" in age -as shown by included pottery fragments- could indicate flood events pre-dating the dam. Nevertheless, since the most part of both Nabatean and younger alluvial deposits hints at repeated flooding events of the Siq-Petra Valley, temporary inefficiencies of the upstream dam and/or overflow episodes can be stressed. It is worth emphasizing that some important alluvial stages burying Nabatean artefacts are recognisable both far downstream the channel diversion and along nearby wadies, thus hinting at rather generalized events, perhaps related to climatic changes or important storms. It is therefore possible that the dam constructions has mitigated the flood impact without completely removing the problem of floods, as indirectly indicated also by an extensive flooding event of the Siq occurred in January 2004. Anyhow, in Nabatean/Roman times important alluvial-fill episodes raised several metres the Siq valley floor burying entire monuments, as demonstrated by recent excavations beneath Al Khazneh (*i.e.* the Treasure), the most famous Petra's monument, and other tombs (figs. 15-16). Other important alluvial-fill episodes clearly postdate the town decline which followed 551 A.D. destructive earthquake and the 663 A.D. Arab conquest. Such decay produced hydraulic system and dam deterioration: floodwater entered again the Siq and both the Roman paving and several architectonic elements were definitively buried by alluvium (fig. 15).

Besides being a geomorphologic hazard for an area with high touristic impact (AL-WESHAH & EL-

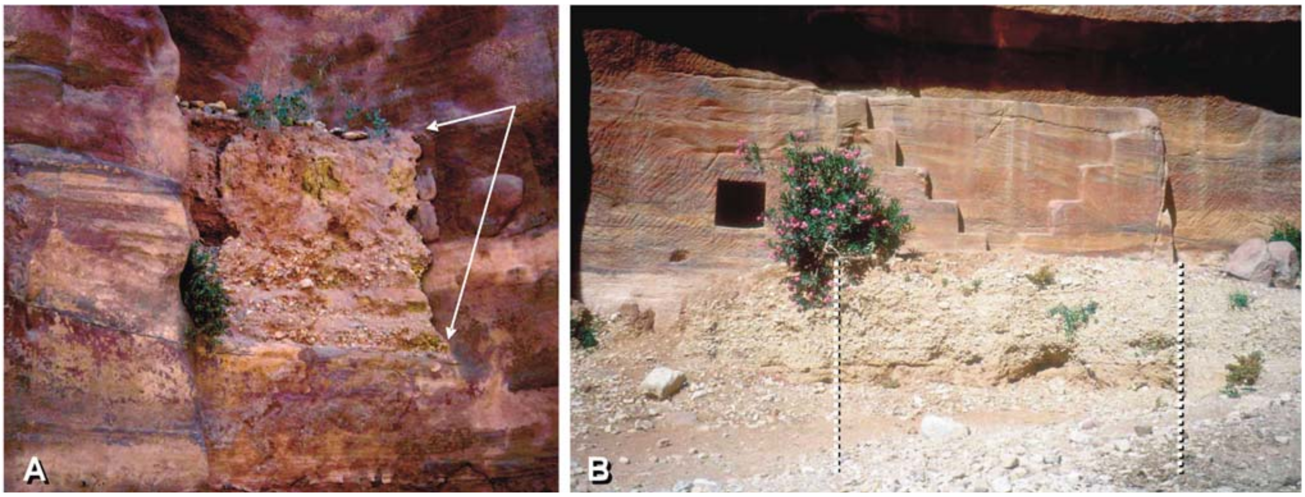

Fig. 14 – Evidence of historical alluvial events in the Siq, Petra. A: an alluvial patch hanging on the left wall of the canyon; B: archaic Nabatean tombs almost completely buried in alluvium.
– *Evidenze di alluvionamenti storici di alluvione nel Siq, Petra. A: materiale alluvionale sulla parete di sinistra del canyon; B: tombe Nabatee arcaiche quasi completamente sepolte da materiale alluvionale.*

KHOURY, 1999), the repeated occurrence of flood events is an intriguing matter scientific research and can be also of some concern in both educational and touristic purposes. Since a detailed reconstruction of the alluvial top-surfaces is needed, in order both to decipher at least a relative chronology of the events and to reconstruct the alluvial bodies, similarly to the Al Habis site, detailed surveys by means of laser scanning and GPS systems have been taken up, starting from the Siq, where the relationship between alluvium and architectural elements is clear enough. Preliminary surveys have allowed the reconstruction of two of the main historical alluvial top-surfaces, including the one shown in figure 15. Buried monuments and alluvial patches can be thus combined in 3-D reconstructions and explicative panels for both the popularisation of geomorphologic topics and their integration into the better-known archaeological context, also fostering new educational paths. Indeed, whatever the causes, timing and extension of the historical alluvial events, their evidence is so striking and so closely related to architectural elements of the monumental areas that both educated tourists and scholars cannot help wandering about such issue.

Fig. 15 – Recent excavation close to a Nabatean tomb, left downstram sector of the Siq, Petra. The highest alluvial patch (1) hints at a first alluvial event post-dating the monument; the monument weathering (2) likely predates both a second alluvial burial and the Roman channel (3) construction; weathering also stresses (4) the top-surface of the second alluvial fill, preserved in some patches (5) hanging on the tomb facade. In the foreground (6) the modern valley floor.
– *Scavo recente di una tomba Nabatea, sinistra idrografica del Siq a Petra. Il pacco di strati alluvionali (1) fa pensare ad un primo evento alluvionale successivo al monumento; l'alterazione del monumento (2) verosimilmente pre-data sia un secondo evento alluvionale, sia la costruzione del canale Romano; l'alterazione evidenzia anche (4) la superficie superiore del secondo riempimento alluvionale, conservato in alcune tasche ghiaiose sulla facciata della tomba. In primo piano (6) il fondovalle alluvionale attuale.*

6. – CONCLUDING REMARKS

Petra and Beida (Jordan), UNESCO sites, are two important adjacent archaeological areas deeply integrated in a striking geomorphologic landscape. The impressive historical, archaeological and monumental heritage as well as a somewhat "exotic" collocation of these sites, are unquestionably the main factors contributing to attract a huge number of tourists in such places. However, several geologic and geomorphologic features blending with monumental elements and appealing to both tourists and scholars are part of the overall indivisible heritage of these sites and suitable for being improved and popularised.

Both Nabatean water exploitation and flow

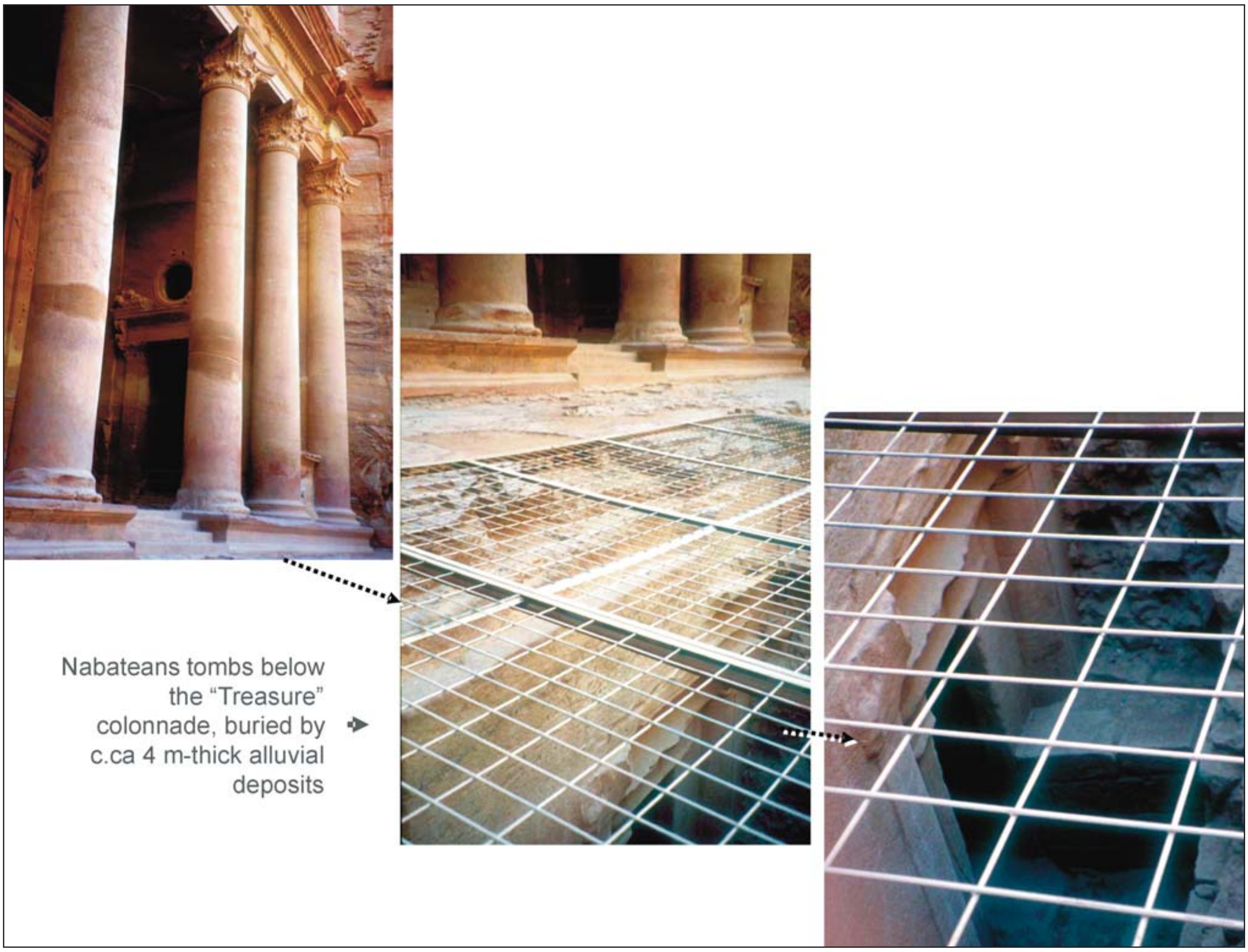

Fig. 16 – Recent archaeological excavation in the alluvial fill beneath Al Khazneh showing buried Nabatean tombs.
– *Recenti scavi archeologici nei depositi alluvionali sotto Al Khazneh mostrano tombe Nabatee sepolte.*

control are fascinating issues and, what's more, they are primary links between archaeological-monumental topics and geomorphologic ones. In this connection, ongoing researches about two topics directly related to both water and geomorphology of the Petra-Beida area –*viz.* water system reconstruction and historical alluvial-fill assessment- are suitable to promote a "geomorphologic culture" among both tourists and scholars. The analysis of both problems has been started by means of laser scanning and GPS systems, in order to obtain detailed measurements and reconstructions. The collected data make it possible to obtain 3D digital reconstruction and interactive models, flow models, alluvial fill modellisations etc., which are all appropriate for being improved as both educational and divulgation tools. Actually, they are suitable for being used in education rooms, employed as illustrative materials in guides, leaflets and explicative-panels and so on. Moreover, the singling out of additional topics could encourage the realization of new thematic touristic paths, able to lighten an overpressure along the usual touristic paths of an area the heritage of which is known to be at risk of decaying.

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figg. 7

Relief of the Podyjí National Park and Geomorphologic Aspects of its Protection (Czech Republic)

Il rilievo del Parco Nazionale Podyjí e gli aspetti geomorfologici della sua protezione (Repubblica Ceca)

KIRCHNER K. (*), DEMEK J. (**)

ABSTRACT – Two National Parks - the Podyjí National Park in Czechia and the Thayatal National Park in Austria, are situated along canyon-like valley of the Dyje/Thaya R. in the SE part of the Czech Republic and in the NE part of Austria. The area is famous for its unique natural beauties among the cultural landscapes of the Central Europe. Due to Iron Curtain the economic activities in the area were very limited in the second half of the 20th century, especially on the territory of Czechia. Therefore natural values of above-mentioned area were protected.
Czech naturalists started intensive scientific research of this area after foundation of the Podyjí National Park (NP) in 1991, incl. geomorphologic studies. Field survey resulted in compilation of detailed geomorphologic maps in the scale 1: 5000 and 1:10,000. Authors distinguished three main relief types: i) etchplain, ii) eastern border slope of the West European platform and iii) canyon-like valley of the Dyje/Thaya R. Quantitative measurements of geomorphic processes (e.g. gravitational processes) are carried out on tests plots and in pseudokarst caves. Steep rocky slopes of the Dyje/Thaya R. valley are particularly deformed by gravitational movements (rock slides and deep seated slope deformations with unique pseudokarst caves).
Geomorphologic maps were used as base for delimitation of landscape-ecological units for management and landscape protection of the Podyjí NP. Nineteen landscape-ecological units were delimited and characterized by unique complex of landforms, recent geomorphologic processes and valuable biotopes, incl. proposals for management.
Within the framework of geomorphologic investigations special attention was paid to anthropogenic landforms, since the area of the NP was formed as a part of the cultural landscape in the border zone between Czechia and Austria during the last millennium. Especially, the eastern part of the NP was modeled by mining, agriculture, settlement, transportation, water engineering, until recently also by military activities and at the present by growing number of visitors. However, historic anthropogenic landforms do not disturb the typical character of the landscape. On contrary they contribute to its specific character, especially in the case of agricultural landforms.
The paper presents new results of geomorphological investigations (particularly of geomorphologic mapping) in relief of the Podyjí NP and its application of its results for needs of the nature conservation and landscape protection.

KEY WORDS: Geomorphology, Landscape protection, Nature conservation, NP Thayatal (Austria) and NP Podyjí (Czechia).

RIASSUNTO – I due Parchi Nazionali di Podyjí nella repubblica Ceca e di Thayatal in Austria, sono ubicati lungo la stretta valle a canyon del Fiume Dyje/Thaya nel settore sud-orientale della Repubblica Ceca e nel settore nord-orientale dell'Austria. L'area è famosa tra i paesaggi culturali dell'Europa centrale per le sue bellezze naturali uniche. A causa della presenza della Cortina di ferro le attività economiche dell'area sono state limitate nella seconda metà del ventesimo secolo, specialmente nel territorio della Cecoslovacchia. Per questo motivo i caratteri di naturalità della sopra citata area sono rimasti preservati.
I naturalisti cecoslovacchi iniziarono a svolgere approfondite ricerche scientifiche, inclusi studi geomorfologici, in quest'area dopo la fondazione del Parco Nazionale del Podyjí nel 1991. Carte geomorfologiche di dettaglio a scala 1: 5000 e 1:10.000 sono state elaborate dopo approfonditi rileva-

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menti di campagna. Gli autori hanno distinto tre grandi tipi di rilievo: i) pianure incise, ii) orlo orientale del pendio della piattaforma europea occidentale e iii) la stretta valle a canyon del Fiume Dyje/Thaya. Misurazioni quantitative dei processi geomorfici (per esempio i processi gravitazionali) sono state effettuate su aree campione e in cavità psuedocarsiche. I ripidi versanti rocciosi della valle Fiume Dyje/Thaya sono interessati da movimenti gravitativi (scivolamenti in roccia e deformazioni gravitative profonde con cavità psuedocarsiche uniche).
Le carte geomorfologiche sono state usate come documenti di base per la delimitazione delle unità di paesaggio-ecologiche per la gestione e la protezione del paesaggio del Parco Nazionale del Podyjí. Diciannove unità sono state individuate e sono caratterizzate da un complesso unico di forme del rilievo, recenti processi geomorfologici e preziosi biotopi.
Nell'ambito delle ricerche geomorfologiche particolare attenzione è stata data alle forme antropiche, poiché l'area del parco nazionale è stata creata come parte del paesaggio culturale nella zona di confine tra la Cecoslovacchia e l'Austria. In particolar modo, l'area orientale del parco è stata interessata e, conseguentemente, modellata da attività mineraria, da attività agricola, dagli insediamenti, recentemente anche dalle attività militari e attualmente dal continuo crescente numero di visitatori. Tuttavia, le forme del rilievo legate alle attività antropiche non alterano il carattere tipico del paesaggio, ma, al contrario, esse contribuiscono a conferirgli il suo specifico carattere.
In questo articolo vengono presentati i nuovi risultati delle ricerche geomorfologiche (in particolar la cartografia geomorfologica) nel rilievo del Parco Nazionale del Podyjí e l'applicazione dei risultati alla conservazione e alla protezione della natura.

PAROLE CHIAVE: Geomorfologia, Protezione del paesaggio, Conservazione della Natura, Parco Nazionale di Thayatal (Austria) e Parco Nazionale di Podyjí (Repubblica Ceca).

1. – INTRODUCTION

National Park Podyjí is situated in the SW part of South-Moravian Region (Czechia), neighbouring with NP Thayatal in Austria (fig. 1). The Dyje/Thaya R. forms in a long section the historical state frontier between the Czech Republic and Austria (the Dyje R. is the name of the border river in Czechia, the Thaya R. is name used in Austria). The deep incised, canyon-like valley of the Dyje/Thaya R. forms the axis of both NP between towns of Znojmo in the East, Hardegg in the central part and Vranov nad Dyjí in the West. The relief strongly influenced the human activities in this particular area since the Neolithic. During the medieval time border castles were built on steep slopes of the Dyje/Thaya R. valley (Hardegg in Austria, Vranov, Nový Hrádek and Znojmo in Czechia). On some slopes there were terraced crop fields and vineyards. In the modern time several mills and paper mills used the waterpower of the Dyje/Thaya R. Due to Iron Curtain established after World War II, economic activities in the area

Fig. 1 – Position of the Podyjí National Park in Czech Republic.
– Ubicazione del Parco Nazionale di Podyjí in Repubblica Ceca.

were very limited in the second half of the 20th century. Natural values of this area were therefore protected and the landscape is less damaged here that in the other cultural landscapes of the Central Europe.

The area is famous for its unique natural beauties among the cultural landscapes of the Central Europe. The Czech government proclaimed the National Park Podyjí in 1991 and the National Park Thayatal in Austria was proclaimed in 2000 (ROETZEL, 2005). The protected area of the NP Podyjí reaches 63 sq. km. Natural forests cover about 84 % of the area. The high geodiversity and biodiversity (especially concerning plants and invertebrates) ranks the area among the most naturally valuable territories in the Central Europe.

2. – GEOMORPHOLOGIC CONDITIONS

Political changes in Europe in the autumn 1989 have brought for Czech scientists a possibility to investigate the formerly forbidden territories adjacent to Iron Curtain. Authors studied relief of the NP Podyjí using the method of detailed geomorphologic mapping (DEMEK, 1972) in the scale 1:5000, quantitative measurements and geoecological methods. Morphostructurally NP Podyjí is situated in the SE marginal part of the Bohemian Massif (part of the West European Platform), composed of Proterozoic metamorphic and granitic rocks. From the geomorphologic point of view it is a part of the Českomoravská vrchovina Highland exhibiting flat or rolling topography in altitude of 300 to 600 m a.s.l. On the other hand, this rather leveled relief contrasts strikingly with deeply incised valley of the Dyje/Thaya R. (fig. 2) and valleys of its short tributaries (IVAN & KIRCHNER, 1994).

Fig. 2 – Canyon-like valley of the Dyje/Thaya River is incised into granite of the Dyje Massif in the eastern part of Podyjí National Park. Steep valley slopes contrast with the flat relief (remnants of the planation surface of etchplain type). Photo M. Havlíček.
– *La stretta valle a canyon del Fiume Dyje/Thaya è incisa nel granito del Massiccio di Dyje nel settore orientale del Parco Nazionale di Podyjí. I ripidi versanti della valle contrastano con il rilievo pianeggiante, ciò che resta della superficie di pedeplanazione. Fotografia di M. Havlíček.*

Authors described three main relief types:

i) Etchplain, which is planation surface leveling folded and faulted Proterozoic metamorphic rocks and granites of the Bohemian Massif which developed by the stripping off thick weathered mantle of the Mesozoic-Tertiary regional planation surface (peneplain) and by the exposition of basal surface of weathering; on some places (e.g. in fractured zones) remnants of kaolinic weathered mantles are preserved; basal surface of weathering is undulated with ruwares and tors;

ii) Eastern marginal slope of the West European platform controlled by a system of faults in the border zone with the Carpathians (fig. 3);

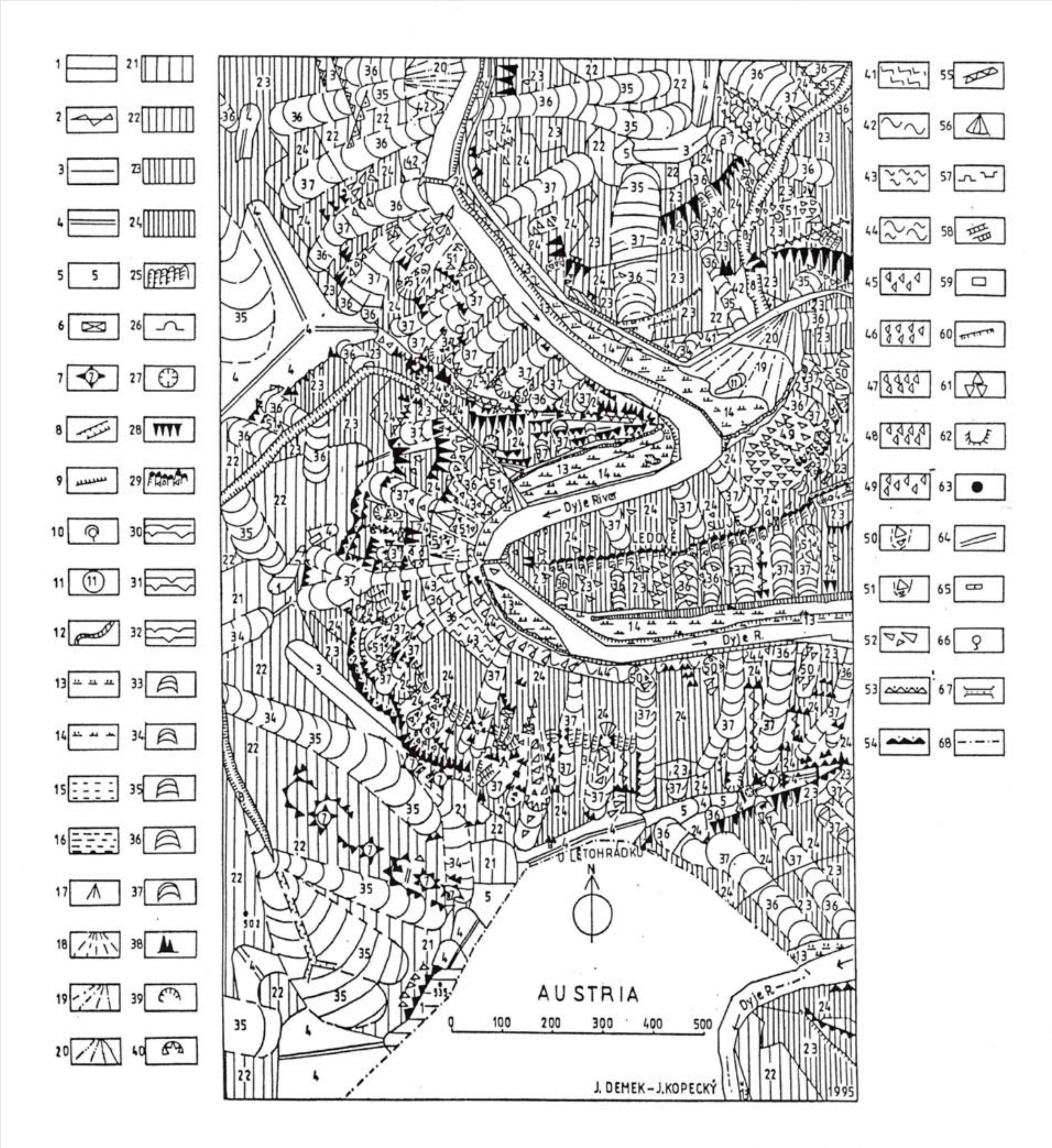
Fig. 3 – Eastern part of the Podyjí National Park is situated on the eastern marginal slope of the West European platform. The marginal slope is controlled by a system of faults in the border zone with the Carpathians. Photo M. Havlíček.
– *Il settore orientale del Parco Nazionale di Podyjí è situato nel settore marginale orientale della piattaforma europea occidentale. Il versante marginale è controllato da un sistema di faglie nella zona a confine con i Carpazi. Fotografia di M. Havlíček.*

iii) Deep incised, canyon-like valley of the Dyje/Thaya R.; this valley is not only of geomorphologic importance, but also a climatic and biological phenomenon.

From the point of view of morphostructure, the area under study consists of two main units, the structurally lower Moravian Unit in the East and the tectonically higher Moldanubian Unit in the West. At the present time these units are morphostructurally interpreted as terranes, which were welded together during Variscan orogenetic period in Paleozoicum. In the NP Podyjí and Thayatal, both situated within the Moravian unit, the bedrock is composed of resistant metamorphic and granitic rocks of Proterozoic age (more than 600 million years old). The Bohemian Massif consolidated by the Variscan Folding as an eastern part of the West European platform developed since Permian under subaerial conditions. As early as at the end of Permian a post-Variscan planation surface developed. Tectonic movements in the Upper Cretaceous, caused by the beginning of Alpine Orogenesis, started the development of younger Mesozoic-Tertiary planation surface of the Bohemian Massif. Tropical climate caused deep, tropical weathering of dry land during the Paleogene Period. Thick weathering mantle of laterite and china clay was formed during this time on the planation surface. In the Eocene, the rise of Alps and Carpathians created a marine basin between the Bohemian Massif and young mountains, called Paratethys. During the Miocene the area of National Parks was frequently inundated by sea from Paratethys. Tectonic movements and climate changes during the Neogene Period firstly caused removal of thick tropical weathering mantles and formation of etchplain and secondly incision of rivers on the southeastern margin of the Bohemian Massif. There is evidence of repeated filling in of river valleys by marine deposits and repeated exhumation. Little is unfortunately known about geomorphologic processes in Pliocene, correlated deposits are missing in this part of the Bohemian Massif. During the Pleistocene many changes of cold and warmer periods together with rise of the margin of the Bohemian Massif caused repeated accumulation and erosion. Many Pleistocene cryogenic forms are the evidence of permafrost presence during cold periods (ice-ages). Pleistocene river terraces are rather rare, loess deposited in cold periods on etchplain and to a lesser extent also in valleys. Through continued incision of rivers, bedrock become unloaded on sides of deep incised valleys and gravitationally forms as rock slides and pseudokarst caves developed (see figure 4). Man settled the area during the whole Holocene. Human activities formed anthropogenic forms as heaps, piles, dams, dumps and agricultural terraces on slopes. Within the National Parks, the power station above the town of Vranov nad Dyjí sends a flood wave downstream twice each day, which has not only enormous effect on the fish population in the Dyje/Thaya R. but also reduces the water temperature and significantly increases erosion of the river bed.

The deep incised, canyon-like valley of the Dyje/Thaya R. valley is the main and unique landscape feature of both National Parks. The river enters the Podyjí NP in the town of Vranov nad Dyjí in Czechia, flows through the town of Hardegg (the smallest town in Austria) in NP Thayatal and its end at the town of Znojmo in Czechia. The actual length the Dyje/Thaya R. valley on the territory of both Parks is 41,6 km. Authors distinguished in the section of the Dyje/Thaya R. valley on the territory of National parks three parts with different morphology:

i)The W part incised in the Býteš orthogneiss between the towns of Vranov nad Dyjí and Hardegg; it is the most incised part of the valley up to 235 m



deep; the valley forms incised meanders, slopes are very steep, vertical at some places with many features of deep-seated creep, cliffs and block streams; pseudokarst ice caves called Ledové sluje developed in the slip-off spur of incised meander;

ii) The central part is incised in less resistant two-mica schist of the Lukov unit (with the important intercalations of marbles); the valley is 120 to 150 m deep, but some slopes are less inclined in comparison with the first part; in this part of the Dyje/Thaya R. valley at the town of Hardegg the only road crosses the Dyje/Thaya R. valley from Austria to Czechia; on less inclined slopes there were orchards and narrow agricultural terraces with vineyards (e.g. in the vicinity of castle Nový Hrádek);

iii) The E part incised into granite of the Dyje Massif is almost 20 km long and the valley depth does not extend 160 m; steep slopes with many tors and exfoliation forms are accompanied with large block fields, block streams and screes; the rock forms are very spectacular and the valley exhibits special natural beauty; there are abandoned incised meanders (e.g. Lipina); since 1497 till 1950 there were 9 mills and a paper mill in this part of valley; famous vineyards are situated on south facing agricultural terraces on the incised meander spur Šobes ; the lowest part of the valley above the town of Znojmo fills water of the Znojmo dam.

3. – GEOMORPHOLOGIC MAPS AND LANDSCAPE-ECOLOGICAL UNITS

Geomorphologic maps in the scale 1:5.000 and 1:10.000 were compiled in NP Podyjí based on IGU Unified key to the detailed geomorphologic map of the World (see Demek, 1972). These geomorphologic maps represent morphography and morphometry, origin and age of the relief and its different forms according to map scale (fig. 4). Knowledge about relief as the abiotic geomorphologic component of landscape and namely ecological assets (see Panizza & Piacente, 2003) enabled delimitation of the landscape-ecological units of the Podyjí NP.

Differentiated natural management represents the base for nature conservation and landscape protection of the territory of National Parks. The whole territory is divided into three zones for this purpose. The most valuable and interesting part represents so-called first zone. In the case of the NP Podyjí this zone includes the unique Dyje/Thaya R. valley and narrow strip of land along the valley, which is strictly protected (e.g. restrictions of visitors movements). In the first zone 19 most interesting and representative landscape-ecological units were delimited. From the point of view of nature conservation and landscape protection, every unit of the first zone represents homogenous landscape-ecological segment with characteristic features in relation to morphography (slope inclination, slope

Fig. 4 – Detailed geomorphological map of the Landscape-ecological unit Ledové sluje (Ice caves) with the incised meander of the Dyje/Thaya River in the western part of the Podyjí National Park (after Demek & Kopecký, 1996).
Legend to the detailed geomorphologic map. Explanations:
1. Remnants of the polygenetic planation surface (etchplain), 2. narrow and rocky ridge, 3. narrow and rounded ridge developed by intersection of valley slopes, 4. broad and rounded ridge developed by the intersection of slopes, 5. spur, 6. rock pillar, 7. monadnock, 8. gully, 9. scarp developed due to lateral river erosion, 10. spring niche, 11. cutoff, 12. abandoned riverbed, 13. low floodplain, 14. high floodplain, 15. accumulation bottom inclined to the axís of valley with inclination 0-2 degreess, 16. accumulation bottom inclined to the axis of valley with inclination 2-5 degreess, 17. accumulation bottom inclined to the axis of valley with inclination 5-15 degreess 18. surface of alluvial cone with inclination 0-2 degrees,19. Surface of alluvial cone with inclination 2-5 degrees, 20. surface of alluvial cone with inclination 5-15 degrees, 21. valley slope inclined 2-5 degrees, 22. valley slope inclined 5-15 degrees, 23. valley slope inclined 15-25 degrees, 24. valley slope inclined 25-35 degrees, 25. valley slope inclined 35 and more degrees, 26. pseudokarst cave, 27. pseudokarst doline, 28. frost-riven cliff, 29. rock wall modeled by cryogenic processes, 30. cryoplanation terrace inclined 0-2 degrees, 31. cryoplanation terrace inclined 2-5 degrees, 32. cryoplanation terrace inclined 5-15 degrees, 33. dell inclined 0-2 degrees, 34. dell inclined 2-5 degrees, 35. dell inclined 5-15 degrees, 36. dell inclined 15-25 degrees, 37. dell inclined 25-35 degrees, 38. tor, castle-koppie, 39. nivation hollow with smooth slopes covered by soil and scree, 40. nivation hollow with cliffs, 41. crest, 42. talus slope inclined 5-15 degrees, 43. talus slope inclined 15-25 degrees, 44. talus slope inclined 25-35 degrees, 45. block field inclined 0-2 degrees, 46. block field inclined 2-5 degrees, 47. block field inclined 5-15 degrees, 48. block field inclined 15 -25 degrees, 49. block field inclined 25-35 degrees, 50. block stream composed of angular block inclined 5-15 degrees, 51. block field composed of angular blocks inclined 15-25 degrees 52. angular block, 53. root area of rock slide, 54. headwall of rockslide, 55. trough, dilated fissure, 56. dejection cone, 57. quarry, active, abandoned, 58. sunken road, 59. pit, 60. agricultural balk, 61. agricultural damp, 62. mine dump, 63. bunker, 64. road, 65. country seat, 66. spring, 67. bridge, 68. state boundary.
– Carta geomorfologica di dettaglio dell'unità di paesaggio-ecologica di Ledové sluje (Ice caves) con il meandro inciso del fiume Dyje/Thaya nel settore occidentale del Parco Nazionale di Podyjí (da Demek & Kopecký, 1996). Legenda: 1. Resti della superficie di pedeplanazione poligenica., 2. stretta cresta rocciosa, 3. stretta e arrotondata cresta sviluppata dall'intersezione di fianchi vallivi, 4. larga e arrotondata cresta sviluppata dall'intersezione di versanti, 5. sperone roccioso, 6. colonna rocciosa, 7. monadnock, 8. incisione, 9. scarpata dovuta ad erosione fluviale laterale, 10. sorgente, 11. taglio, 12. letto abbandonato, 13. bassa piana alluvionale, 14. alta piana alluvionale, 15. depositi di accumulo inclinati verso l'asse della valle con inclinazione 0-2 gradi, 16. depositi di accumulo inclinati verso l'asse della valle con inclinazione 2-5 gradi, 17. depositi di accumulo inclinati verso l'asse della valle con inclinazione 5-15 gradi, 18. cono alluvionale con inclinazione 0-2 gradi, 19. cono alluvionale con inclinazione 2-5 gradi, 20. cono alluvionale con inclinazione 5-15 gradi, 21. fianco vallivo con inclinazione 2-5 gradi, 22. fianco vallivo con inclinazione 5-15 gradi, 23. fianco vallivo con inclinazione 15-25 gradi, 24. fianco vallivo con inclinazione 25-35 gradi, 25. fianco vallivo con inclinazione 35 gradi o superiore, 26. grotta pseudo carsica, 27. dolina pseudo carsica, 28. scogliera frost-riven, 29. parete in roccia modellata da processi criogenici, 30. terrazzo di crioplanazione con inclinazione 0-2 gradi, 31. terrazzo di crioplanazione con inclinazione 2-5 gradi, 32. terrazzo di crioplanazione con inclinazione 5-15 gradi, 33. vallecola con inclinazione 0-2 gradi, 34. vallecola con inclinazione 2-5 gradi, 35. vallecola con inclinazione 5-15 gradi, 36. vallecola con inclinazione 15-25 gradi, 37. vallecola con inclinazione 25-35 gradi, 38. tor, 39. nicchia di nivazione con pareti levigate coperta di terra e detrito, 40. nicchia di nivazione con pareti verticali, 41. cresta, 42. cono detritico con inclinazione 5-15 gradi, 43. cono detritico con inclinazione 15-25 gradi, 44. cono detritico con inclinazione 25-35 gradi, 45. campo di pietre con inclinazione 0-2 gradi, 46. campo di pietre con inclinazione 2-5 gradi, 47. campo di pietre con inclinazione 5-15 gradi, 48. campo di pietre con inclinazione 15-25 gradi, 49. campo di pietre con inclinazione 25-35 gradi, 50. block stream composto da blocchi spigolosi con inclinazione 5-15 gradi, 51. campo di pietre composto da blocchi spigolosi con inclinazione 15-25 gradi,52. blocchi spigolosi, 53. area sorgente di rock slide, 54. scarpata di rock slide, 55. truogolo, fessura dilatata, 56. cono di deiezione, 57. cava, attiva, abbandonata, 58. strada che ha ceduto, 59. miniera, 60. terrapieno agricolo, 61. discarica agricola, 62. discarica mineraria, 63. bunker, 64. strada, 65. residenza di campagna, 66. sorgente, 67. ponte, 68. confine di stato.

orientation), morphostructure (bedrock), genesis, soils and biota. Most of these units (12) are situated on steep slopes of the Dyje/Thaya R. valley and in deep valleys of its tributaries, 6 units are situated on the eastern marginal slope of the Bohemian Massif with xerothermic steppe flora and 1 unit on the etchplain (wetland with fishponds) (fig. 5).

The following criteria were applied in the process of selection of landscape-ecological units:

i) Representativity – segments represent all main relief types and biotopes;

ii) Cover – segments cover the whole Dyje/Thaya R. valley;

iii) Degree of nature qualities – this criterion concerns mainly the state of biota, especially vegetation;

iv) Degree of biodiversity;

v) Exceptionality – natural abiotic and biotic phenomena specific for NP (e.g. pseudokarst caves in gneiss with cave ice called Ledové sluje (Ice Caves), virgin forest on steep valley slopes in segment Braitava);

vi) Historic values – typical land-use forms, e.g. system of agricultural terraces on slopes which developed in medieval time and preserved up to present time – segment Hradištské terasy in the vicinity of Znojmo, prehistoric and medieval castle sites and their surroundings with many anthropogenic forms – segment Nový Hrádek (New Castle).

Landscape-ecological units were mapped in the scale 1:10.000, characterized (e.g. altitude, areal extent, morphography, geological composition, specific phenomena, biota, forestry, historical monuments, proposals for management, etc.), digitalized and stored in computers.

4. – EXAMPLES OF LANDSCAPE-ECOLOGICAL SEGMENTS IN THE DYJE/THAYA VALLEY

Segment Braitava

The steepest and highest (235 m) concave undercut slope segment with many examples of slope deformations due to undercutting by the

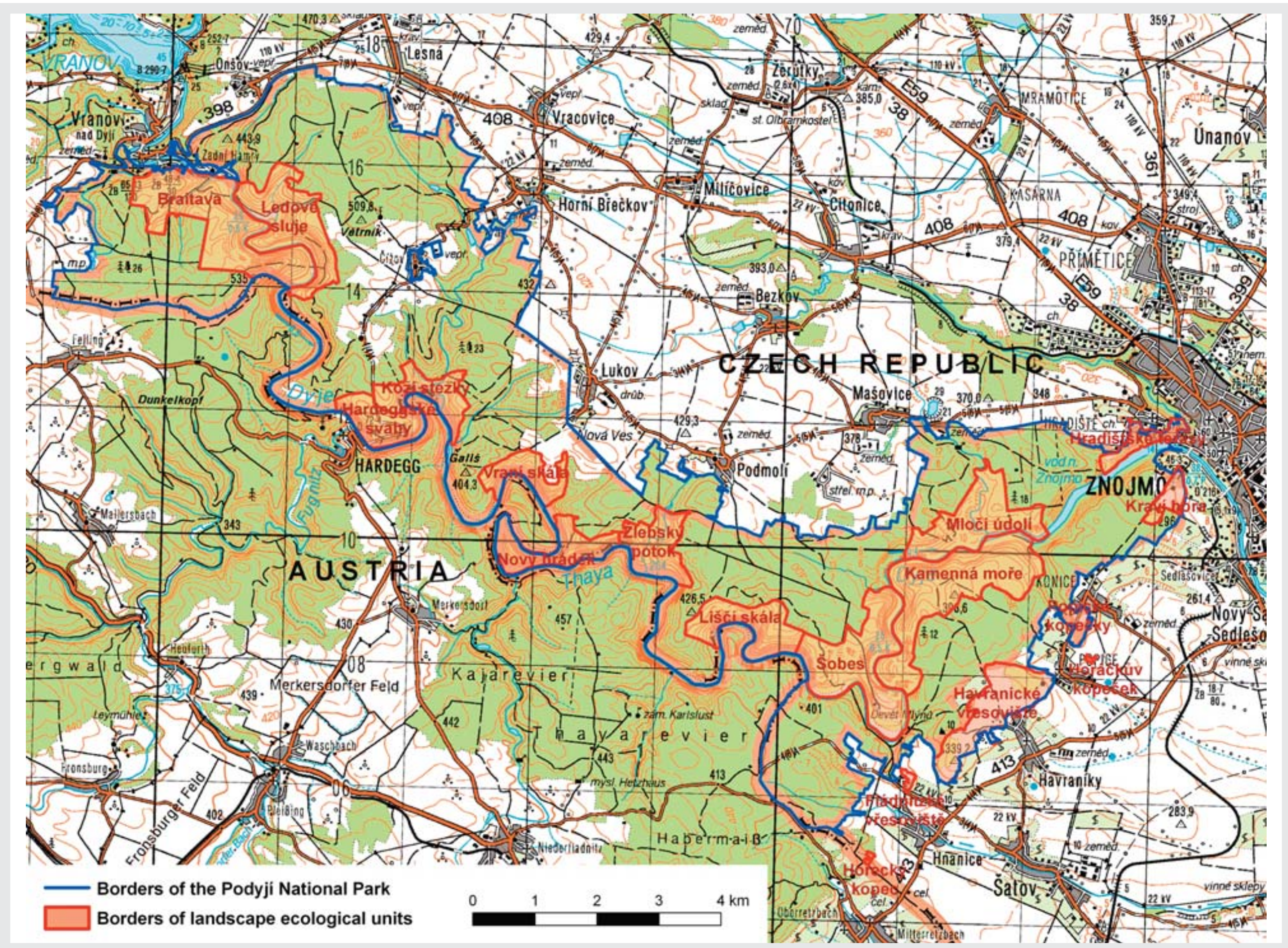


Fig. 5 – Landscape-ecological units in the Podyjí National Park.
– *Unità di paesaggio-ecologiche nel Parco Nazionale di Podyjí.*

river and following unloading of Bíteš orthogneiss. There are many well-developed rock forms (cliffs, rock pillars, tors, block fields, block streams, pseudokarst caves, honeycomb weathering, etc.). A slope virgin forest covers this steep valley slope.

Segment Ledové sluje (Ice Caves)

Special phenomenon on slip-off spur of entrenched meander and neighboring abandoned meander incised into Bíteš orthogneiss (see DEMEK & KOPECKÝ, 1996). Unloading of bedrock after incision of the Dyje/Thaya R. (and maybe an earthquake) caused rockslides, opening of fissures and formation of several hundred of meters long and tens of meters deep pseudokarst caves in gneiss (fig. 6). Due to special microclimatic conditions cave ice remains in pseudokarst caves up to August. Rare glacial relicts of invertebrates were found in these caves and in block fields on slopes. The segment is a habitat for 17 species of bats. Quantitative measurements of gravitational movements are carried out in caves and in block fields. Segment is closed for public.

Segment Kozí stezky

The segment occupies the left valley slope of the entrenched meander of the Dyje/Thaya R. and deep valley of the Klapperův potok Creek. Mica schist of the Lukov Unit of the Moravian Unit forms this steep slope. There are many cryogenic forms (frost-riven cliffs, etc) from Pleistocene ice-ages on the slope. Very complex catena developed from rock steppe and forest-steppe in the upper part of the slope, natural broad leaf forest in the middle part up to floodplain forest at the valley bottom. Anthropogenic forms (originated by mining) from the medieval time can be found in this segment. At the mouth of the Klapperův potok Creek karst forms with karst spring in marble developed.

Segment Nový Hrádek (New Castle)

Segment is situated on the left valley slope of the Dyje/Thaya R. valley and on a rocky spur of the entrenched meander with the medieval castle of Nový Hrádek. The bedrock is formed by mica schist with quartzite dikes of the Lukov Unit of the Moravian Unit. Wonderful developed entrenched meanders in Czechia (Ostroh) and in Austria (Umlaufberg NE from the village of Merkersdorf) are unique features in this segment. This segment was settled since prehistoric time and therefore there are many anthropogenic forms (fortification forms, sunken road cut into the bedrock, agricultural terraces). Movements of visitors are allowed on marked tourist trails only.

Segment Šobes

A core of the segment lies on a slip-off spur of an impressive entrenched meander and neighboring abandoned meander Lipina with rocky outlier of the Dyje/Thaya R. The bedrock is formed by granite of the Dyje Massif. Man settled this area already 30.000 years B.P. and continuous settlement was established since 4300 years B.C. There are many forms of weathering of granite (large corestones, block fields, block streams). Original forest steppe and xerothermic vegetation were mostly replaced by vineyards on agricultural terraces (already since Roman times – 1st Century A.D.). In this part of the valley 9 mills were situated since 1497, floods destroyed 3 mills already during the 16th century.

Segment Kamenná moře (Block fields)

Landscape-ecological unit is situated on the right steep slope of the Dyje/Thaya R. valley between Papírna (Paper Mill) and the mouth of the Trauznický potok Creek. Bedrock is formed by granites of the Dyje Massif. Detailed geomorphologic mapping in the scale 1:5000 has shown a great variety of granite landforms (see IVAN & KIRCHNER, 1998) in this segment. Due to unloading of granite and following frost weathering in the Pleistocene ice-ages originated rugged ridges, rock pil-

Fig. 6 – Ledové sluje (Ice-caves). Pseudokarst caves in gneiss originated by gravitational processes are unique phenomenon of landscape-ecological unit. Photo J. Kopecký.

– *Ledové sluje (Ice-caves). Queste cavità pesudocarsiche nello gneiss dovute a processi gravitazionali sono fenomeni unici nell'unità di paesaggio. Fotografia di J. Kopecký.*

lars, tors, pseudokarst caves, block fields and block streams (fig. 7). On granite corestones and rock forms developed pseudokarst lapiés and weather pits. Natural and semi-natural forest covers the most of segment – from floodplain forest on the valley bottom up to pines on granite slopes. In upper parts of slopes rock steppe developed. Segment is open for visitors on marked trails only.

Segment Hradištské terasy (Agricultural terraces of Hradiště)

Man activities substantially changed left granite slope of the Dyje/Thaya R. valley. Medieval farmers built on the steep slope a complex system of agricultural terraces for gardens and orchards, which is preserved up to now. Several old mining forms can be also found among orchards. Around granite tors and corestones preserved remnants of warm forest steppe. This ancient type of South Moravian cultural landscape is still used partly by farmers, partly for recreation. The aim of management is to keep the landscape equilibrium among natural conditions and Man activities in this part of the National Park.

Fig. 7 – Landscape-ecological unit Kamenná moře. A lot of granite rock forms (rugged ridges, rock pillars, tors, block fields) are situated on the right steep slope of the Dyje/Thaya R. valley in the eastern part of the Podyjí NP. Photo M. Havlíček.
– Unità di paesaggio-ecologiche di Kamenná moře. Molte delle forme nelle rocce granitiche (tor, campi di pietre ecc.) sono situate nel ripido versante destro della valle del fiume Dyje/Thaya nel settore orientale del Parco Nazionale di Podyjí. Fotografia di M. Havlíček.

5. – CONCLUSION

Geomorphological mapping was the basic information source for delimitation of landscape-ecological units in the first zone of the National Park Podyjí, especially in deep incised valley of the Dyje/Thaya R. valley. Landscape-ecological division is aimed for purpose of nature conservation and landscape protection of extremely valuable landscape on the frontier between Czechia and Austria.

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figg. 11

Geomorphology and Archaeology: an integrated heritage along the Roman *Via Flaminia* in the mid Metauro River valley (Central Italy)

Geomorfologia e Archeologia: un patrimonio integrato lungo la Via Flaminia nella media Valle del Metauro (Italia centrale)

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ABSTRACT – The sector of the mid Metauro River valley (northern Marchean Apennines) run across by the Roman *Via Flaminia* owns a remarkable geomorphologic, naturalistic and historical heritage. Indeed, major Roman vestiges well integrated with landforms do occur in such places, originating a significant blend of geomorphologic and archaeological components. The presence throughout the study area of such remarkable cultural components distributed all along the "historical" *Via Flaminia* is suitable to promote an integrated approach to landscape exploitation. This paper has two primary objectives: to enhance the scientific and cultural knowledge of the "integrated" landscape of the mid Metauro River valley and to apply an integrated approach for a suitable exploitation of the geomorphic and archaeological heritage for a sustainable and responsible tourism. In this concern, a geo-archaeotouristic itinerary along the Roman *Via Flaminia* is proposed and the three most remarkable sites of geomorphologic and archaeological interest pertaining to considered sector of the "historical" road are taken into account and described.

KEY WORDS: Geomorphosites, Geoarchaeology, *Via Flaminia*, Metauro River valley, Central Italy.

RIASSUNTO – La media valle del Metauro (Appennino nord Marchigiano) attraversata dalla Via Flaminia possiede uno straordinario patrimonio geomorfologico, naturalistico e storico. Qui, le maggiori vestigia romane, ben integrate con il paesaggio, originano una significativa miscela di componenti geomorfologiche e archeologiche. La presenza in tutta l'area di studio di componenti culturali così straordinarie distribuite lungo la storica Via Flaminia ben si presta per promuovere un approccio integrato per la valorizzazione del paesaggio. Questo lavoro ha due obiettivi principali: contribuire alla conoscenza scientifica e culturale del paesaggio integrato della media valle del Metauro e applicare un approccio integrato per una appropriata valorizzazione del patrimonio geomorfologico e archeologico al fine di sviluppare un turismo sostenibile e responsabile. In questo senso, viene proposto un itinerario geoarcheoturistico lungo la Via Flaminia e i tre siti di interesse geomorfologico e archeologico più presenti nel settore considerato della via storica vengono presi in considerazione e descritti.

PAROLE CHIAVE: Geomorfositi, Geoarcheologia, Via Flaminia, Valle del Matauro, Italia centrale.

1. – INTRODUCTION

The landforms of the mid Metauro River basin are impressive as well as crucial to unravelling the Plio-Quaternary evolution of this sector of the Apennines (e.g. DI BUCCI *et alii*, 2003 and references therein; MAYER *et alii*, 2003 and references therein). In this area the geomorphologic constituents flawlessly integrate into a wider naturalistic and historical-cultural context (VARIOUS AUTHOR, 2003). Indeed, major Roman vestiges do occur widespread (e.g. LUNI, 2003), often originating a significant blend of landforms and archaeological elements (DILIGENTI *et alii*, 2005). The over 500 m-deep Furlo Gorge is certainly the most famous site in the area, being well known for both its geologic-geomorphologic substance and beauty as well as for Roman works, such as tunnels chiselled out of rock and the imposing walls of the *Via Flaminia* road (DILIGENTI *et alii*, 2005; LUNI, 1993).

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Hence, taking into account these peculiarities of the landscape, the Furlo Gorge area has been proposed (DILIGENTI *et alii*, 2005) as a Geomorphosite (*sensu* PANIZZA, 2001). Few kilometres downstream, the remains of the Roman *Forum Sempronii* town are placed (GORI & LUNI, 1993) close to the *Metauro* River, on a meander which was abandoned by stream-flow only in post-Roman times (SAVELLI *et alii*, 2004). Between the Furlo Gorge and the Roman *Forum Sempronii*, along the *Via Flaminia* road, the San Lazzaro Gorge site is found, an area of the Metauro River valley characterised by significant geologic, geomorphologic and historical-cultural components (GORI, 1993; PERGOLINI, 1990). Recently a geologic itinerary has been suggested in this site (SAVELLI & TRAMONTANA, 2001) in the framework of the paths proposed for the Umbria-Marchean Apennines by the Italian Geological Society.

Since the *Via Flaminia* constitutes an "historical" road connecting all these places (LUNI, 1989), an itinerary is being proposed along this route, which could allow students and tourists to benefit from an integrated approach to the remarkable geomorphologic, historical and archaeological heritage of this area. Moreover, the general aim of this work is to propose a geotouristic pathway in a sector of the Apennines chain that could be one of the first examples of sustainable use of the integrated landscape of the *Marche* region.

This work has been performed within the framework of a national research project which was supported by the Italian Ministry of Instruction, University and Research (COFIN 2004, Scientific Coordinator prof. M. PANIZZA) and focused on the suitable exploitation of the geomorphic heritage for a sustainable and responsible tourism.

2. – GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The study area lies in the northern *Marche* Apennines, a northeast-verging fold-and-thrust belt (BOCCALETTI *et alii*, 1971) made up of a stratigraphic succession evolving upward from carbonatic to terrigenous terms (COCCIONI *et alii*, 1994). The chain emerged definitely during the late Pliocene–lowermost Pleistocene (MAYER et *alii*, 2003) and a drainage network developed where the main streams followed an approximately sub-parallel pattern, mainly SW–NE oriented, and essentially perpendicular to the structural grain (MAZZANTI & TREVISAN, 1978). In the study area, the main carbonatic anticlines are prominent ridges (fig. 1) in the modern topography and the major streams cross-cut them in deep and narrow gorges (e.g. the Furlo Gorge, the most important and suggestive one) as they flow into the Adriatic Sea (fig. 1). The Marchean ridge is the most relevant morphostrocture of the study area. Significatively (MAYER *et alii*, 2003), the *Pietralata* and *Paganuccio* Mts. (Marchean Ridge) match to an axial culmination of the structure. More to the east, minor ridges - up to a few hundred of meters - can be found (e.g. the calcareous and marly-calcareous *Monti della Cesana* minor Ridge (fig. 1). Close to the coast, the mountain chain area merges in a hilly piedmont and coastal zone, where slightly deformed Plio-Quaternary terrains predominate.

The landscape is influenced by the inherited Pleistocene landforms referable to periglacial morphogenesis, characterized by slope and fluvial depositional processes. Alluvial deposits are arranged in at least four different levels of terraces (FANUCCI *et alii*, 1996) formed as response to aggradation and erosion phases of rivers, associated to Quaternary climatic oscillations and regional uplift (NESCI & SAVELLI, 1986; BISCI & DRAMIS, 1991).

3. – ARCHAEOLOGICAL OUTLINE

Besides its environmental and geologic-geomorphologic features, the target area is distinguished by remarkable historical-archaeological elements. In the first instance, it is run across by a primary Roman arterial road formerly joining Rome and Rimini, the *Flaminia* consular road, opened by consul C. Flaminius around 220 BC. In ancient times, the *Flaminia* was the major road link between the Roman world and northern Italy and, later on, with Mideastern Europe. It is marked by the constant presence of Roman age infrastructure such as bridges, sluice gates, viaducts, rock cuts, tunnels, pavements, milestones and inscriptions. Moreover, a lot of Roman settlements rose in close proximity to the consular road which could guarantee easy communications and economic development. The *municipium* of *Forum Sempronii*, by today's *Fossombrone*, stands out among them on account of its being favourably located in the middle of the Metauro valley, close to the river; here visitors can admire one of the most important archaeological parks in the region. The best known and visually impressive site is undoubtedly the Furlo Gorge, where geologic-geomorphologic components perfectly complement historical-archaeological ones. Here the *Flaminia* road wedges into a narrow canyon, thus proving the Romans' extraordinary skill in exploiting and capitalising on natural elements. The road is provided with retaining walls, rock cuts and artificial tunnels to allow crossing even where difficult.

4. – THE ROMAN *VIA FLAMINIA* ITINERARY BETWEEN *FORUM SEMPRONII* SITE AND THE FURLO GORGE

An integrated geo-archaeotouristic itinerary along the "historical" *Via Flaminia* road is here proposed. It covers an interval of about 15 km along the S.S. n° 3 road, a secondary way of communication with a low frequency of traffic. This road is parallel to the S.S. n° 3 *bis* motorway which nowadays constitutes the main connection way in this sector of northern *Marche* region. The proposed itinerary matches approximately the ancient Roman *Via Flaminia* road. Actually, travelling along this road is just like to travel along the ancient Roman one. The proposed itinerary (fig. 2), from the *Forum Sempronii* site to the *San Lazzaro* one, runs entirely in the Metauro River valley. From the *Calmazzo* village up to the upstream end of the Furlo Gorge, the itinerary leaves the *Metauro* River valley-floor entering the *Candigliano* River valley - the major tributary of the *Metauro* River- and here crosses the *Furlo Gorge*.

The three most remarkable sites of geomorphologic and archaeologic interest pertaining to considered sector of the Roman *Via Flaminia* road are taken into account (fig. 2) and described. Hence, the geologic, palaeontologic and geomorphologic characteristics of the Furlo Gorge, the geomorphologic relevance of the San Lazzaro Gorge and, finally, the archaeological and historical components of the *Forum Sempronii* area will be considered. The presence of several and remarkable cultural components well distributed throughout the area and along the "historical" *Via Flaminia* road is suitable for promoting an integrated approach in landscape exploitation for this sector of the *Marche* Apennines.

4.1. – THE ROMAN *FORUM SEMPRONII* SITE

The Roman town of *Forum Sempronii* is set upon a wide upper Pleistocene terrace, on the left flank of Metauro River valley, about 20 m above the present valley-floor (SAVELLI *et alii*, 2004) (fig. 3). A

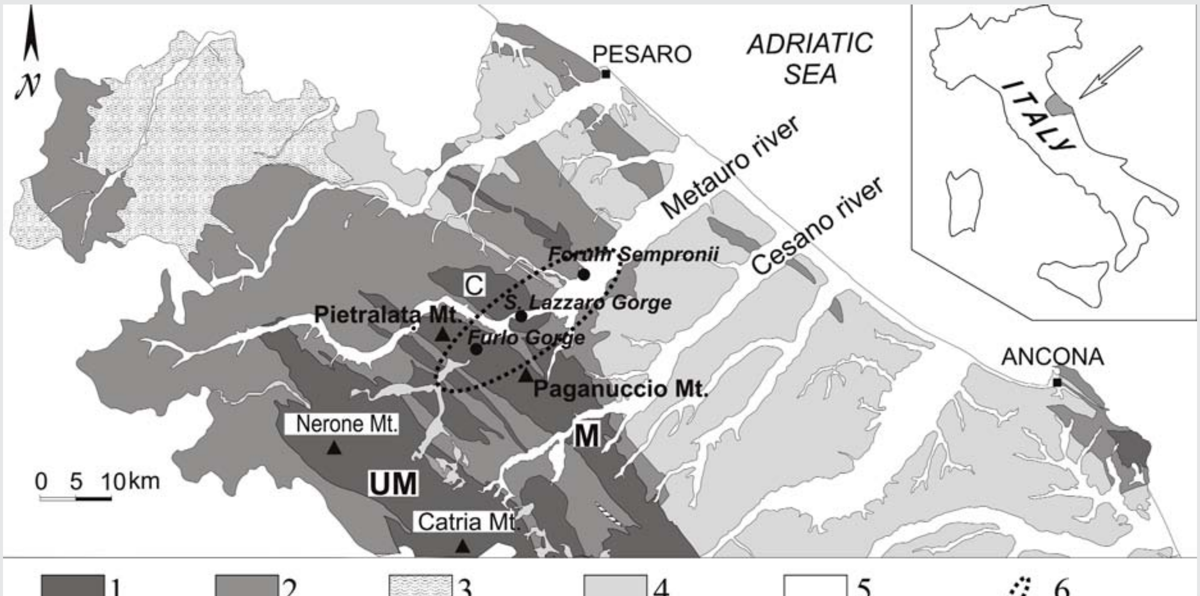

Fig. 1 – Geological sketch of the northern *Marche* Apennines and location of the study area (after: CAPACCIONI *et alii*, 2004, redrawn). 1) Meso-Cenozoic calcareous and marly-calcareous units of the carbonatic ridge; 2) Cenozoic marly-calcareous, evaporitic and siliciclastic units; 3) *Val Marecchia* allochthonous units; 4) Plio-Pleistocene terrigenous units; 5) middle Pleistocene-Holocene fluvial and coastal deposits; 6) study area; UM) Umbro-Marchean Ridge; M) Marchean Ridge; C) *Monti della Cesana* minor Ridge.

– Schema geologico del settore settentrionale dell'Appennino Marchigiano e ubicazione dell'area di studio (da: CAPACCIONI et alii , 2004, ridisegnato). 1) Unità Meso-Cenozoiche calcaree e marnoso-calcaree della dorsale carbonatica; 2) Unità Cenozoiche marnoso-calcaree, evaporitiche e silicoclastiche; 3) Unità alloctone della Val Marecchia; 4) Unità terrigene Plio-Pleistoceniche; 5) depositi fluviali e costieri del Pleistocene medio - Olocene; 6) area di studio; UM) dorsale Umbro-Marchigiana; M) dorsale Marchigiana; C) dorsale minore di Monti della Cesana.

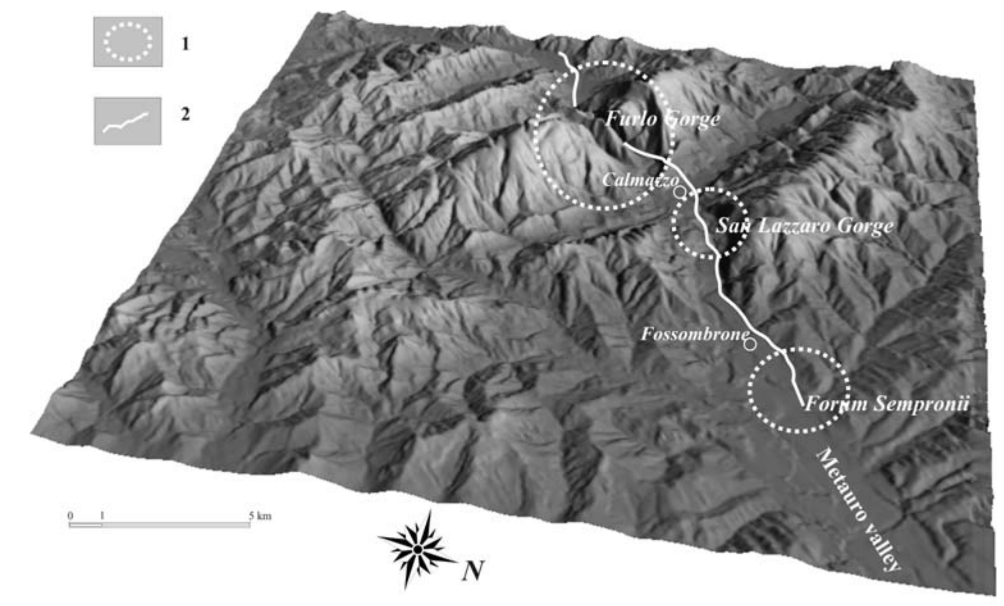

Fig. 2 - Digital Terrain Model (DTM) of the study area (kriging grid, 25 m resolution; vertical amplification: 1: sites described in the text. 2: the Roman *Via Flaminia*.
- *Modello Digitale del Terreno (DTM) dell'area di studio (kriging grid, 25 m risoluzione; amplificazione verticale: 1: siti descritti nel testo. 2: la Via Flaminia.*

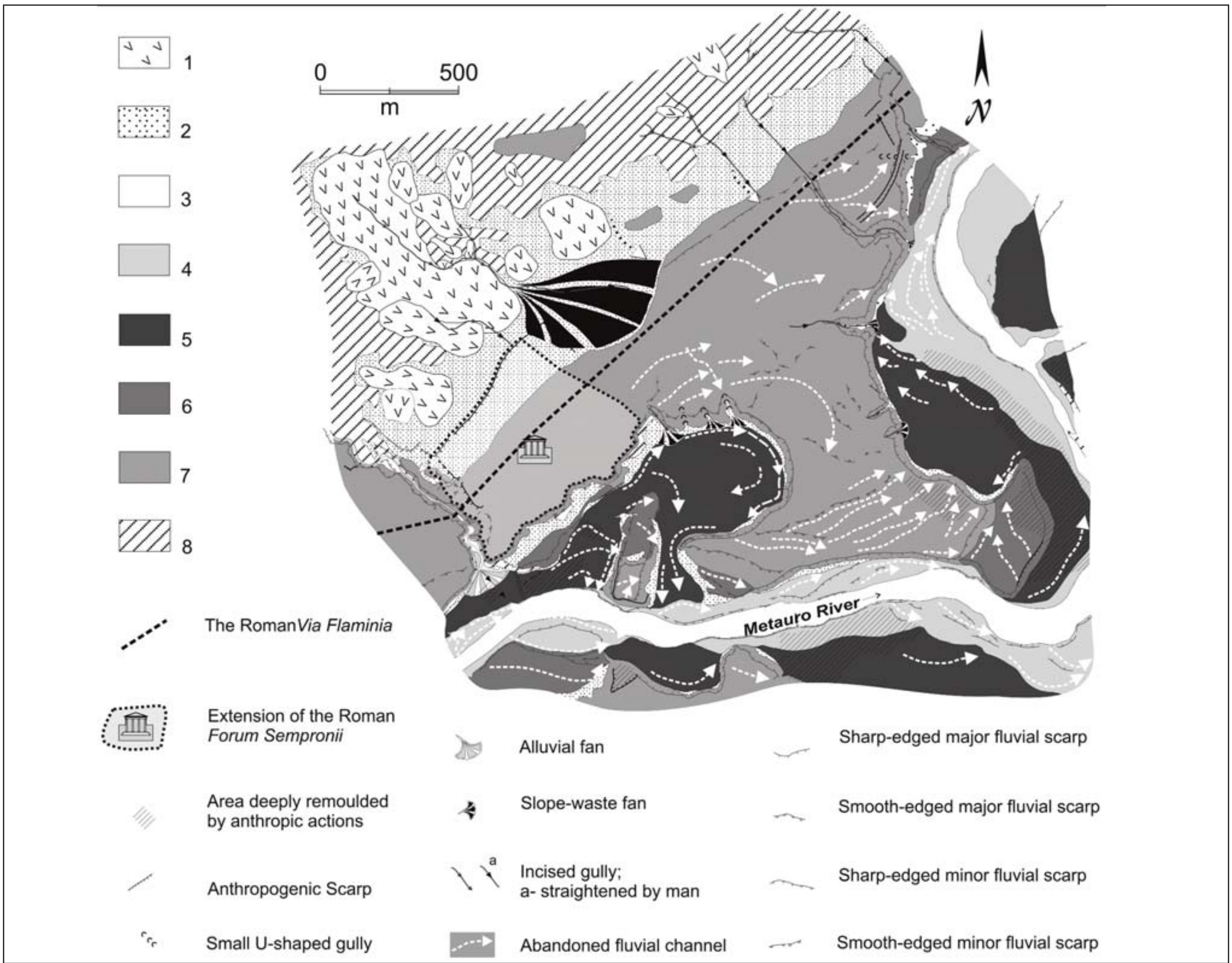

Fig. 3 – Geomorphological sketch of the *Forum Sempronii* area (after: SAVELLI *et alii*, 2004). 1: Landslide body; 2: Slope-waste deposits; 3: Active alluvial deposits; 4: partially re-incised alluvium post-dating the 50ies; 5: Terrace alluvium post-dating the 4th-5th century AD; 6: Terrace alluvium (Holocene); 7: Terrace alluvium (middle-upper Pleistocene); 8: Bedrock.

– *Schema geomorfologico dell'area di Forum Sempronii (da: SAVELLI et alii, 2004). 1: Corpo di frana; 2: Detrito di versante; 3: Depositi alluvionali attivi; 4: Depositi alluvionali in parte reincisi posteriori agli anni 50; 5: Terrazzo alluvionale posteriore al 4°-5° secolo AD; 6: Terrazzo alluvionale (Olocene); 7: Terrazzo alluvionale (Pleistocene medio-sup.); 8: Substrato.*

broad relict meander of the Metauro River is certainly one of the most important landform of the modern landscape immediately close to the archaeological site (fig. 4). The abandoned meander cuts the upper Pleistocene terrace-alluvium and is bounded to the north by the terrace scarp where the southern wall of the Roman town was built (fig. 3). The scarp enclosing the abandoned meander separates the upper Pleistocene terrace-alluvium from the Holocene one. This scarp is well-preserved and shows a sharp upper edge and scarce colluvium/debris accumulation at the toe. Furthermore, the abandoned Metauro River channel is still well recognisable along almost all the scarp toe. The excellent preservation of such landforms hints at quite a recent cut-off of the meander neck and abandonment of the previous course. On the basis of several considerations (e.g. Roman bricks and tiles in alluvial deposits at the mouth of the meander, historical maps dating to 16th-18th century) it can be assumed that in Roman times the Metauro River flowed through the present day abandoned meander, at the toe of the southern walls of the town.

Forum Sempronii was founded, in a site populated in pre-Roman times, between 132 and 126 BC, probably by *Caius Sempronius Gracchus*, whose presence in that area is documented by an inscription (CIL, I^2, 719), recovered in the 18th century on the hill of *Monte Giove*, not far from Fano. The so-called "*cippo graccano*" mentions the activity of the triumviral committee appointed to enforce the *lex Sempronia* of 133 BC, aimed at reorganising the *ager publicus* by parcelling out and allotting the agricultural land. *Forum Sempronii*, which turned into a *municipium* during the 1st century BC, has been ascribed to the *Pollia* tribe and mentioned by Strabo (Suda V, 2, 10), Plinius (HN, III, 113) and Tolomeus (III, 1, 46), as well as in the *Itineraria*. Marked by a flourishing Christian community since the late 4th-early 5th century AD and known as bishopric (VERNARECCI, 1903: 97-116), the city was heavily damaged during the greek-gothic war of 535-553 AD. After that, most of the inhabitants, for defensive reasons, moved to a nearby hill, thus originating the centre which evolved during medieval and renaissance times under the name of *Fossombrone*. The former city was almost completely abandoned, but the new settlement kept its name, despite some alterations due to the passing of time and language changes (LUNI, 2001, 16).

The site of the ancient *municipium* had been lo-

Fig. 4 - The abandoned meander of *Metauro* River.
– *Il meandro abbandonato del fiume Metauro.*

cated, since the 15th century, on the vast plain where the modern village of *S. Martino del Piano* is, about 2 km east of Fossombrone, after the recurrent discovery of artefacts during the ploughing-season (Vernarecci, 1903: 30-34; Mercando 1983: 83-84; Gori & Luni, 1983: 91-96). Besides affecting town layout, the *Flaminia* road, built around 220 BC, played a major role in the city's economic development, mainly in the first two centuries of the empire.

At least three sides of the Roman town walls took advantage of geomorphologic elements. Indeed, they were against the foothill to the north; to the west they ran along the edge of a steep scarp on the left of *Fosso della Conserva* (a small left-tributary stream of the Metauro River), and they rose southwards on the edge of the Pleistocene terrace. Relations with modern geomorphological features are more problematic in the eastern side of the town: nevertheless, recently, Savelli *et alii* (2004) have found some correlation of Roman town and the course of an ancient, no longer recognisable gully. Large cemeteries were found both to the west, over the *Fosso della Conserva*, and to the east of the settlement, thus allowing us to mark the boundary of the ancient urban area. The existence of some Roman tombs was reported in the easternmost sector of the scarp which borders the city south-east. Probable sections of defensive walls and the rests of two quadrangular towers in *opus quadratum*, incorporated in the foundations of two farmhouse (Gori & Luni, 1983: 92, 103), are currently visible on the southern side, while a wall section and a circular tower in *opus tumultuarium* (dated to the half of the 6th century AD and connected with the Greek-gothic war) were discovered on the very eastern side. Here, in 1806, some structures were found probably pertaining to a gate, in the same place where, on 3rd October 1603, an inscription mentioning the *Porta Gallica* was recovered (CIL, XI, 6136; Vernarecci, 1903: 34-35; Gori & Luni, 1983: 103). As a consequence, the settlement was extended for about 30 hectares, having a squared road network, with parallel and perpendicular streets crossing each other at right angles (fig. 5). The members of the Urbino University Archaeological Institute, in collaboration with the regional board of the Ministry of Cultural Heritage, have systematically studied the city since 1974, through surveys and soundings, locating and

Fig. 5 – Roman paved streets of *Forum Sempronii*.
– *Strade lastricate Romane di Forum Sempronii.*

digging out two baths, a urban stretch of the *Flaminia* consular road, as well as the stretches of other streets, thus allowing us to recognise at least one rectangular *insula*, measuring 2 by 3 *actus* (ca. 70x105 m.; LUNI, 2001: 11-16; LUNI, 2003).

4.2. – THE SAN LAZZARO GORGE AREA

This area is located in the neighbourhood of the village of *Calmazzo* (fig. 2), where the Metauro valley crosses and deeply cuts the *Monti della Cesana* minor Ridge (fig. 1). Here, the valley shows a strong flanks asymmetry. The left valley flank is steep and completely lacking in terraces older than upper Pleistocene (fig. 6); these latter on the contrary are preserved on the right valley side. In addition, the left valley flank shows significant gravitational instability stressed by extensive erosional processes, deep landslides, marked slope-waste production and formation of alluvial fans (fig. 6). The gravitational instability of this valley side is also underlined by the 1934 landslide, which produced 11 victims and is remembered by a commemorative inscription. The different characteristics of the two valley sides suggest a major tectonic control in the valley profile evolution (SAVELLI *et alii*, 2002). The most significant geomorphologic feature of this area is a gorge, up to 30 meters deep, carved by the Metauro River out of the Cretaceous limestones of the *Maiolica* Fm (fig. 6). Well preserved giants potholes (fig. 7) are the most relevant landforms of the gorge. Six major potholes, both active and fossil, can be easily watched from the so-called *Ponte di Diocleziano* on the left gorge side; nevertheless, several minor potholes are present all along the gorge.

San Lazzaro is sometimes reported as bearing a Roman bridge, the so-called *Ponte di Diocleziano*. However, such bridge is not Roman, but younger in age, i.e. not older than Medieval times (LUNI, 2003, and references therein). Worth mentioning is the discovery of Roman burials at *Ponte Rotto*, *Calmazzo* (some 10 km west of *Forum Sempronii*), and, further to the west are the remains of an important Imperial age burial ground belonging to the local *gens Cissonia* (fig. 8). Indeed, a fairly important settlement, maybe a *vicus*, likely to be situated by *Calmazzo*, where the *Flaminia* branched off into a *diverticulum* connecting the consular road with middle-upper Metauro valley *municipia* (GORI, 1993). In the past, several archaeological finds – remains, pottery and various building materials – were recovered in close proximity to such key

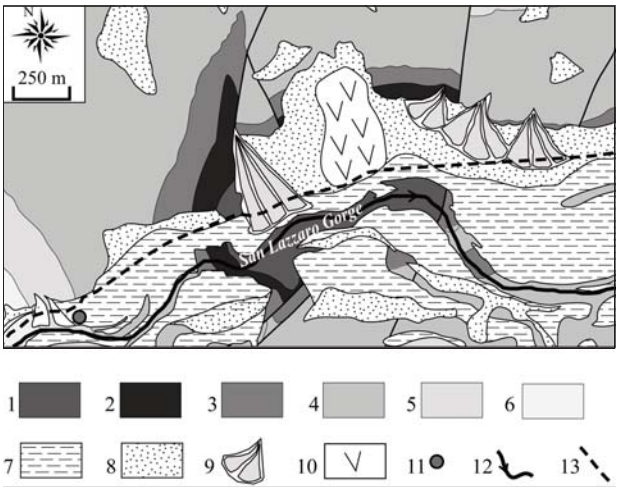

Fig. 6 – Geological sketch of the San Lazzaro Gorge site. (after: SAVELLI & TRAMONTANA, 2001, redrawn). 1: *Maiolica* Fm. (upper Jurassic-middle Cretaceous); 2: *marne a Fucoidi* Fm. (middle Cretaceous); 3: *Scaglia Bianca* Fm. (middle Cretaceous–upper Cretaceous); 4: *Scaglia Rossa* Fm. (upper Cretaceous-middle Eocene); 5: *Scaglia Variegata* Fm. (middle Eocene-lower Oligocene); 6: *Scaglia Cinerea* Fm. (lower Miocene); 7: terrace alluvium (middle Pleistocene-Holocene); 8: slope-waste deposits (upper Pleistocene-Holocene); 9: alluvial fan (Holocene); 10: the 1934 *San Lazzaro* landslide; 11: roman burials; 12: *Metauro* river; 13: the Roman *via Flaminia*.
– *Schema geologico dell'area delle Gole di San Lazzaro (da: SAVELLI & TRAMONTANA, 2001, ridisegnato). 1: formazione della Maiolica (Giurassico sup.-Cretacico medio); 2: formazione delle Marne a Fucoidi (Cretacico medio); 3: formazione della Scaglia Bianca (Cretacico medio –Cretacico sup.); 4: formazione della Scaglia Rossa (Cretacico sup.-Eocene medio); 5: formazione della Scaglia Variegata (Eocene medio - Oligocene inf.); 6: formazione della Scaglia Cinerea (Miocene inf.); 7: terrazzi alluvionali (Pleistocene medio-Olocene); 8: detrito di versante (Pleistocene sup.-Olocene); 9: conoide alluvionale (Olocene); 10: la frana del 1934 di San Lazzaro; 11: tombe romane; 12: fiume Metauro; 13: la via Flaminia.*

Fig. 7 – The potholes of the San Lazzaro Gorge.
– *Marmitte dei giganti delle Gole di San Lazzaro.*

Fig. 8 – *Gens Cissonia*'s burial ground, *Calmazzo* village.
– *Recinto sepolcrale della Gens Cissonia, Calmazzo.*

crossroads and some burial areas have been detected. Chief among the latter is *gens Cissonia* burial ground, the excavation of which was performed, since 1989, by the university of Urbino in alliance with the regional board of the Ministry of Cultural Heritage. The area, approx 135 square metres, is bordered by a stone kerb originally bearing ashlar limestone slabs positioned at regular intervals. Inside the burial ground were two sepulchral altars, respectively dedicated to *C. Cisso Festus* and *C. Cisso Zosymus* and his wife *Cissonia Festa*. Noteworthy among the tools found inside the tombs is a gold necklace, as well as balsam and ointment vases, lamps and pottery. The funeral monument can be dated at early imperial age.

4.3. – The Furlo Gorge

The *Furlo Gorge* site is well know for a striking canyon deeply cut by the *Candigliano* River, the major tributary of the Metauro River, transversally crossing the anticline mountains of *Pietralata-Paganuccio* Mts. (named *Monti del Furlo* according to a local designation). The gorge cuts the Jurassic-Paleogene calcareous and marly-calcareous formations of the Umbria-Marchean Succession. This area is one of the best example of such puzzling

Fig. 9 – Geologic and geomorphologic map of the Furlo Gorge area (after: Diligenti *et alii* , 2005, redrawn). 1: *Calcare Massiccio-Corniola* Fms. (upper Triassic-lower Jurassic); 2: *Rosso Ammonitico* Fm. (lower Jurassic); 3: *Bugarone-Maiolica* Fms. (middle Jurassic-middle Cretaceous); 4: *Marne a Fucoidi* Fm. (middle Cretaceous); 5: *Scaglia Bianca-Scaglia Cinerea* Fms. (middle Cretaceous-Oligocene); 6: *Bisciaro* Fm. (lower Miocene); 7: landslide (upper Pleistocene-Holocene); 8: slope-waste deposits (upper Pleistocene-Holocene); 9: present day flood plain deposits and Holocene terrace alluvium; 10: terrace alluvium (middle Pleistocene-upper Pleistocene).
– *Carta geologica e geomorfologica dell'area delle Gole del Furlo (da:* Diligenti et alii*, 2005, ridisegnato). 1: formazioni Calcare Massiccio-Corniola (Triassico sup.-Giurassico inf.); 2: formazione Rosso Ammonitico (Giurassico inf.); 3: formazioni Bugarone-Maiolica (Giurassico medio- Cretacico medio); 4: formazione delle Marne a Fucoidi (Cretacico medio); 5: formazioni Scaglia Bianca-Scaglia Cinerea (Cretacico medio-Oligocene); 6: formazione Bisciaro (Miocene inf.); 7: frana (Pleistocene sup.-Olocene); 8: depositi di degradazione di versante (Pleistocene sup.-Olocene); 9: depositi attuali di pianura alluvionale e terrazzo alluvionale Olocenico; 10: terrazzo alluvionale (Pleistocene medio-Pleistocene sup.).*

landforms typical of central and northern Apennines and shows the main geomorphologic peculiarity of the area. Recently, taken into account its attractive and scenic beauty and scientific/educational relevance (BARTOLINI & PECCERILLO, 2002) the *Monti del Furlo* area has been proposed (DILIGENTI *et alii*, 2005) as a Geomorphosite (*sensu* PANIZZA, 2001). Moreover, several fossiliferous sites as well as the outcropping of the regional-markers *Bonarelli* level and K/T stratigraphic bound, contribute to enhance the environmental significance of the integrated landscape of the Furlo Gorge site. Finally, recently the area was included in the Riserva Naturale Statale Gioa del Furlo.

The approximately NW-SE striking *Pietralata-Paganuccio* anticline is characterized by a slightly asymmetric box fold without any clear evidence of emergent thrust in its forelimb (CAPACCIONI *et alii*, 2005). The anticline rapidly plunge-down both towards the NW and the SE where forms a wide depressed area crossed by the *Cesano* River (fig. 1). The axial culmination of this structure matches with the Furlo Gorge. In particular, the Furlo Gorge is entrenched in the lower Jurassic *Calcare Massiccio* Fm., an over 500 m thick formation which manly consists of massive dolomitic limestones (CECCA *et alii*, 1999). This formation, the oldest outcropping in the area, is overlain by an approximately 600-700 m thick sedimentary sequence, manly characterized by calcareous, marly-calcareous and marly terrains, extending in age from lower Jurassic to lower Miocene (fig. 9).

Nevertheless the sub-vertical walls, hanging over 500 m high on present valley-floor (fig. 10), represent the main scientific and scenic attraction of the site, from a geomorphologic standpoint the area is also characterized by several minor, yet noticeable, landforms and landform assemblages. Actually, *Il Buzzo* minor gorge, approximately parallel to the main Furlo Gorge (fig. 9) and well-preserved flatirons immediately over the gorges, certainly represent some of the main landforms. Moreover, karst, fault-related and fluvial landforms (DILIGENTI *et alii*, 2005) can also be observed widespread in the area (fig. 9).

The Furlo Gorge, frequented since prehistory, represented the natural access from the coast to pastures and Apennine passes. Such key function was then heightened in Roman times with the opening of the *Via Flaminia* around 220 BC and the imposing works performed in order to make the gorge traversable. The significant remains both of the consular road and its associated structures make the Furlo Gorge an important and renowned archaeological site. Rock cuts and imposing walls were made (fig. 11), on the rock spur to the left flank of the Candigliano River, to get and sustain the road (the amount of removed rock is reckoned at 1500 m^3). Later on two tunnels were opened: a smaller one, the dating of which is uncertain (1st century BC – first half of the 1st century AD), and Vespasiano one, dated to 76 AD. This latter is one of the most significant examples of tunnelling in Roman times. The long-lived, primary function of the gorge as natural barrier played a prominent part in the Greek-Gothic war (535-553 AD) and, reputedly, in Longobardic times (6th-8th century AD; LUNI, 1989, 2003).

Fig. 10 – The Furlo Gorge.
– *Le Gole del Furlo.*

Fig. 11 – Roman walls in the downstream sector of the Furlo Gorge.
– *Costruzioni Romane nel settore a valle delle Gole del Furlo.*

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LXXXVII (2009), pp. 109-122
figg. 4 - tabb. 4

Geomorphological hazard assessment on natural rock wall for free climbing practice

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

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PECCI M. (***)

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

Key Words: geomorphological hazard, slope stability, tourism, geological-technical survey, geomorphological risk, free climbing.

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

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

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

1. – INTRODUCTION

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

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

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

2. – METHODS AND TOOLS

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

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

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

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

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

2.1. – Assessment of the site use capability

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1. Crag height

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

2. Rock features

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

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

3. Climate features

3.1. Local climate

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

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

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

4. Frequentation capability

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

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

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

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

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

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

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

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

6. Development capability

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

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

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

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

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

7. Fame

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The *Pietra* is also characterised by high value for the history of Alpinism: the first ascent is dated 1922 along the path called *Via degli Svizzeri*; subsequently, between the 1940s and the '60s, most part of the easier paths were climbed, soon becoming "classic" and well equipped. In the same years the first artificial lines were climbed, often attracting the most important italian mountaineers. Since the end of the '70s free climbing development started together with the equipment of a great number of paths, characterising also today the southern and equipped face (fig. 2).

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

3.2. – THE FULL-FILLED FORM

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

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

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

$$2·1.3·1·1·1·1·1·1.2·1·1·1·1.4·1·1.2·1.5·1·2 = 15.7$$

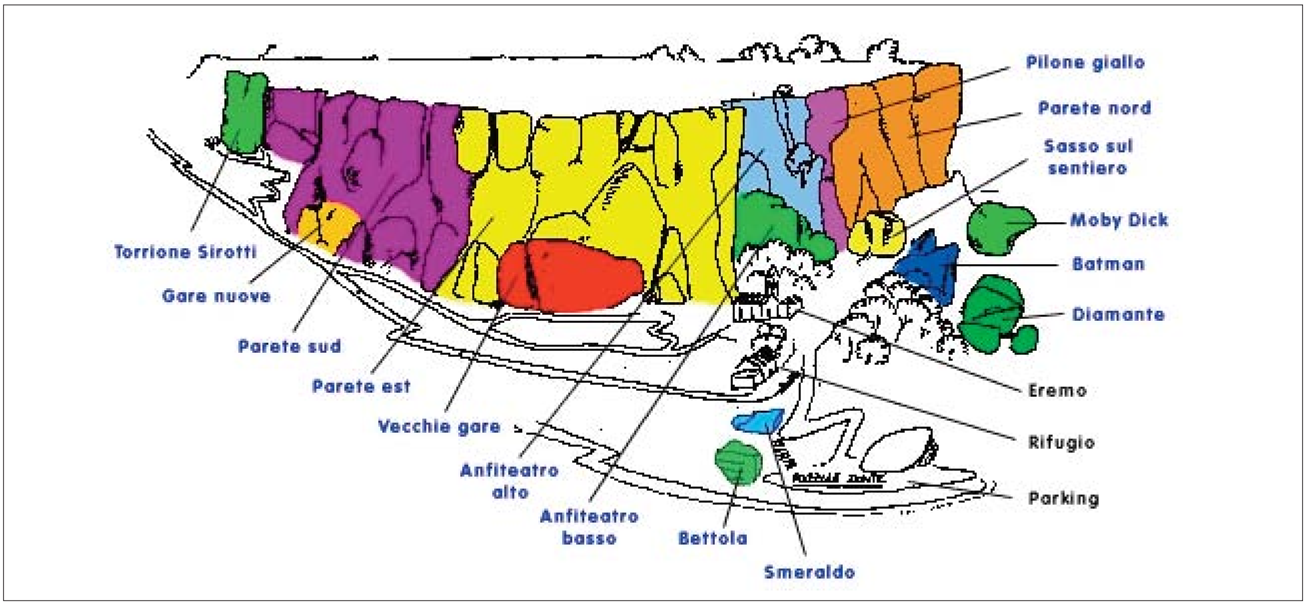

Fig. 2 – Sketch of the equipped walls of the *Pietra di Bismantova (www.sincretech.it/bismantova/html/arrampicata).*
– *Schema delle vie attrezzate per il freeclimbing della Pietra di Bismantova (www.sincretech.it/bismantova/html/arrampicata).*

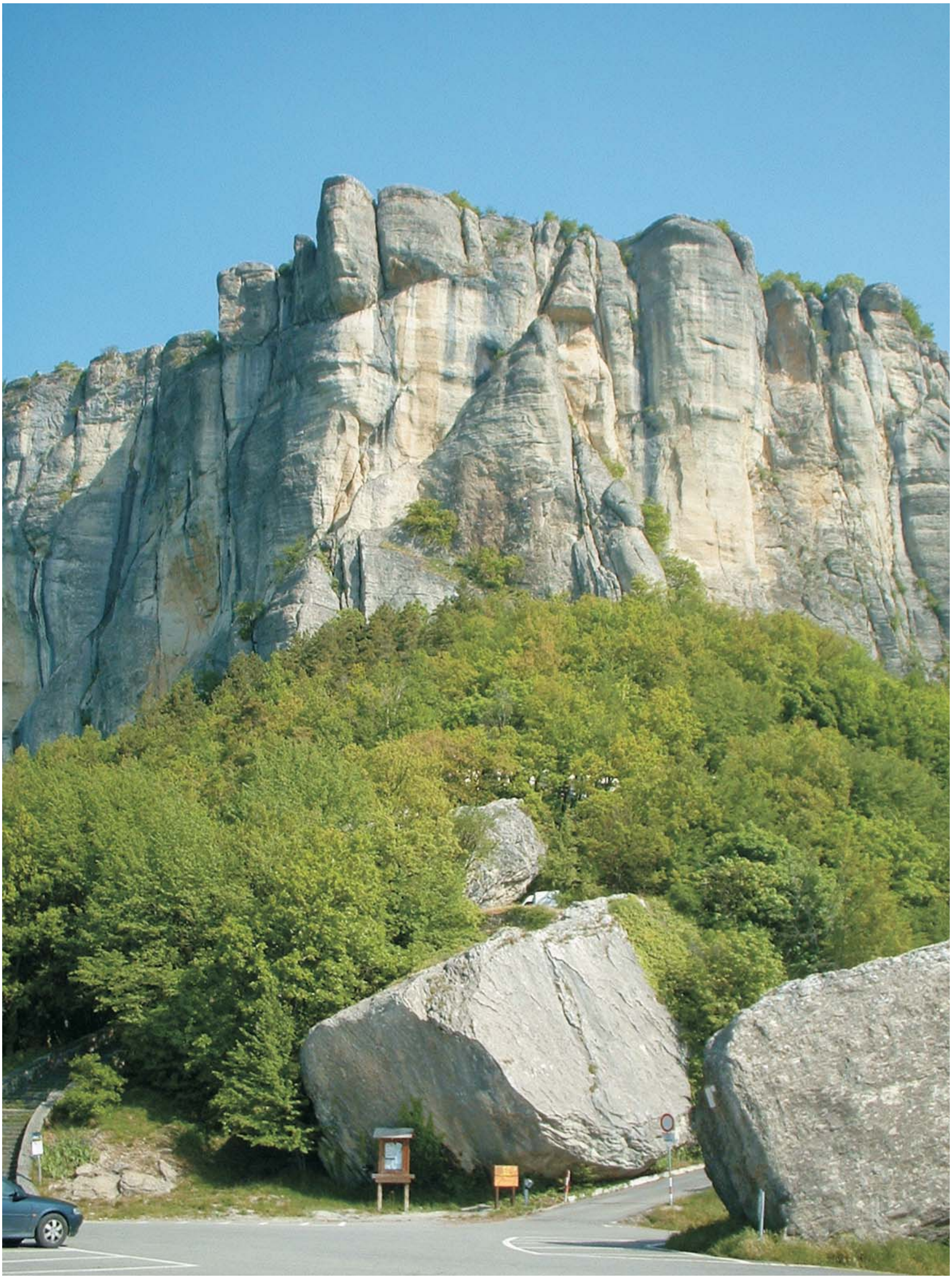

Fig. 3 – The high walls of the southern slope.
– *Le alte pareti del versante meridionale.*

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

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

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

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

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

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

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

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

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

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

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

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

GEOMORPHOLOGICAL HAZARDS PART 3.1

Hazard typology: rock falls

Spatial characteristics:
☐ areal ☒ linear ☐ punctual

Cause
☒ Natural
☐ Man made

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

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

Rock characteristics:
Lithotype: Arenaceous limestone

Weathering degree:
☐ hight ☐ average ☒ low

Joint rating: ☐ hight ☐ average ☒ low

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

Potential frequency of the phenomenon:

Ten-year
yearly
seasonal
monthly
continuous

Hazard degree associated to the event: Low

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

4. - CONCLUSIONS AND PERSPECTIVE

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

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

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

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

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

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

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figg. 17

Enhancement of glacial and periglacial Geomorphosites based on geomorphological and dendrochronological research. An example from the Trafoi Valley (Ortles - Cevedale Group)

La valorizzazione dei geomorfositi glaciali e periglaciali sulla base delle ricerche geomorfologiche e dendrocronologiche. Un esempio dalla Val Trafoi (Gruppo Ortles - Cevedale)

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LEONELLI G. (*), MARTINOLI M. (**) , SANTILLI M. (*)

Abstract – Many studies on geomorphology, glacial geology and glaciology have been carried out for years on the Alps with the goal of reconstructing the glacier history of the upper Holocene and the Little Ice Age. However, the results of this research are typically almost exclusively used by specialised researchers and their dissemination is lacking for people not working in these fields. At the same time, people enjoying the alpine environment are becoming more interested in learning about biotic and abiotic natural topics. These needs can be satisfied by creating naturalistic itineraries suitable for the communication of the scientific results in an easy and correct language. The scientific support can be given by naturalistic guides, illustrated panels or simply by brochures. The goal of this work is to demonstrate how both geomorphological and vegetational aspects concur in the reconstruction of Holocene glacier history. Moreover, this kind of integration allows to understand the sequence of the glacial processes. Finally, these naturalistic aspects can be easily observable along high mountain trails. The proposed work is an example showing how to apply these concepts along a thematic itinerary where geomorphology and dendrochronology are the two main subjects. In particular, the results about Quaternary geology, geomorphology and dendrogeomorphology recently carried out in upper Val Venosta (Trafoi Valley-Alto Adige), with the goal of reconstructing the glacier history of the Madaccio Glacier, are reported. Apart from proposing an itinerary, this work suggests how to prepare a "geotouristic" guided trail, able to easily transfer to a wide public the results of the basic research. Beyond logistic information, an explanation of the geomorphological evolution of the territory, using description, illustrations and drawings has been included.

Key Words: Madaccio Glacier, Glacier History, Dendrochronology, Geomorphosite.

Riassunto – Da anni sulle Alpi sono in corso studi di geomorfologia, geologia glaciale e glaciologia, finalizzati alla ricostruzione della storia glaciale nell'Olocene superiore e nella Piccola Età Glaciale. I risultati di queste ricerche vengono utilizzati quasi esclusivamente dagli "addetti ai lavori" e manca un'opportuna divulgazione verso chi non opera in questi specifici settori. Parallelamente si assiste ad un crescente interesse verso la conoscenza degli aspetti naturalistici biotici ed abiotici. Queste esigenze possono essere soddisfatte attraverso la realizzazione di itinerari naturalistici che trasmettono in modo comprensibile ma scientificamente rigoroso i risultati delle ricerche di base. Il supporto scientifico agli itinerari può essere fornito da guide naturalistiche, note illustrative, carte geoturistiche o semplici brochure. Obiettivo del presente lavoro è dimostrare come aspetti geomorfologici e vegetazionali si integrino per la ricostruzione della storia glaciale olocenica, come essi siano stati utilizzati per la ricostruzione di determinate situazioni ambientali e come siano oggetti di interesse naturalistico facilmente osservabili lungo gli itinerari d'alta montagna. Si propone un esempio che ben si presta per applicare questi concetti lungo un percorso tematico che vede come protagonista la geomorfolo-

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gia e la dendrocronologia. In particolare vengono illustrati alcuni aspetti derivanti da ricerche di geologia del Quaternario, di geomorfologia e di dendrogeomorfologia in atto da alcuni anni, nell'alta Val Venosta (Valle di Trafoi – Alto Adige) in prossimità del Ghiacciaio del Madaccio, finalizzate alla ricostruzione della storia glaciale degli ultimi secoli. Il presente lavoro, oltre a dimostrare come i risultati della ricerca di base possano essere facilmente divulgati/trasferiti ad un ampio pubblico, si configura come proposta di itinerario e suggerisce le modalità di allestimento di un percorso geoturistico guidato. Oltre alle informazioni di tipo logistico sono state inserite esemplificazioni dell'evoluzione geomorfologica del territorio, trasmesse attraverso immagini, disegni, foto e schemi.

PAROLE CHIAVE: Ghiacciaio del Madaccio, Storia glaciale, Dendrocronologia, Geomorfosito.

1. – INTRODUCTION

Many studies on geomorphology, glacial geology and glaciology have been carried out for years on the Alps with the goal of reconstructing the glacier history of the upper Holocene and the Little Ice Age (DENTON & KARLEN, 1977; OROMBELLI & PORTER, 1982; GROVE, 1988; PELFINI, 1988, 1992, 1999 A-B; PELFINI & SMIRAGLIA, 1992; BARONI & CARTON, 1996; DELINE & OROMBELLI, 2005). However, the results of this research are typically almost exclusively used by specialised researchers and their dissemination is lacking for people not working in these fields. For a better use and management of the territory, people enjoying the mountain (such as mountaineers, hikers and tourists) or people working on the mountains should know well the past natural history and possible future evolution of the environments they frequent.

At the same time, people enjoying the Alpine environment are becoming more interested in learning about biotic and abiotic natural topics. These needs can be satisfied by creating naturalistic itineraries suitable for the communication of the scientific results in an easy and correct language.

In many tourist areas, several traditional trails have been recently transformed into thematic paths. For example, the S. Vito - Forcella Grande - Foresta di Somadida naturalistic trail (CARTON, 1991), the Vittorio Sella glaciological path close to the Ventina Glacier (Servizio Glaciologico Lombardo, 1992), the Luigi Marson glaciological path close to the Fellaria Occidentale Glacier (realized by Servizio Glaciologico Lombardo), the glaciological trail close to Forni Glacier (SMIRAGLIA, 1995), the Antelao naturalistic-glaciological path (SCORTEGAGNA, 2001), the Dos Capèl geological path (DELL'ANTONIO & ROGHI 2001). The scientific support can be given by naturalistic guides (fig.1), illustrated panels or simply by brochures. Besides transmitting naturalistic information, these solutions can be also a way of passing on the results of the basic research.

Informing also not-specialised people through different approaches about scientific topics is one of the goals of the national research project, financed in 2004 by the Italian Ministry of Education, University and Research (MIUR), "The geomorphological heritage as resource for sustainable tourism" (national coordinator M. Panizza). Another aim of this project is how to transfer the scientific knowledge to the possible users and the local communities. Within this project, many researchers have organized guided itinerary as a tool to give information about different

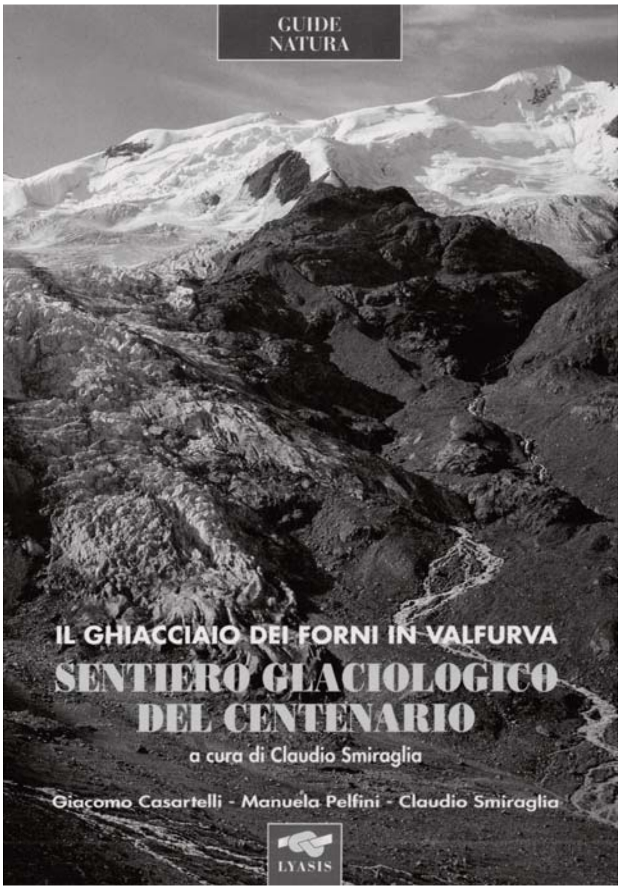

Fig. 1 – Cover of the volume illustrating the Centenary glaciological trail at the Forni Glacier, prepared to celebrate the 100 years since the institution of the "Comitato Glaciologico Italiano". In this popular-scientific guide readers will find much information about the recent glacier history and about the landscape forms recognisable along the path. The trail crosses also the glacier's tongue. It is possible to observe from different perspectives the Forni Glacier and its glacial landforms.
– *Copertina del volume che descrive il sentiero glaciologico del centenario nel Ghiacciaio dei Forni, realizzato per celebrare il centenario dell'istituzione del Comitato Glaciologico Italiano. In questa popolare guida scientifica i lettori possono trovare informazioni sulla storia recente del ghiacciaio e sulle forme dl rilievo osservabili lungo il percorso. Il sentiero attraversa anche la lingua del ghiacciaio. È possibile osservare da diverse prospettive il Ghiacciaio dei Forni e le forme glaciali caratteristiche.*

scientific results in geomorphology, geology, glaciology, botany, ecology, zoology, etc.

In upper Val Venosta (Trafoi Valley-Alto Adige), close to the Madaccio Glacier, many different researches had been performed for years with the goal of reconstructing the glacier history of the last centuries through studies in Quaternary geology (BINI *et alii*, 1996), in geomorphology (MARTINOLI, 2005) and in dendrogeomorphology (PELFINI, 1999 a-b). The goal of this work is to demonstrate how geomorphological and vegetational aspects both concur in the reconstruction of Holocene glacier history. Moreover, this kind of integration allows to understand the sequence of the glacial processes. Finally, these naturalistic aspects can be easily observable along high-mountain trails. The proposed work is an example showing how to apply these concepts along a thematic itinerary where geomorphology and dendrochronology are the two main subjects.

2. – STUDY AREA

The upper Trafoi Valley is located inside the Stelvio National Park, in the Alto Adige side of the Ortles-Cevedale Group (fig. 2).

This valley is highly attractive for tourists and it is frequented by thousands of people going to the Passo dello Stelvio, visiting the surroundings and walking along the numerous tourist paths towards the mountain tops and huts.

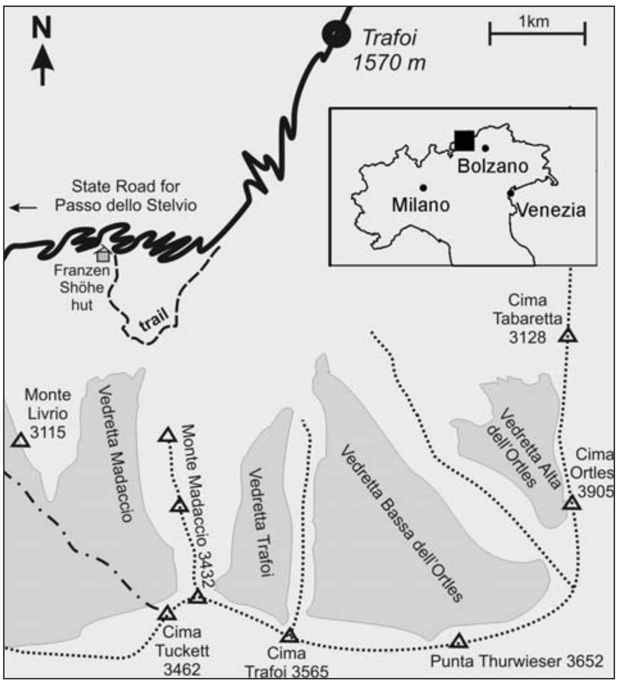

Fig. 2 – Location map of the study area. The proposed trail (broken line) starts from the road for Passo dello Stelvio and stop near a hut (see details of the trail in figure 6).
– *Inquadramento geografico dell'area di studio. Il sentiero proposto (linea tratteggiata) inizia dalla strada per il Passo dello Stelvio e termina vicino al rifugio (cfr. dettagli del sentiero in figura 6).*

The idea to propose a naturalistic thematic path in the upper Trafoi Valley comes also from the recent requirement to widen the tourist offer during summer months. This is done as an alternative to the summer ski activities, which in the recent years have seen a progressive reduction in the available period because of the contraction of the glacial surfaces on which ski runs are open (DIOLAIUTI *et alii*, 2006).

In Trafoi Valley six glaciers are currently present: Vedretta della Tabaretta, Vedretta Alta dell'Ortles, Vedretta Bassa dell'Ortles, Vedretta di Trafoi, Vedretta del Madaccio and Vedretta Piana.

Each of them has left erosion landforms and deposits which clearly describe the historical fluctuations. Madaccio glacier (fig. 3) and its proglacial area present some clear, easily accessible geomorphologic aspects and dendrochronological data made available from the past, given the continuous interactions between the glacier advances and tree vegetation.

3. – TREE GROWTH AND GLACIER FLUCTUATIONS

The numerous remains of conifers found in living and uprooted positions (fig. 4) offer an opportunity to understand how they contribute to the chronological reconstruction of the different glacial events.

During the advancing phases, glaciers can impact forested areas, sweeping up and burying trees which are sometimes found re-emerging from the debris,

Fig. 3 – Panoramic view of Madaccio Glacier and its proglacial area (photo by Bozzoni, summer 2005).
– *Vista panoramica del Ghiacciao del Madaccio e dell'area proglaciale (fotografia di Bozzoni, estate 2005).*

Fig. 4 – Typical half-buried trunk in the proglacial area (photo by Pelfini, 2004).
– *Tipico tronco parzialmente sepolto nell'area proglaciale (fotografia di Pelfini, 2004).*

and sometimes damaging the trees beside the tongue or those at the limit of the area, in the frontal position, reached by the glacier terminus (fig. 5).

Generally, trees at the margins of the advancing tongue, record the same climatic events recorded by the trees growing at a larger distance from the glacier. The situation when the glacial ice reaches the stem or the roots is quite different. In this case the tree suffers and forms particularly narrow rings (SCHWEINGRUBER, 1996). In both cases trees allow precise reconstruction of the glacier history. In fact the date of tree death obtained from stems still *in situ* allows precise determination of the year in which the glacier reached a certain position. If this position is coincident with a frontal moraine, it is possible to date the moraine deposition phase. Similarly, damage or disturbances found on living trees, such as scars and compression wood, allow to date the glacier impact (fig. 5). On the contrary, logs buried in the lateral moraines can only indicate the thickness of the glacier tongue at the moment of the insertion into the moraine itself. In fact, their death could have happened also years before and also can be due to different causes (SCHWEINGRUBER, 1988; PELFINI, 2003; 2006).

4. – GLACIAL AND PERIGLACIAL LANDFORMS AS GEOMORPHOSITES

The combination of attributes and values of the "Madaccio" site in general and in its details, allow the area to be defined as a possible geomorphosite, as proposed by PANIZZA (2005); PANIZZA & PIACENTE, (2003), PELFINI & SMIRAGLIA (2003), CARTON *et alii* (2005), PRALONG & REYNARD (2005), REYNARD, (2005).

Concerning the scientific attribute, the area in which the Madaccio Glacier is located represents a *didactic example*, a model of *geomorphological evolution* and a *paleoenvironmental evidence*. The didactic example is given by a series of very well preserved erosion and accumulation landforms, typical of a glacial landscape, allowing observation and understanding of the abrasion processes (roches moutonnées, striae, crescentic gouges, glacial valley "rieghel" etc.), and of deposition ones (accretion moraines, superposition moraines, proglacial fans, etc.). The *geomorphological evolution* model comes from the interactions of the glacial, slope and fluvial forms describing the complex vicissitudes alternating over time, during repeated glacier advance, stasis and retreat phases. The *paleoenvironmental evidence* is documented by a series of morainic ridges, mainly dated, allowing the reconstruction of relative or absolute chronology. It is possible to add also the *ecological support* given by

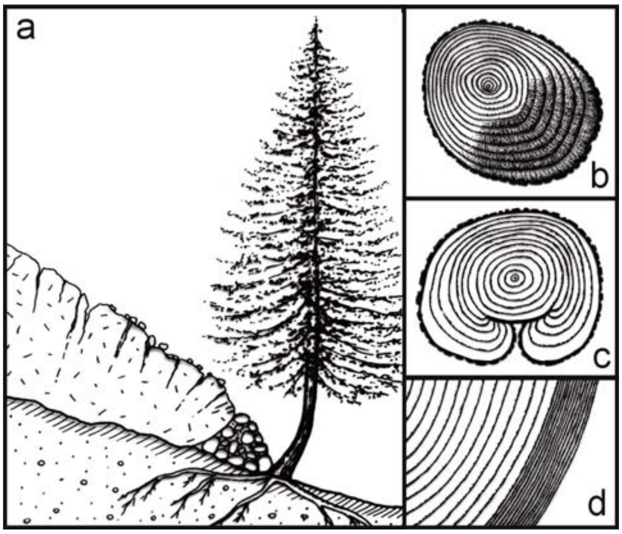

Fig. 5 – The different reactions of a tree to glacial ice pressure (a). Trees can form compression wood, typical reaction wood which conifers produce also making eccentric rings to recover the vertical position (b). Trees can be directly damaged and the scars can be used to date the year in which the contact happened (c). Trees can form narrow rings until the glacier retreats (d) (from PELFINI, 2006).
– *Differenti reazioni di un albero alla pressione esercitata dal ghiacciaio (a). Gli alberi possono formare legno di compressione, tipico legno di reazione che le conifere producono anche attraverso anelli eccentrici per riprendere la posizione verticale (b). Gli alberi possono essere danneggiati direttamente e, successivamente, le cicatrici possono essere usate per datare l'anno in quale il contatto con il ghiacciaio è avvenuto (c). Gli alberi possono formare stretti anelli fino al ritiro del ghiacciaio (d) (da PELFINI, 2006).*

the dendrochronological documentation to these attributes. The presence of easily visible buried trunks and the numerous trees damaged and deformed by the geomorphological processes and by atmospheric events, provide added value to the geomorphosite, not only concerning the dating of glacial deposits, but also with regard to the paleoenvironmental reconstruction of the site.

The morphological and vegetational elements can be observed either walking along a trail within the proglacial area (fig. 2) or along a panoramic one (trail no. 20, connecting the Garibaldi hut, near Passo dello Stelvio and the end of the "Forcola" chair lift) on the opposite side of the valley.

The possibility of exploring the same subject firstly in detail and then in its entirety, also plays an educational role because it shows to the tourists the scientific approach, resolving a naturalistic problem starting from the analysis of the single aspects which are later jointly interpreted, leading to a synthetic vision. The reading of past history using the data supplied by the glaciological and dendrochronological studies, gives also to the tourists an example of an integrated approach for reading the landscape, equally involving both biological and geological disciplines.

5. – THE TRAIL

The proposed trail (figures 2 and 6) starts as a cart-road from the State Road leading to the Passo dello Stelvio, just above the Weißer Knott hotel (1923 m), it then follows the path indicated by the trail no. 13 and 14, and ends close to the Franzen Shöhe hut (2180 m) on the same road.

Both the departure and arrival points can be reached by bus or car during the summer season. The itinerary descends along the slope until it reaches the Trafoi River. Next, it goes along the proglacial area. The trail crosses frontal moraines of the Little Ice Age and continues in a complex of glacial and debris flows deposits inside the proglacial area, reaching the sharp east lateral moraine (fig. 7).

The moraine ridge can be walked both along the edge (exposed path) and outside it (path no 14). Once the upper portion of the moraine is reached, it is possible to go down along its inner slope (fig. 7) and then to cross some roches moutonnées, below the glacier terminus, and join the trails on the slope leading to the Franzen Shöhe hut.

The development of the trail and its altimetrical characteristics are summarised in a profile (fig. 8)

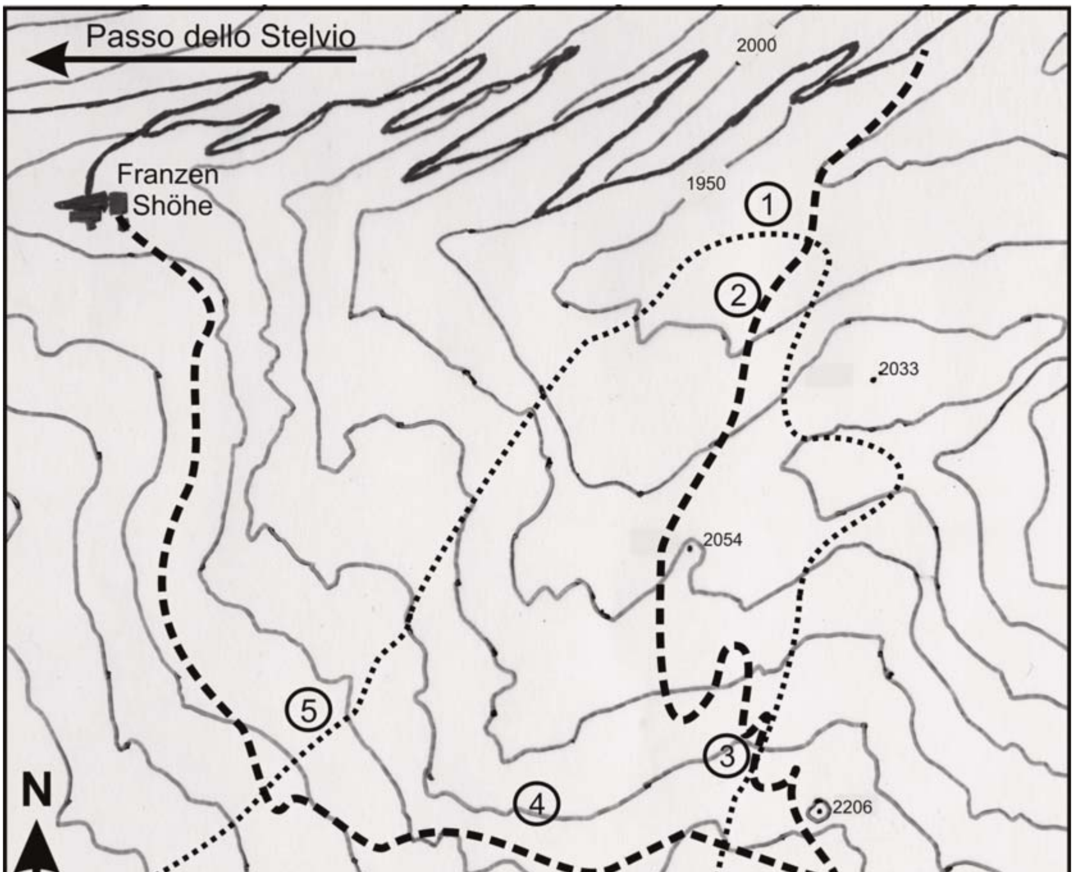

Fig. 6 – Simplified map showing the position of the proposed naturalistic trail (broken line) with the stops (numbered circles) suggested for the geomorphological and dendrochronological observations. The dotted line corresponds to the maximum advance during the LIA peak reached by the Madaccio Glacier.
– *Carta semplificata che mostra la posizione del sentiero naturalistico proposto (linea tratteggiata) con l'indicazione degli stop (cerchi numerati) suggeriti per effettuare le osservazioni geomorfologiche e dendrocronologiche. La linea a punti corrisponde alla massima avanzata del Ghaicciaio del Madaccio durante la Piccola-Età Glaciale.*

equipped with useful information for the hiker (e.g., width and morphology of the footpath, type of substrate etc.) (BOZZONI & PELFINI, 2007).

The itinerary we would like to create will be structured into stops allowing detailed observations, and sometimes panoramic views, of the landforms that characterises a proglacial area. Depending on the illustrative support, the itinerary will be provided with panels, guides, geotouristic map, etc.; the single situations will be described in detail with the aid of drawings and commented photos, referring, when necessary, to basic concepts useful to explain the phenomena.

6. – LANDFORMS AND TYPICAL SITUATIONS ALONG THE TRAIL

Using the results of scientific researches, some particularly meaningful points along the itinerary will be shown as an example of how we want to illustrate the entire path.

The Madaccio is the largest glacier of the Trafoi Valley and occupies a wide and irregular valley extending, north-south for 4.5 Km, between the three rocky peaks of the Madaccio mountain, on the east side, and the wide glacialized ridge that reaches the Passo dello Stelvio (2758 m) from Punta degli Spiriti (3465 m). This glacier is a typical alpine type, constituted by a wide accumulation area which originates one tongue reaching 2650 m. Its moraines deposed during the Little Ice Age and following advance and retreat phases are well represented almost everywhere (fig. 9).

The outmost frontal moraines, located at 1930 m, document the maximum Holocene advance corresponding to the LIA peak, which can be dated to 1821 (PELFINI, 1999 a-b) for the Madaccio Glacier (fig. 10) preceded by an advancing phase at the end of the 18th century.

The limits reached by the glacier tongue during the LIA are documented by portions of well preserved moraines, some of which are very sharp. On their inner slopes it is locally possible to ob-

Fig. 7 – The eastern lateral moraine of the Ghiacciaio del Madaccio. The pseudostratification given from the process of superposition is visible. The arrows indicate the small trail that crosses down the inner moraine slope (photo by Bozzoni, 2005).
– *Morena laterale orientale del Ghiacciaio del Madaccio. È visibile la pseudo stratificazione dovuta ai processi di sovrapposizione. Le frecce indicano lo stretto sentiero che attraversa il versante interno della morena (fotografia di Bozzoni, 2005).*

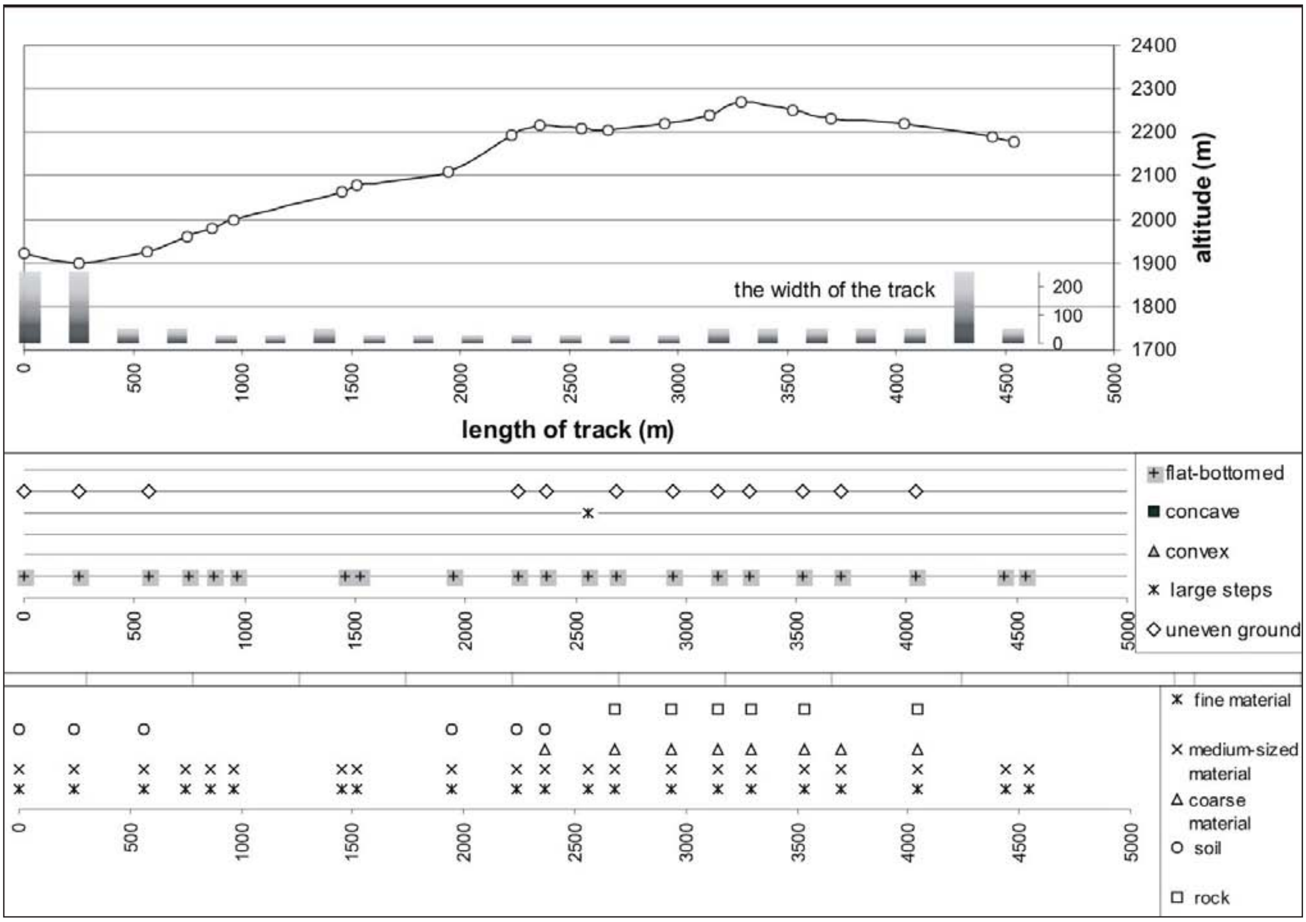

Fig. 8 – Profile of the Madaccio-Franzen Shöhe hut trail. The diagram evidences the altimetrical course referred to the real distance walked; the vertical bars in the upper diagram show how the width of the track changes along the trail; the table below supplies information about the morphological characteristics of the footpath (flat, concave, convex, irregular) and its surface (fine, medium, coarse, bedrock).

– *Profilo del sentiero del rifugio del Madaccio-Franzen Shöhe. Il diagramma evidenzia l'andamento altimetrico riferito alla distanza reale percorsa; le colonne verticali nella parte superiore del diagramma mostrano come la larghezza del sentiero cambia lungo il percorso; la tabella sottostante fornisce informazioni sulle caratteristiche morfologiche del sentiero (piatto, concavo, convesso, irregolare) e sulle caratteristiche del fondo (fine, medio, grossolano, roccia).*

serve the typical superposition structure. The trail segments located on the glacial deposit allow visitors to observe the sedimentological features and the moraine depositional processes in detail. The advances following the LIA maximum are widely documented by a network of low accretion and superposition moraines observable along the northwest margin (figures 9 and 11).

The Little Ice Age maximum extension of the glacier can be seen at the distal part of the moraine system (fig. 10). The trail allows to observe a stem half buried in the frontal moraine (figure 12; stop 1 in figure 6).

In this case, the buried trunk was useful to reconstruct the LIA acme phases (Pelfini, 1999 a-b): the stem could have been buried during the advancing phases already started at the end of the 17th century. The sequence of the glacier advances and retreat phases has been reconstructed by using also the ages of still living trees growing at the base of the outmost moraine and in the surrounding proglacial area. In fact, the trees located on the moraines indicate their minimum ages, while the age of those located in the proglacial area suggest when the glacier has retreated.

This is a representative case of how geomorphological and dendrochronological surveys are necessary one to the other in order to carry out paleoclimatic and paleoenvironmental reconstructions.

The proglacial area is characterised by the presence of many other tree remains deformed by the passage of the glacier and mostly uprooted (stop 2 in figure 6). In this case they can anyway supply information about the events characterising the upper Trafoi Valley in recent centuries. In fact many of the logs found in the proglacial area belong to trees buried between the end of the 17th and the second half of the 18th century. They probably testify the climatic crisis that caused the death of many trees.

The eastern margin of the glacier is delimited by a long and sharp moraine the crest of which can be walked along by a diversion of the proposed trail (fig. 7, 13).

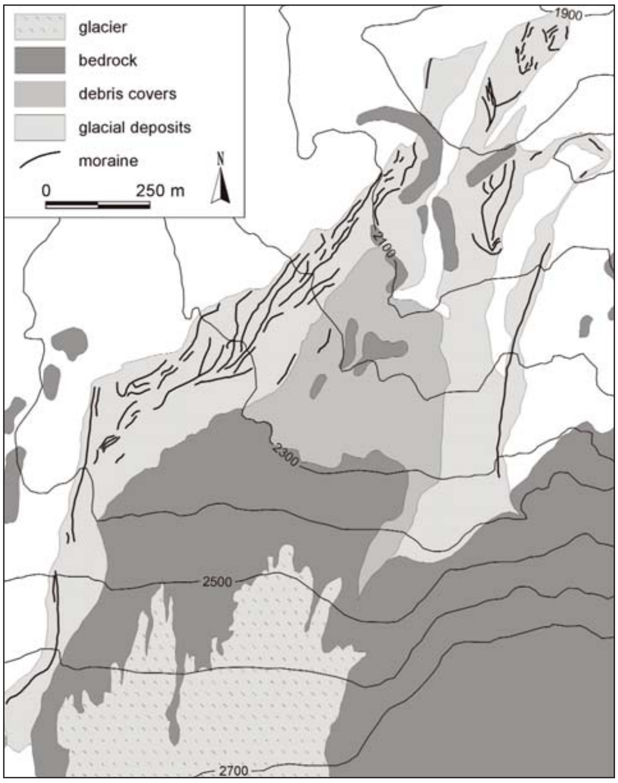

Fig. 9 – Sketch map of the proglacial area of the Madaccio Glacier. All the moraines recognised during the field survey are represented in this map. In the east side the past glacier boundary is represented by a huge moraine; in the west side minor glacier fluctuations are documented by a great number of small ridges.
– *Mappa schematica dell'area proglaciale del Ghiacciaio del Madaccio. Tutte le morene individuate durante il rilevamento di campagna sono state rappresentate in carta. Nel settore orientale il limite dell'estensione passata del ghiacciaio è rappresentata da una grande morena; nel settore occidentale fluttuazioni minori del ghiacciaio sono documentate da un grande numero di piccole creste.*

On the inner slope, subject to erosion, it can be seen the typical superposition structure characterising a great part of lateral moraines. Along this slope, at 2170 m and about 80 cm below the top, a fragment of larch (*Larix decidua* Mill.) emerges, being buried inside the moraine (fig. 13), while another log, placed along the glacier flow direction was found slightly further down-valley (stop 3 in figure 6). To precisely identify the species of the two buried trunks, an anatomical identification using wood sections and microscope (SCHWEINGRUBER, 1982) was done (fig. 14).

The position of the first sample in relation to the moraine in which it was recovered indicates that the construction of this lateral moraine occurred in two steps (fig. 15).

Initially, this tree probably died for other causes (e.g. mass movement) and later it has been left on an initial glacial deposit. Later, a new glacier advance has placed more till on the first moraine burying the dead tree. Successively, erosion of the inner slope of the moraine, connected with glacier shrinkage, exposed again the buried tree. Moreover, it is possible that the top part of the tree was broken by the glacier in advance and dragged a little further down-valley.

The chronostratigraphic situation indicates that at the date of death of the tree (second decade of the 19th century) the glacier was still in a growing phase, as demonstrated by the thickness of debris covering the log (figures 13 and 15).

The trail portion crossing the bedrock below the glacial tongue (2200 m of altitude), allows to observe the glacial erosion (stop 4 in figure 6). The glacier striae, lunate fractures and roches moutonnées are well preserved and common.

Along this part of the trail, and partially on its left side, traces of faded red painted marks are visible on the bedrock (fig. 16).

Many of them are difficult to decipher. They are

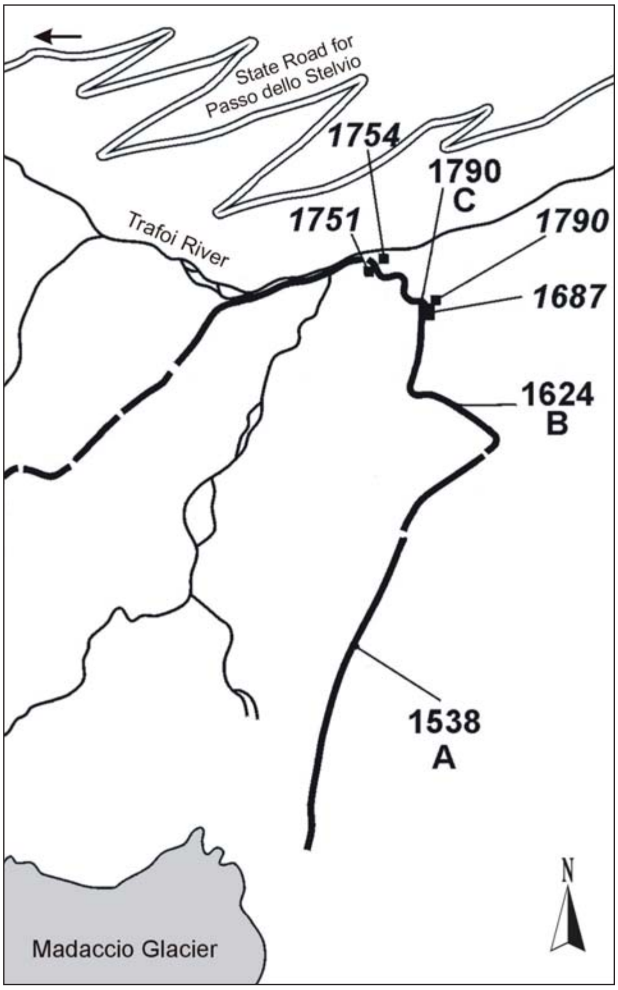

Fig. 10 – Limit of the maximum expansion of the Little Ice Age of the Ghiacciaio del Madaccio. The numbers correspond to the years of death of the trees buried in the frontal moraine. The data come from previous researches (modified from PELFINI, 1999a).
– *Limite della massima espansione del Ghiacciaio del Madaccio durante la Piccola Età Glaciale. I numeri corrispondono all'età di morte degli alberi sepolti dalla morena frontale. I dati provengono da ricerche precedenti (modificato da PELFINI, 1999a).*

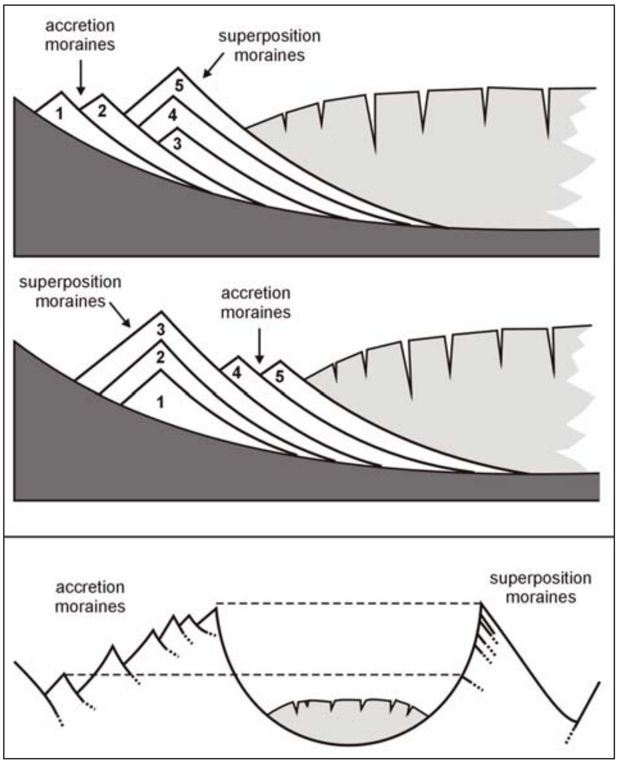

Fig. 11 – This kind of scheme, showing the formation of accretion and superposition moraines, helps visitors to better understand what they can observe in the field. This model is typical of many moraines of Madaccio Glacier and it is recognizable walking along the upper Trafoi Valley (fig. 7).
– *Questo tipo di schema, che mostra la formazione delle morene per sovrapposizione e accrezione, aiuta a comprendere meglio ciò che si può osservare sul terreno. Questa struttura caratterizza molte delle morene del Ghiacciaio del Madaccio ed è facilmente riconoscibile camminando lungo la Valle del Trafoi (fig. 7).*

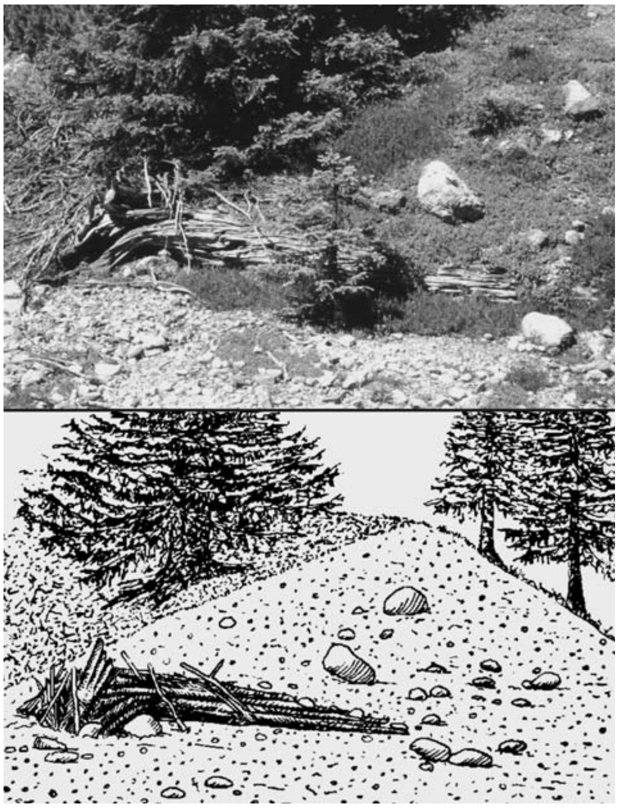

Fig. 12 – Buried trunk in the frontal moraine built by Madaccio Glacier (stop 1, figure 6) (taken from PELFINI, 1999a).
– *Tronco sepolto dalla morena frontale del Ghiacciaio del Madaccio (stop 1, figura 6) (tratto da PELFINI, 1999a).*

benchmarks used in the past as photographic stations, for annually reading the glacier terminus, or as references for measuring the distance from the glacier tongue. Repeated measurements over time allows to evaluate advances and retreats of the glacier tongue. Long-enough data series allow the creation of time-distance curves (fig. 17), from which glacier behaviour can be analysed (advanced, stasis, retreat).

These benchmarks are now abandoned because they are too far away from the terminus, and have been replaced by other more recent ones at higher altitude near the present glacier margin. Use of these benchmarks can be found in the reports of past glaciological surveys, but the message that they must transmit to tourists is to show the remarkable glacier retreat in the field.

On the west side of the valley, outside the Madaccio Glacier moraine system, it is possible to observe an interesting network of lateral moraines (fig. 9), from different points along the trail (stop 5 in figure 6). The moraines indicate the presence of a glacier tongue not thicker as the lateral one, but depressed as documented by the low profile assumed by the several ridges. The short adjacent

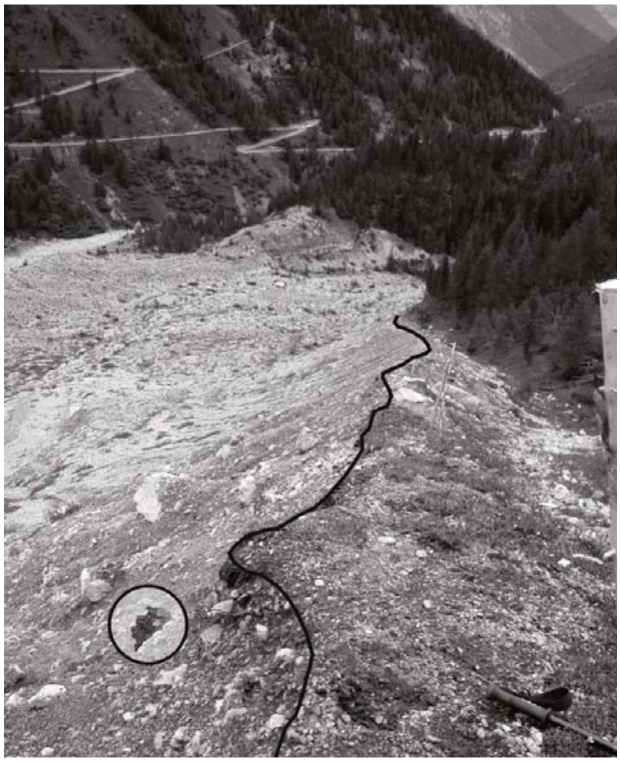

Fig. 13 – The edge of the east lateral moraine (black line) and a buried log emerging along the inner slope (in the circle) (photo by Pelfini, 2004).
– *Cresta della morena laterale orientale (linea nera) e tronco sepolto che emerge lungo il versante interno (nel cerchio) (fotografia di Pelfini, 2004).*

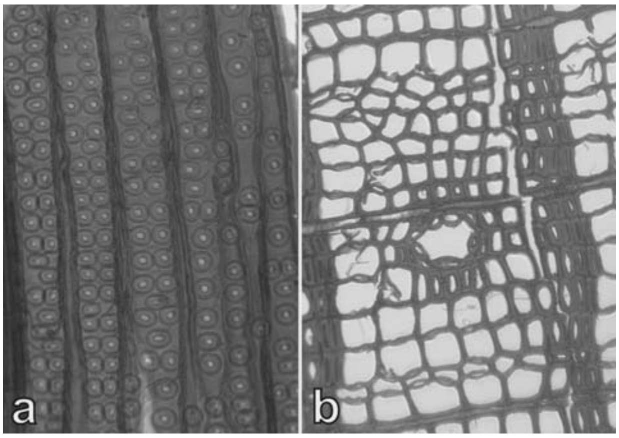

Fig. 14 – Thin section (15 µm thick, 200x) prepared for species identification. Both samples are *Larix decidua* Mill. (a) radial section, (b) transversal section (photo by Leonelli, 2005).
– *Sezioni sottili (15 µm di spessore, 200x) preparata per l'identificazione delle specie. Entrambi i campioni sono Larix decidua Mill. (a) sezione radiale, (b) sezione trasversale (fotografia di Leonelli, 2005).*

and locally overlapped moraines were deposited in relation to short-term climatic changes. They testify that the glacier margin remained in this position for rather a long time or that the front reached it after an advance followed by a phase of retreat. It is interesting to note that the moraine edges are sometimes close side by side, and that in other situations they emerge from the sides of larger ridges.

Focussing on the edges of single moraines, we can imagine the different shapes and extensions the glacier margin assumed here sometimes. At a certain moment in this complex succession of events, the glacier also tried to generate a small lateral tongue. This is documented by the two lobe shaped moraines departing from the previous moraine system and heading towards the small fluvioglacial plain.

7. – CONCLUSION

From the illustrated examples, we conclude that classic geomorphological research supplies the basis for understanding phenomena and processes leaving extremely detailed documentation in the field, but usually it can be recognized only by the expert eye. However it is possible to offer a correct and scientific knowledge through simplifications easily realizable using photos, schemes, drawings etc also to people without a naturalistic culture. In this way, an itinerary, where the beauty of the landscape dominates, supplies also the possibility to give a good scientific formation.

In the specific case here presented, the support of other disciplines such as dendrochronology, allows not only a detailed reconstruction of histor-

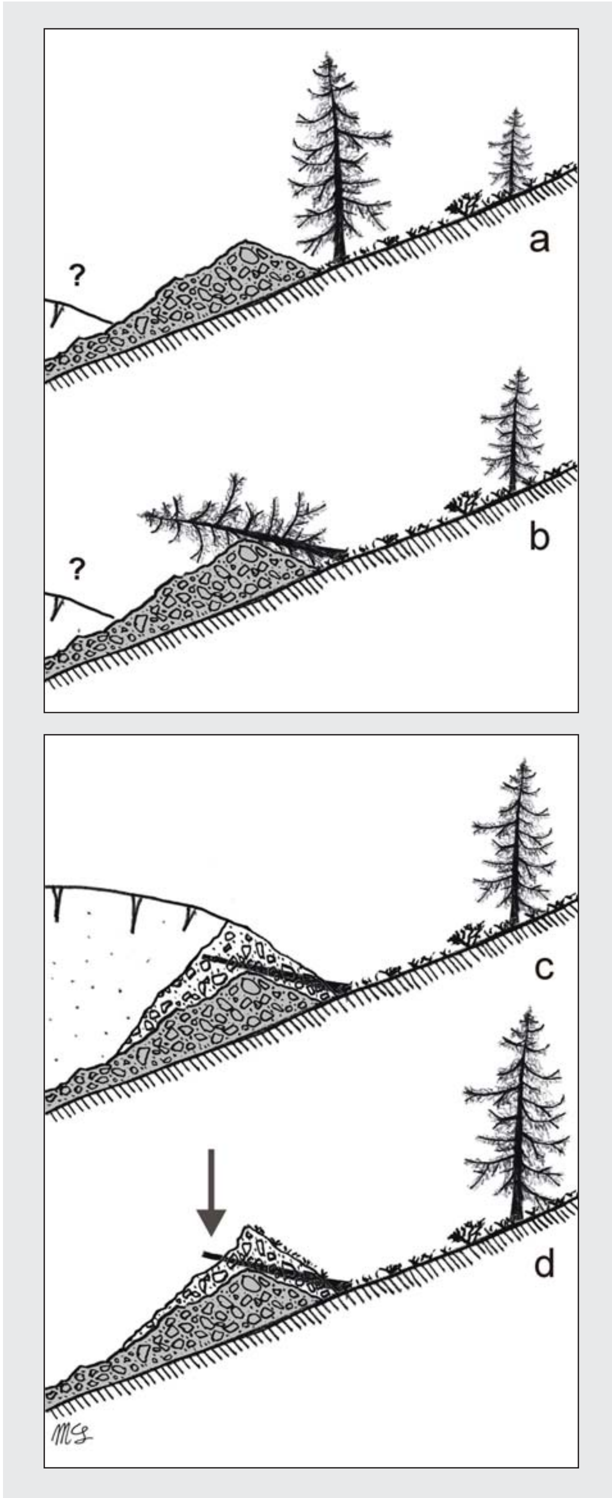

Fig. 15 – The scheme represents the hypothetical "history" of the buried tree. The tree is still living (a). The tree dies from unknown causes, but not ones due to direct glacier action, and lies down on the forming moraine (b). The glacier is still growing and continues to deposit till on the previous moraine covering the trunk (c). When the glacier retreats, the top of the trunk emerges due to erosion processes active on the inner moraine slope (d).
— *Lo schema rappresenta l'ipotetica "storia" del tronco sepolto. L'albero è ancora vivo (a). L'albero muore per cause ignote, comunque non legate all'azione diretta del ghiacciaio e cade sulla morena che si sta formando (b). Il ghiacciaio continua a crescere e ad accumulare materiale sulla morena ricoprendo il tronco (c). Quando il ghiacciaio arretra la parte superiore del tronco affiora a causa dei processi erosivi attivi sul versante interno della morena (d).*

Fig. 16 — Black benchmark (red in the field), now in disuse, used for measuring the frontal variations of the glacier tongue. Numbers and acronyms codify the mark and refer to the glaciological operator and to the year in which the bench mark was placed (photo by Carton, 2004).
– Caposaldo (rosso nell'immagine), ora in disuso, utilizzatio per misurare le variazioni frontali della lingua del ghiacciaio. Numeri e codici individuano il segno e si riferiscono all'operatore glaciologico e all'anno in quale il caposaldo è stato posizionato (fotografia di Carton, 2004).

ical glacier fluctuations but also the identification of events (e.g. glacier advances) whose geomorphological evidences have been cancelled by erosion processes or are now unrecognisable in the field. The help of images and schemes proposed in the various stops, permits a detailed understanding of the evolutionary phases of a natural event and offers suggestions for enquiry from other sectors of naturalistic disciplines. In this case, for example, in order to proceed with dendrochronological dating, tree species identification is necessary, and demonstrates how also the disciplines that analyse very specific details can contribute to a broad research.

Apart from proposing an itinerary, this work suggests how to prepare a geotouristic, guided trail,

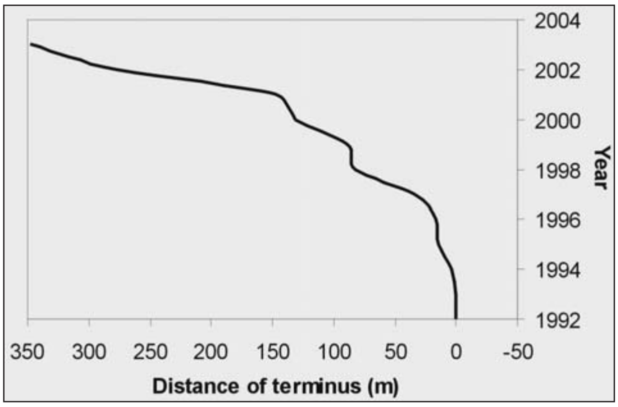

Fig. 17 — Example of a time/distance curve outlining Madaccio glacier terminus movements over time (modified from Ghezzi, 2004).
– Esempio di curva tempo/distanza che evidenzia i movimenti della fronte glaciale nel tempo (modificato da Ghezzi, 2004).

able to easily transmit to a wide public the results of the basic research. Moreover, beyond logistic information indicating difficulty, walking times, unevenness, etc., it wishes to emphasize the importance of including an explanation of the geomorphological evolution of the territory; in our case the trail emphatize glacier history, glacier morphology, the documentation of the geomorphological processes and the climatic signal in the tree vegetation, using description, illustrations and drawings of the phenomena at the stops. Often an image, even if just seen rapidly along a mountain trail, can explain better and in a more effective way than a written text. In any case the realization of this itinerary, like any other one realized in mountain areas, must first observe the land management laws and rules imposed by the single Countries. The path here proposed has the aim to outline and enhance the important relationships between the scientific knowledge and the educative applications.

Infact we think that all the tourist mountain paths should be associated to a scientific support in order not only to enjoy the itinerary and improve people naturalistic knowledge but also to promote the dissemination of the scientific results, also increasing the link between academic activities and educational purposes.

Acknowledgements

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The geomorphological heritage approach in protected areas: Geoconservation *vs.* Geotourism in Portuguese natural parks

L'approccio del patrimonio geomorfologico nelle aree protette: Geoconservazione contro Geoturismo nei parchi naturali portoghesi

PEREIRA P. (*), PEREIRA D.I. (*),
CAETANO ALVES M.I. (*)

ABSTRACT – As in many other countries, geology and geomorphology are absent from the majority of the Portuguese protected areas statutes. These areas could be places to protect landforms as a significant component of the natural heritage. However, joining the preservation effort to some ecotourism activities or other human activities could damage or even destroy geomorphological sites. During the last decade, multidisciplinary projects were developed in protected areas from Northern Portugal, with special emphasis in supporting geoconservation strategies and making available products for public advertising of geological and geomorphological features. This paper shows the results of our activities on Montesinho Natural Park (PNM) and International Douro Natural Park (PNDI). Deliverables are being made available to protected areas managers as scientific support for management plans. Other products and initiatives have been implemented in order to raise public awareness of geodiversity and geoconservation and also to improve geotouristic offer. These products are developed in dialogue with park managers who can include them in management plans. Preserving geomorphological sites and making them public at the same time can be possible in protected areas. This approach can be applied to other protected areas with positive results.

KEY WORDS: Geomorphological heritage; Geoconservation; Geotourism; Protected areas; Portugal.

RIASSUNTO – Come in molti paesi, la geologia e la geomorfologia sono praticamente assenti dagli statuti delle aree protette del Portogallo. Queste aree potrebbero essere luoghi dove proteggere le forme del rilievo come componenti significative del patrimonio naturale. Tuttavia, gli sforzi per la conservazione unitamente ad alcune attività di ecoturismo o ad altre attività antropiche possono danneggiare o addirittura distruggere i beni geomorfologici. Durante l'ultimo decennio, sono stati sviluppati progetti multidisciplinari in aree protette del nord del Portogallo, ponendo particolare attenzione alle strategie di geoconservazione e sviluppando prodotti per divulgare ad un pubblico vasto le caratteristiche geologiche e geomorfologiche del paesaggio. In questo articolo vengono illustrati i risultati delle attività svolte nel Parco Naturale del Montesinho (PNM) e nel Parco naturale internazionale del (PNDI). Una documentazione appropriata è stata fornita alle aree protette come supporto scientifico ai loro piani di gestione. Sono stati inoltre sviluppati prodotti ed iniziative con lo scopo di aumentare la sensibilità del grande pubblico ai temi della geodiversità e della geoconservazione ed anche per migliorare l'offerta per un turismo geologico. Questi prodotti sono stati realizzati di concerto con i parchi e talvolta sono stati inseriti nei piani di gestione. Conservare i beni geomorfologici e renderli allo stesso tempo fruibili ai turisti è infatti possibile nelle aree protette. Questo approccio può essere applicato ad altre aree protette con risultati positivi.

PAROLE CHIAVE: Patrimonio geomorfologico; Geoconservazione; Geoturismo; Aree protette; Portogallo.

1. – INTRODUCTION

The expression "geomorphological heritage" is being used to define groups of geomorphological sites (PEREIRA *et alii*, 2002). Several studies have established these sites as landforms that are perceived to have a special value, namely scientific, ecological, aesthetic, cultural and/or economic (REYNARD, 2005a). Some authors consider also the landforms with a functional value, as the support

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of environmental system, both physical and biological (GRAY, 2004). In recent years, special emphasis is being given to the relation between geomorphology and culture (PANIZZA & PIACENTE, 2003), namely to the interaction between peculiar landforms and specially connected human activities.

Geomorphological heritage has been discussed in Portugal since the beginning of the 1990's, but practical strategies such as inventories and specialized working groups have begun recently. The geomorphological heritage as well as all the heritage assets should have some kind of statutory protection. In many cases, geomorphological sites have no specific legal protection even when located inside protected areas. However, the heritage protection and its conservation should be included in public policies (REYNARD, 2005b), even when this heritage is part of abiotic nature. As these public conservation strategies demand financial support, it is necessary to carry out a correct inventory and evaluation of geomorphological sites. These can be used to obtain the financial return on that investment by promoting initiatives aimed at tourism and educational purposes. On the other hand, the implementation of tourism strategies, though sustainable, can expose geomorphological sites to damage and destruction. Following this point of view, it is important to discuss the association of protection and promotion strategies and the role of protected areas.

The Portuguese protected areas system covers about 7% of the mainland territory, including: one national park, twelve natural parks, nine natural reserves, three protected landscapes, ten classified sites, and five natural monuments (fig. 1). Besides these, there are other protected areas with specific regional statutes, both on the mainland and on the Madeira and Azores archipelagos.

Usually, the Natural Monument and Classified Site statutes are mostly applied for conservation of remarkable geological or geomorphological heritage features (CARVALHO, 1999). However, due to their size and significance, National Parks and Natural Parks are key zones to implement geoconservation strategies and to increase public awareness of all aspects of nature, biological and geological (BRILHA, 2002). As in many other countries, Portuguese nature conservation is primarily interested in biology, underrating geological and geomorphological criteria in the majority of the protected area statutes. In recent years, efforts have been developed by geologists and geomorphologists in order to change this situation. Nowadays some park managers are beginning to demand relevant geological information for their park management plans. The work and discussion done about geomorphological and other geological elements of landscape, selected as sites to protect and/or advertise, have changed the approach to abiotic nature in some parks. This new perspective is mainly due to researchers' efforts in raising the awareness of protected area managers on the need for geoconservation.

Nevertheless, there is a long road to run in order to improve the knowledge on geological and geomorphological heritage in Portuguese nature conservation policies. This paper presents the results of a research project carried out in two natural parks from NE Portugal, where products and initiatives were developed in both geoconservation and geotourism.

2. – THE GEOMORPHOLOGICAL HERITAGE APPROACH IN MONTESINHO NATURAL PARK AND INTERNATIONAL DOURO NATURAL PARK (NE PORTUGAL)

Two major protected areas are implanted in NE Portugal (fig. 1): Montesinho Natural Park (PNM) and International Douro Natural Park (PNDI), covering an extensive area of 1601 km^2 (PNM 750 km^2, PNDI 851 km^2). These parks were created in 1979 and 1998, respectively, mainly due to the high relevance of the wildlife, natural flora and cultural heritage (ALVES *et alii*, 2004; DIAS & BRILHA, 2004).

PNM is located on the Portuguese-Spanish border, in the southern extremity of the Cantabria-Leon Mountain Range. PNM is characterised by a remarkable geodiversity and by the occurrence of exotic terranes, presenting a complex geology. The high lithological diversity and the Cenozoic tectonics have been the main influence in distinctive geomorphological features, such as planation surfaces, fluvial incised valleys, residual relief, tectonic basins and granite landforms (MEIRELES *et alii*, 2002; PEREIRA *et alii*, 2004a, 2004b). These landforms support the diversity of natural and agricultural occupation, with characteristic oak and chestnut groves and pastures. Some minor landforms, such as granite weather pits in Montesinho Mountain, are the habitat for endemic flora.

The PNDI is an example of a national protected area with a notable geodiversity and distinctive landscapes associated with the fluvial canyons of the Douro and Águeda Rivers (NE Portugal-Spain border). The park is a narrow contiguous area of the old peneplain landscape known as Iberian Meseta. The incision of the Douro River and its

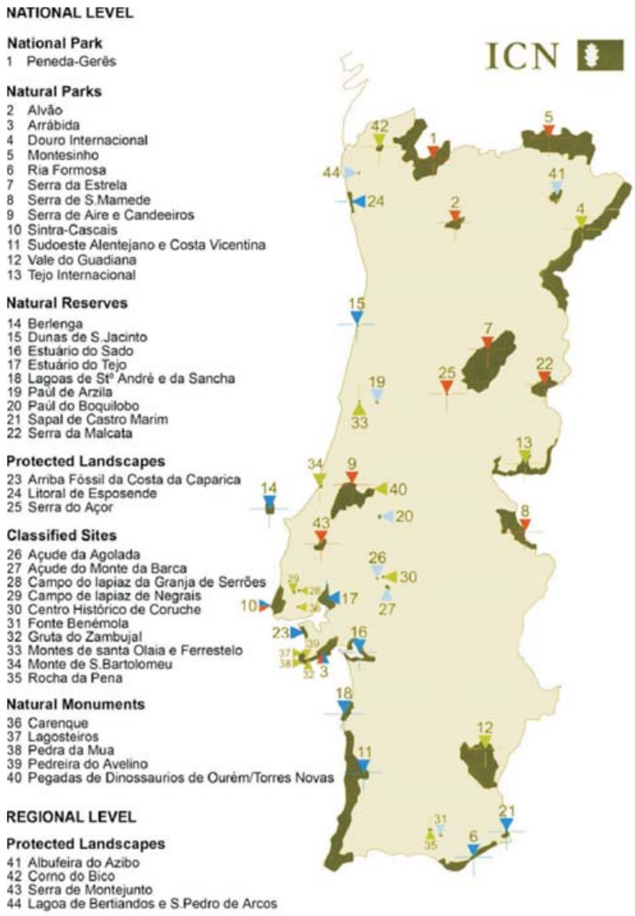

Fig. 1 – Protected areas in mainland Portugal. Adapted from Portuguese Nature Conservation Institute (http://www.icnb.pt).
– *Aree protette del Portogallo. Immagine adattata dall'Istituto Portoghese di Conservazione della Natura (http://www.icnb.pt).*

tributaries on the Iberian Meseta has developed spectacular steep cliffs, regionally named *Arribas do Douro*, the 'ex-libris' of the PNDI. This landscape provides the microclimatic conditions for the traditional production of wine, olive and almond, as well as the support for a great biodiversity. The PNDI is one of the most important nesting habitats in Europe for vultures, eagles and black storks. The floristic heritage found on the rock slopes and ancient floodplains is also relevant. This natural park has a geomorphological heritage that provides the support to human occupation and biodiversity (Ferreira *et alii*, 2001, 2003; Alves *et alii*, 2004).

These areas are mainly rural, with a low population ratio, 12 person / km^2 in PNM and 16 person / km^2 in PNDI. Therefore, the interaction between the resident population and the natural environment creates a human imprint in the landforms and supports a harmonious biodiversity. Evidence of the close relationship between culture, geology and geomorphology is given by the millenarian human occupation of these areas.

The research on the geological and geomorphological heritage in Natural Parks of NE Portugal began in the form of a multidisciplinary research project (PNAT Project), sponsored by the Portuguese Science and Technology Foundation and the Portuguese Nature Conservation Institute. The project aims, presented by Dias & Brilha (2004), were: (i) improve the geological and geomorphological knowledge; (ii) proceed with the inventory and characterisation of geosites; (iii) create scientific instruments to support a sustainable management of resources and territory; (iv) contribute to the increase of public awareness of Natural Heritage. In order to achieve the above objectives activities were developed (Dias *et alii*, 2005a, 2005b), such as: (i) improvement of the geological mapping; (ii) characterisation of geomorphological features and processes and development of the geomorphological mapping; (iii) inventory of geological resources; (iv) systematic inventory and characterisation of geosites, with reference to its content, value, utility and relevance, and their integration in a database; (v) characterisation of geological materials through specific studies, as a support for mapping and geosites characterisation.

3. – GEOMORPHOLOGICAL SITES

The multidisciplinary Earth Sciences researchers of the PNAT Project inventoried PNM and PNDI geosites. In the inventory were considered geomorphological (Gm), palaeontological (Pa), mineralogical (Mi), petrological (Pt), mining (Mn), tectonic (Te), stratigraphical (St) and archaeological-mining (Am) sites. The geomorphological sites were selected, according to a methodo-logy specially developed for geomorphological heritage (Pereira, 2006; Pereira *et alii*, 2007). This methodology is based on the experts' knowledge of the studied area and selection of the outstanding landforms, considerig their scientific, ecological, cultural, aesthetic and/or economic values.

The inventory of geological sites in the Natural Parks on NE Portugal resulted in 209 sites selected, 139 in PNM and 70 in PNDI (tab. 1).

In the PNM, the high geodiversity allowed the selection of numerous palaeontological, mineralogical and petrological sites. Most of the PNM geomorphological sites are viewpoints, from where it is possible to observe and describe geomorphological features, such as plain surfaces, incised valleys (fig. 2A) and tectonic basins. Other sites were selected in the Montesinho Mountain, due to its high richness in granite landforms (fig. 2B).

Tab. 1 – *Geosites/geomorphological sites ratios in Montesinho Natural Park (PNM) and International Douro Natural Park (PNDI).*
– Rapporto geositi/geomorfositi nel Parco Naturale del Montesinho (PNM) e nel Parco naturale internazionale del (PNDI).

	Geosites			
	Geomorphological sites	Other sites with geomorphological value	Sites without geomorphological value	Total
PNM (750 Km²)	26 (20%)	6(4%)	107(76%)	139
PNDI (851 Km²)	32 (46%)	8(11%)	30(13%)	70

In the PNDI, the percentage of geomorphological sites is higher than in the PNM (tab. 1). Areas of great richness in granite landforms were also selected in the PNDI (fig. 2C). The most significant geomorphological features are the fluvial canyons of the Douro River and its tributary, the Águeda River, dissecting the high plateau of the Iberian Meseta (fig. 2D).

All natural and cultural features should be considered in Natural Park management, specially the natural heritage which the managers have the responsibility to preserve. Thus, all information about the inventoried geosites was made available to park managers.

The definition of the geotourism interest of geosites should be made with special care (PRALONG, 2005). Only those that present a low risk of damage by the touristic activities should be considered. Thus, geotourism sites were selected (tab. 2) according to five criteria: value, vulnerability, accessibility, visibility and spatial distribution.

About half of the inventoried geomorphological sites were selected for public use (50% in the PNM and 44% in the PNDI). This selection was due to a high scenic and touristic value.

Geosites suitable for public use represents only 24% of the total number of geosites in the PNM and 29% in the PNDI. The predominance of geomorphological sites is related to a lower damage risk compared with other geosites, particularly the mineralogical, petrological and palaeontological ones.

The making public strategy in these parks is aimed at attracting new visitors interested in abiotic nature. One of the concerns was the spatial distribution of the geomorphological sites in order to cover all the parks areas. Also considered were accessibility and the viewing conditions. In that way, geomorphological heritage can contribute to the local sustainable development, promoting complementarity between traditional land uses and geoconservation.

4. – DELIVERABLES FOR MANAGEMENT

Several deliverables were made available to park managers as scientific support for management plans (MEIRELES *et alii*, 2005; DIAS *et alii*, 2005a, 2005b), namely: geological, geomorphological, geological resources and geological sites maps (fig. 3). A fruitful dialogue between researchers and parks staff had as a consequence the understanding of their need for more knowledge about geoconservation and geological heritage. This new perspective led to the preparation of management plan reports to meet the demand of park managers.

The geosites map contains all the selected geosites, organised by frameworks, namely palaeontological, mineralogical, petrological, mining, tectonic, and geomorphological sites (fig. 4). This document also contains information about the susceptibility of geosites. In general, the most vulnerable sites have palaeontological and petrological value. Geomorphological sites susceptibility is considered mainly in order to avoid their damage and destruction by the implementation of quarries, roads or other engineering structures.

The training of technical staff and park rangers was another important activity because it was the very first approach to geodiversity, geological and geomorphological heritage and geoconservation issues. Therefore, the technical staff usually skilled in bioconservation issues will be more aware of geological and geomorphological subjects.

Tab. 2 – *Number and density of geomorphological sites and the total of geosites for public advertisement in Montesinho Natural Park (PNM) and International Douro Natural Park (PNDI). Density =number of sites / 100 km².*
– Numero e densità di siti geomorfologici e totale dei geositi utili per la valorizzazione turistica nel Parco Naturale del Montesinho (PNM) e e nel Parco naturale internazionale del (PNDI).
Densità = numero di siti / 100 km².

	Geomorphological sites				Geosites (total)			
	management		public		management		public	
	Number	Density	Number	Density	Number	Density	Number	Density
PNM (750 Km²)	26	3.6	13 (50%)	1.8	139	18.6	33 (24%)	4.4
PNDI (851 Km²)	32	3.7	14 (44%)	1.6	70	8.2	22 (29%)	2.6

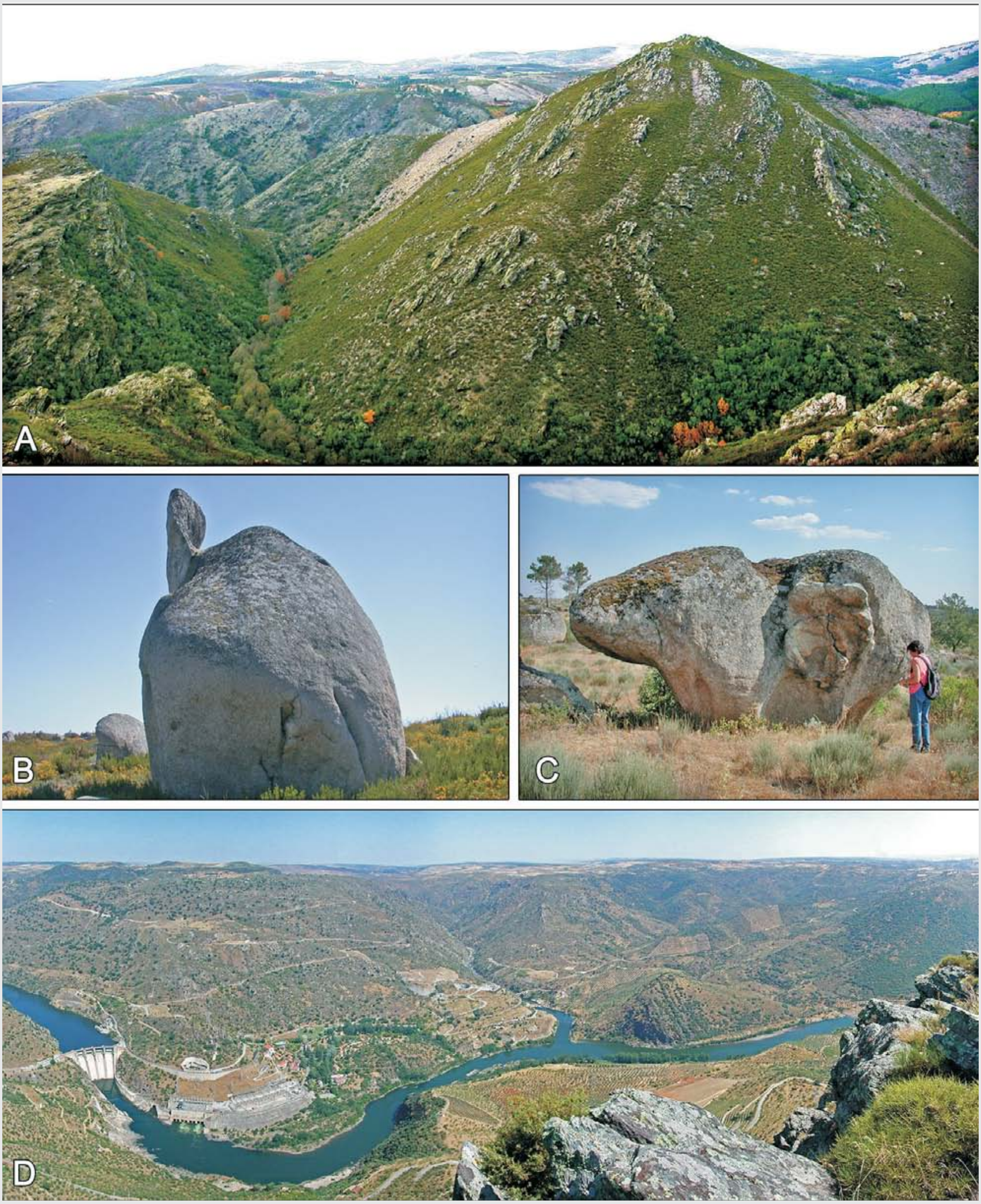

Fig. 2 – Examples of geomorphological sites in Montesinho Natural Park (PNM) and International Douro Natural Park (PNDI): A. Assureira valley (PNM); B. Granite landforms, Montesinho Mountain (PNM); C. Granite landforms, Trigueiras (PNDI); D. Penedo Durão viewpoint (PNDI).
– Esempi di siti geomorfologici nel Parco Naturale del Montesinho (PNM) e nel Parco naturale internazionale del (PNDI): A. Valle dell'Assureira (PNM); B. Forme nel granito Parco Naturale del Montesinho (PNM); C. Forme nel granito Parco Naturale del Montesinho (PNM), Trigueiras (PNDI); D. Vista del Penedo Durão (PNDI).

Fig. 3 – Deliverables and tools for the management of the geomorphological heritage in Natural Parks of NE Portugal.
– Prodotti e strumenti per la gestione del patrimonio geomorfologico nei parchi naturali del settore nordorientale del Portogallo.

5. – PRODUCTS AND INITIATIVES FOR GEOTOURISM AND GEOEDUCATION

Products and initiatives have been implemented, in order to raise public awareness of geodiversity and geoconservation and to improve geotouristic and geoeducational offerings (fig. 5). The output was prepared aiming in particular at the general public, school population and parks staff (DIAS & BRILHA, 2004; DIAS *et alii*, 2005a, 2005b).

Guided tours

Summer field trips addressed to the general public are being organised, as well as guided field trips specifically addressed to school populations. The Portuguese government promotes, since 1998, a very successful programme called "Geology in the Summer" with the aim of raising public awareness of geology. During the summer season, geoscientists organize field trips and other activities all over the country, which constitute an excellent opportunity to talk about geodiversity, geological heritage and geoconservation, and the importance of geology in our society (DIAS & BRILHA, 2004). Several "Geology in the Summer" activities inside the PNM and the PNDI were organised, where visitors could learn about geomorphology and geomorphological sites (fig. 5A). The experience in these and other parks shows that the public and the school population appreciated guided walks and personal interaction with geoscientists.

Pedestrian trails

Traditionally, protected areas have a set of different pedestrian trails that emphasise natural and cultural features. In fact, these trails have usually biological, cultural or archaeological interest with few or no references to geology or geomorphology. Because of that, the production of information regarding the geological interpretation of pedestrian trails is of great importance. Thus, the insipient information about geomorphology in the booklets of the existing pedestrian trails was expanded. In both parks, new pedestrian trails were developed linking some of the inventoried geomorphological sites (fig. 5B).

Simplified maps and booklets.

Geomorphological mapping was done for each natural park using vectorial software, assembling in several layers different geomorphological information as well as other important natural and cultural features. Digital editing allows the selection of specific layers resulting in a simplified map, addressed to non-expert public. These simplified geomorphological maps are presented at 1:100,000 scale. They include major landforms and faults, simplified lithology, hydrography as well as some anthropogenic features like roads, villages, mines and water reservoirs. These maps also include the location of geomorphological sites as well as pedestrian trails and interpretative panels (fig. 5C).

Interpretative panels

The on-site interpretative panels constitute a support for a synthesis of the observed geological and geomorphological features. Contents, design and presentation of the panels follow a set of

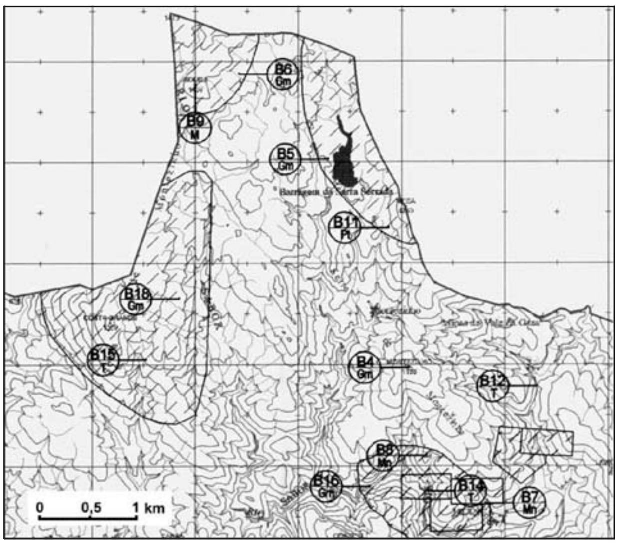

Fig. 4 – Section of the Geosites Map of Montesinho Natural Park. Geosites: Gm - geomorphological; M - mineralogical; Pt - petrological; T - tectonic, Mn - mining (MEIRELES *et alii*, 2005).
– Stralcio della carta dei geositi del Parco Naturale del Montesinho: Gm - geomorfologici; M - mineralogici; Pt - petrologici; T - tettonici, Mn – minerari (MEIRELES et alii*, 2005).*

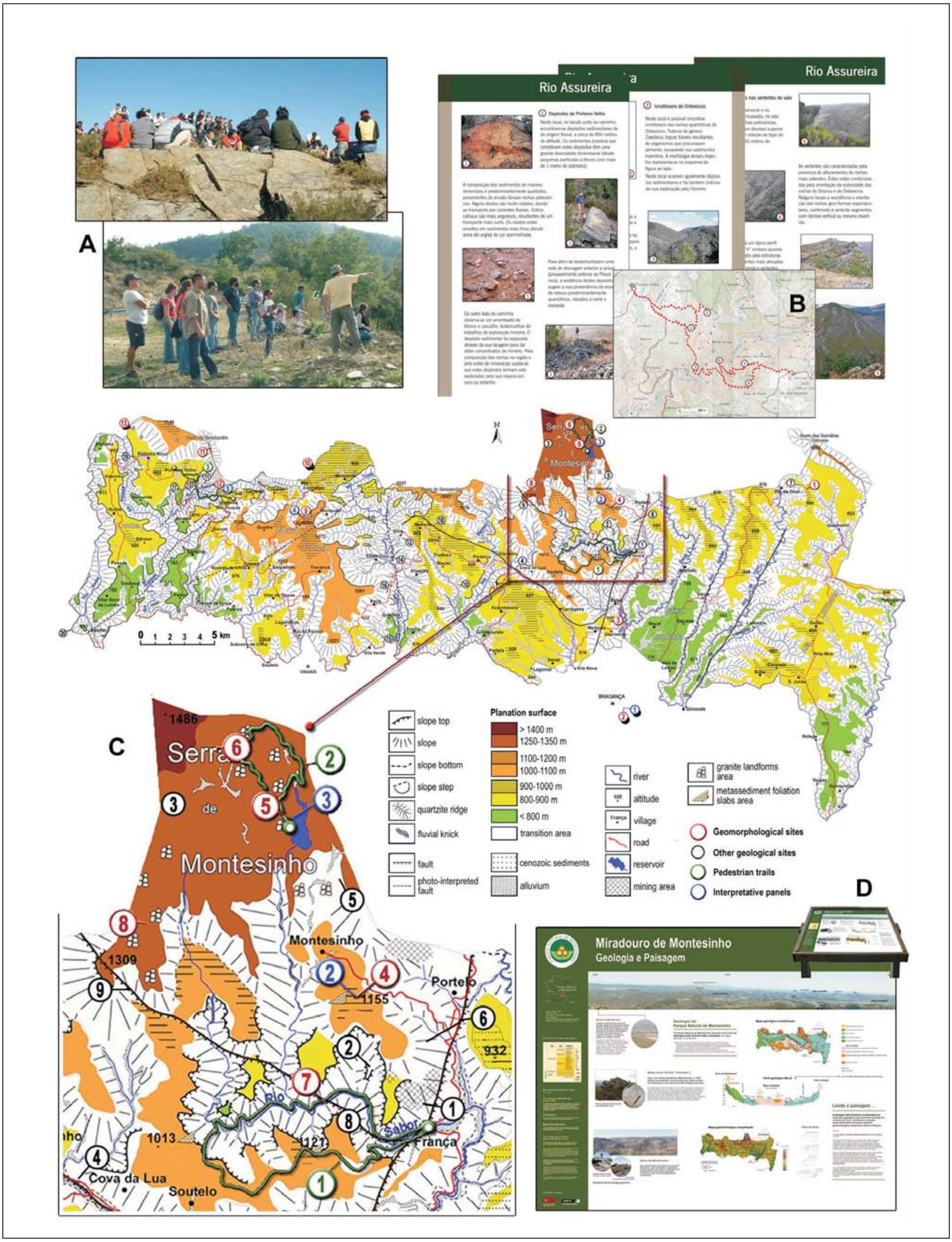

Fig. 5 – Products and initiatives aiming the promotion of geomorphological heritage. Examples from Montesinho Natural Park: A. Guided tours for school population and general public; B. Assurerira river pedestrian trail; C. Simplified geomorphological map; D. Montesinho viewpoint interpretative panel.
– *Prodotti ed iniziative per la promozione del patrimonio geomorfologico. Esempi nel Parco Naturale del Montesinho: A. Tour guidati per scuole e turisti in genere; B. Sentiero lungo il Rio Assurerira; C. Carta geomorfologica semplificata; D. Pannello turistico del Montesinho.*

guidelines, in order to be appellative for a wider public. Contents are interpretative rather than informative and based on features that can be observed (lithology, folding and land-shaping processes), with a clear distinction between observation and interpretation. A lectern-type (130x100 cm) presentation and a graphics-rich/text-poor layout are used (fig. 5D). Basic contents are displayed at the centre of the panels, occupying the majority of the surface (DIAS *et alii*, 2003; DIAS & BRILHA, 2004; PEREIRA *et alii*, 2004a). Additional information and/or interpretation are given in a left-side coloured strip. At the bottom schematic cross-sections present the geomorphological evolution of the region. Some of these panels are already installed and technical staff of both natural parks is implementing others.

Guide books

The production of geological guide books for each park is one more possibility. These books include an overview on the geological and geomorphological evolution of the natural park areas. A chapter about geoconservation contains the description of geotourism sites and geo-pedestrian trails. The guide books contain also other information about geological resources, mining history and the simplified geological and geomorphological maps. The geomorphological maps are illustrated with photos of the geomorphological sites and a 3D digital elevation model.

Webpage contents

Environmental education can also be supported by electronic resources distributed on the Internet. The use of these resources in protected area webpages was already exemplified in the Peneda-Gerês National Park (BRILHA *et alii*, 1999). Normally, geomorphology and geoconservation information on protected area webpages is rather poor and unattractive. For pnm and pndi several multimedia resources were developed in order to promote geosciences and geodiversity for a wider public and included in the protected areas institucional webpages (http://www.icnb.pt).

6. – CONCLUSIONS

The interest in geomorphological sites has been growing during recent years. The research in this theme emphasises the conservation, education and tourism attractiveness of geomorphological sites. The experiences in Natural Parks of NE Portugal show that geoconservation and geotourism can be developed simultaneously. To achieve this goal, park managers' awareness of the importance of geomorphological heritage should be enhanced by the involvement of geoconservation experts. Geomorphological information and an adequate technical staff support and training may contribute to the protection of geomorphological sites, reducing their modification, damage or destruction. In spite of being the most public-friendly of all types of geosites, geomorphological sites may be damaged by human pressure. Therefore, managers should attend to this vulnerability and establish limits to the use of these landforms. On the other hand, it should be emphasised that the widespread awareness of geomorphology and geomorphological sites as natural heritage constitutes a key factor in tourism appeal and environmental education.

The geoconservation and geotourism aims need the support of several types of initiatives and products in order to achieve different target groups. The deliverables for management should be technical, though of easy to understand and use by the natural parks staff. The products for the public should be designed according to the target public, although simplified, attractive and well-structured products can be understood by different types of public even without awareness of geomorphological heritage and geoconservation.

Despite its usual connection with biological conservation, protected areas can have an important role in the protection of geomorphological heritage. Being places to which visitors are attracted, they are also perfect displays of these landforms. Therefore, the geomorphological heritage approach can have good results in such areas. Comprehensive projects should be applied to other natural parks where the knowledge and management of geological and geomorphological heritage is still far from adequate.

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figg. 5

Target Groups and Geodidactic Tools: the need to adapt tourist offer and demand

Gruppi "target" e strumenti geodidattici: la necessità di adattare l'offerta turistica alla domanda

PRALONG J.P. (*)

ABSTRACT – This paper deals with the assessment of didactic goods and services proposed to visitors of natural sites with interesting Earth science features. Because of the lack of studies regarding the tourist demand in relation to such tools, a questionnaire study was carried out at different geomorphological sites located in the areas of *Crans-Montana-Sierre* (Switzerland) and *Chamonix-Mont-Blanc* (France) during the summer of 2004. With a new approach of the geotourist demand, this study allows geoscientists to classify the different target groups, which have specific social, cultural and psychological characteristics. Results are use to specify the wishes and needs of day-trippers and tourists, as well as their environmental sensitivity and opinions on didactic tools.
These indicate that, at first sight, interest in Earth science is quite moderate in comparison to that for biology and, especially, nature and landscape. However, the demand for explanation is significant, especially for Earth science, and is clearly expressed in a sense of "geohistory" and "cultural integrated landscapes" (PANIZZA & PIACENTE, 2003). For day-trippers and tourists, the aims of didactic goods and services should provide an introduction to the site as well as allowing people to obtain new knowledge. As a consequence of this fact, the ensuing tools must be developed with a basic level of popularisation. To achieve these goals, traditional tools, such as educational signs, guided tours, books, booklets or displays, are preferred. Finally, this study identifies the importance of learning more about target groups and their ideas and questions regarding Earth science. Only a better understanding of the needs and wishes of day-trippers and tourists allows geodidactic tools to be adapted.

KEY WORDS: Geomorphological sites; Geotourism; Didactic tools; Questionnaire study; Target groups.

RIASSUNTO – Questo articolo riguarda la valutazione di strumenti e servizi didattici proposti a visitatori di siti naturalistici interessati ai temi trattati dalle Scienze della Terra. A causa della mancanza di studi che analizzano la domanda turistica in relazione a questo tipo di strumenti, è stato messo a punto un questionario testato in diversi siti gemorfologici ubicati nelle aree di *Crans-Montana-Sierre* (Svizzera) e di *Chamonix-Mont-Blanc* (Francia) durante l'estate 2004. Lo studio realizzato, improntato su un nuovo approccio all'analisi della richiesta geoturistica, permette agli scienziati delle Scienze della Terra di individuare e classificare gruppi "target", con specifiche caratteristiche sociali, culturali e psicologiche. I risultati ottenuti possono essere così utilizzati per stabilire e comprendere i desideri e le necessità di visitatori e turisti, nonché la loro sensibilità ambientale e le loro opinioni sugli strumenti didattici.
In prima analisi, questi studi evidenziano come l'interesse per le Scienze della Terra sia modesto se comparato a quello dimostrato nei confronti della biologia e, soprattutto, della natura e del paesaggio in generale. Tuttavia, l'interesse e la richiesta di spiegazioni riguardanti temi geologici appare significante e riguarda soprattutto i concetti di "geostoria" e di "paesaggio culturale integrato" (PANIZZA & PIACENTE, 2003). Secondo visitatori e turisti, prodotti e servizi didattici dovrebbero consentire di avere una descrizione introduttiva del sito, fornendo anche nuove e più approfondite conoscenze. A questo scopo, strumenti tradizionali come pannelli, tour guidati, libri, brochure, di facile comprensione sono da preferire. Solo una migliore comprensione delle esigenze e dei desideri di visitatori e turisti permette di realizzare strumenti geodidattici adeguati.

PAROLE CHIAVE: Siti geomorfologici, Geoturismo, Strumenti didattici, Questionari, Gruppi "target".

1. – INTRODUCTION

In terms of cultural geomorphology (PANIZZA & PIACENTE, 1993, 2003), geological and geomorphological sites are defined by four different values: scientific, scenic/aesthetic, historical/cultural

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and social/economic. Therefore, the interest of these natural objects depends not only on their scientific characteristics, but also on, for instance, their context, beauty, and utilisation. These values also constitute the tourist value of geological and geomorphological sites (PRALONG & REYNARD, 2005). The optimisation of this value may create different uses, such as economic and landscape resources or natural and cultural heritage. In turn, these uses may modify the values of geological and geomorphological sites.

In the context of tourist and recreation utilisation of these sites, didactic goods and services are generally proposed to day-trippers and tourists, to provide information concerning the level of protection of the site, to make visitors sensitive to the usefulness of its protection, to manage and control crowds, to satisfy the demand for information, and to increase the interest and the quality of the visit (PAGE, 1994). According to Hose (1), the provision of interpretative facilities and services have to "*promote the value and social benefit of geologic and geomorphologic sites and their materials and to ensure their conservation, for the use of students, tourists and other casual recreationalists*".

Because of the lack of studies into tourist demand in relation to such tools – except for HOSE (1994, 1996) and Asters and Espace Mont-Blanc (2002) –, a survey was carried out during the summer of 2004, in order to assess geodidactic goods and services from the tourist view point. For this study, specific questionnaires were distributed at different geomorphological sites (karstic cave, glacier, gorges and stream) located in the areas of *Crans-Montana-Sierre* (Switzerland) and *Chamonix-Mont-Blanc* (France). Using this method, the wishes and needs of different target groups have been specified, as well as their environmental sensitivity and opinions on didactic tools.

For this paper, the geotourist offer and demand are firstly defined. Regarding the latter, a typology of day-trippers and tourists is proposed, inspired by a study on cultural tourism (ORIGET DU CLUZEAU, 1998). The results from the questionnaire survey are presented and discussed, with a focus on visitors' interest in geology and geomorphology, the objectives of their visit, and the themes and purposes of didactic explanations. The contribution of "geohistory" and "cultural integrated landscapes" concepts (PANIZZA & PIACENTE, 2003) is also considered. Finally, several perspectives underline the need to study target groups further, especially to learn more about their ideas and questions regarding Earth science, in order to propose appropriate didactic tools.

2. – THE GEOTOURIST OFFER AND DEMAND

Figure 1 shows the main components of the offer and demand (PRALONG, 2006). On the one hand, the link between geological and geomorphological sites, their values and different tourist and scientific stakeholders explains the existence of didactic goods and services, considered as the effective offer. On the other hand, the effective demand of numerous target groups, which have specific social, cultural and psychological characteristics, depends on two kinds of factors (permissive and incitative ones according to BARRAS, 1987) allowing us to understand the behaviour and actions of the visitors.

These components and their relationships determine the geotourist activities, and include displays, museums, web sites, interactive computer tools, lectures, didactic panels, books, booklets and guided tours (KEENE, 1994). For the offer, the main scientific interests of the geosites considered for this study are presented in the next chapter; their characteristics notably create the tourist attraction, which follows from the number and the kind of didactic goods and services intended for day-trippers and tourists. Concerning the demand, the target groups are numerous, because their residence, civil status or age, for instance, have an influence on their social and cultural background, as well as their income, free time and, above all, their wishes and needs.

As a consequence of this statement, it seems useful for tourist stakeholders (e.g. travel agencies, tourism offices, managers) as well as for geoscientists interested in the popularisation of the discipline to have a classification of visitors. For instance, according to ORIGET DU CLUZEAU (1998), the target groups of cultural tourism may be classified into three categories:

- pecialists of a topic, people genuinely motivated;
- people genuinely motivated, but for any cultural topics;
- occasional visitors, simply inquiring into the site – these are the majority of visitors in cultural sites found in tourist areas; they prefer emotions, sensations and entertainment rather than acquiring new knowledge.

(1) HOSE T. A. (2000) - *European Geotourism - An overview of the promotion of geoconservation through interpretative provision.* www.erdgeschichte.de

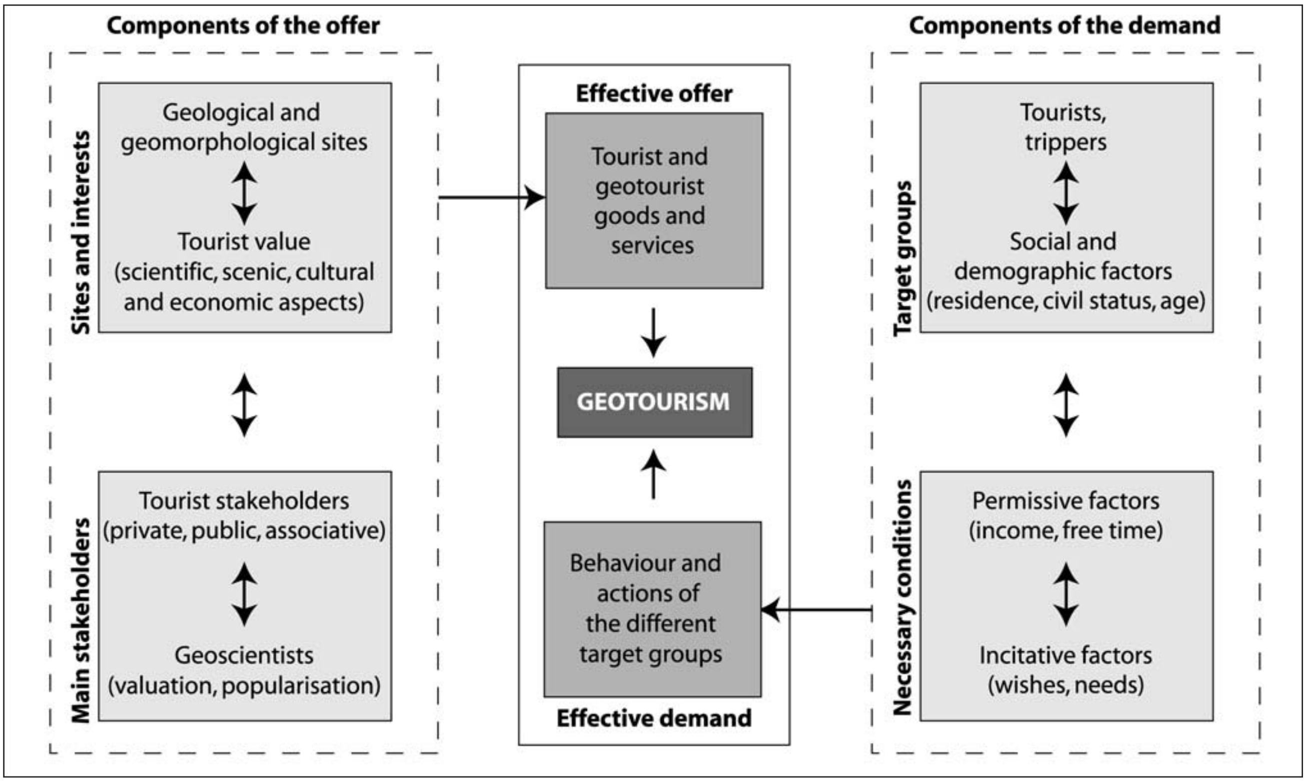

Fig. 1 – The main components of the geotourist offer and demand. Their relationships determine the activities of geotourism (adapted from Pralong, 2006).
– *Le principali componenti dell'offerta e della domanda geoturistica. Le loro relazioni determinano le attività geoturistiche (adattato da Pralong, 2006).*

From our point of view, the transposition of this classification towards geotourism is possible, because it seems to correspond to a reality in terms of target groups (see below); moreover, it does not consider the general public as a single and homogeneous category, such as those proposed by Keene (1994) or Hose (1998). In this sense, the first visitor type corresponds to a group already interested in Earth science and who the existing literature may satisfy. Given that its type of knowledge – specific to some topics (e.g. mineralogy, paleontology, glaciology) and sometimes comparable to that of an academic student – and education, only a few people of the general public are concerned by this group.

The second category is a target group potentially willing to become interested in Earth science, for cultural reasons. For this kind of visitor, cultural and historical geosites as well as cultural and historical approaches (see Panizza, 2003) may be the right way to "conquer" them. Therefore, the links between natural landscapes and cultural heritage, such as works of art, historical and architectural monuments or scientific and biological assets, should be underlined and explained in a transdisciplinary and integrated approach, in order to demonstrate that geology and geomorphology are, in a broad sense, components of the cultural heritage.

Finally, the last category contains the majority of the general public. For that reason, other strategies for popularising must be used, allowing any imagination or emotional aspect to be considered that Earth science may produce. In this way, the inquisitiveness of this kind of visitor can be stimulated, by presenting the palaeogeographic, geodynamic and palaeoclimatic interests of a current landscape. Therefore, its optimisation may use, for instance, limestone, basalt or moraine ridge respectively as proof of seas, oceans and glaciers that have since disappeared, in order to generate sensations and imaginations. With this target group, general and clear ideas are more relevant than accurate pieces of information; the aim of such an approach tends to show that Earth science is a "wonderful and exciting world", in which there are numerous fascinating stories for children and adults.

3. – QUESTIONNAIRE SURVEY: A LARGE DEMAND FOR "GEOHISTORY"

To learn more about visitors' interest in geology and geomorphology, their objectives in visiting natural sites, and the themes and purposes of didactic explanations, two thousand questionnaires were distributed by hand during the summer of 2004, at four different geomorphological sites (fig. 2). A total of 469 were returned completed and were available for analysis, with an average response rate of 23.5%. A letter explaining the aims of the research and the institution concerned was enclosed with the survey which was translated into three languages (French, German and English). Before presenting and discussing the main results, the selection criteria of the chosen sites as well as their major geoscientific characteristics are explained.

3.1. – Selection criteria and presentation of the sites

The geosites considered were chosen because of their scientific interest (see below), the existence of didactic goods and services (e.g. guided tours, booklets, didactic trails, web sites) and the possibilities for distributing the questionnaires (e.g. "closed" site, assistance of their manager). In fact, this selection of sites has a high scientific value, easy accessibility, more than ten thousand visitors per year and three of them already have various popularisation tools. In the case of the fourth (*Diosaz* gorges), it is used to analyse the influence of the existence of didactic goods and services on visitor response and experience (fig. 2).

In the area of *Crans-Montana-Sierre* (Switzerland), *Finges* is located in the *Rhône* valley and composed of two different parts. The first one, which contains a range of hills and small lakes, is the result of a huge tardiglacial rockfall (Burri, 1997). The second is the river itself and its wild alluvial areas, where biological species depend especially on the variability of the flow. For the other site of this area (underground lake of *St-Léonard*), it was discovered in 1943-1944 by speleologists and is currently the biggest natural underground lake in

Fig. 2 – The four geomorphological sites considered by the current study. At the top (area of *Crans-Montana-Sierre*), *Finges* (on the left) and the underground lake of *St-Léonard* (on the right). At the bottom (area of *Chamonix-Mont-Blanc*), the *Bossons* glacier (on the left) and the *Diosaz* gorges (on the right). pictures by J.P. Pralong.

– I quattro siti geomorfologici considerati nel presente studio. In alto (area di Crans-Montana-Sierre), Finges (a sinistra) e il lago sotterraneo di St-Léonard (a destra). In basso (area di Chamonix-Mont-Blanc), il ghiacciaio di Bossons (a sisnistra) e le gole di Diosaz (a destra) (fotografie di J.P. Pralong).

Europe. Paradoxically, a serious earthquake in 1946 made the lake accessible for tourists. From a geological point of view, this site is located in the most important area of gypsum in Switzerland (Wildberger & Preiswerk, 1997).

For the region of *Chamonix-Mont-Blanc* (France), the *Bossons* glacier is the longest glacial slope in Europe (3500 meters from the top of the Mont-Blanc to its snout in the *Chamonix* valley), and one of the rare large white glaciers in the Alps. Moreover, as a consequence of an average slope of 50%, its annual flow speed is about 300 to 400 meters in its lower part (Vivian, 2001). As for the *Diosaz* gorges, this attraction is the tourist part of a large torrential system coming from the *Aiguilles Rouges* massif and joins the *Arve* river downstream. Formed by underglacial water courses, this site presents different waterfalls, in spite of an hydroelectric dam upstream. Furthermore, a boulder allows visitors to see the gorges from above (fig. 2) in its higher section.

3.2. – Results and discussion regarding didactic aspects

Divided into three sections focusing on environmental sensitivity, opinions on didactic tools and personal data, this study aimed to answer these questions:

What are the visitors' interests in nature and landscape, and in rocks and landforms?

What are the objectives of visiting natural sites?

Is there a demand for didactic goods and services? If yes, on which themes, in what form?

To what purposes should the explanations be intended? Is geodidactic offer adapted to demand?

Of the 469 people questioned, the average age of visitors at the four sites ranges from 40 and 43 years, with the exception of *Finges* (49 years of age). The majority of day-trippers and tourists come from the country where the geosites are located; moreover, they generally come with their family. The kind of holidays they prefer includes engagement with nature and landscape aspects, followed by culture and sport. This set of preferences shows the existence of a potential market for geotourist activities, although what people do is not always the same as what they say.

The interest in Earth science is, at first sight, quite moderate in comparison to that for biology and, especially, nature and landscape (fig. 3). For this latter element, a high or very high interest is expressed by about 95% of the people questioned, whereas for fauna and flora this percentage is around 80% and for geology and geomorphology (2) it is between 50 and 55% on average. But it can be observed that day-trippers and tourists older than 50 years of age have the greatest interest in Earth science. Furthermore, the objectives of the visit show that the particular characteristic of the objects concerned (e.g. cave, glacier, gorges), the motivation to visit a natural site or to discover a

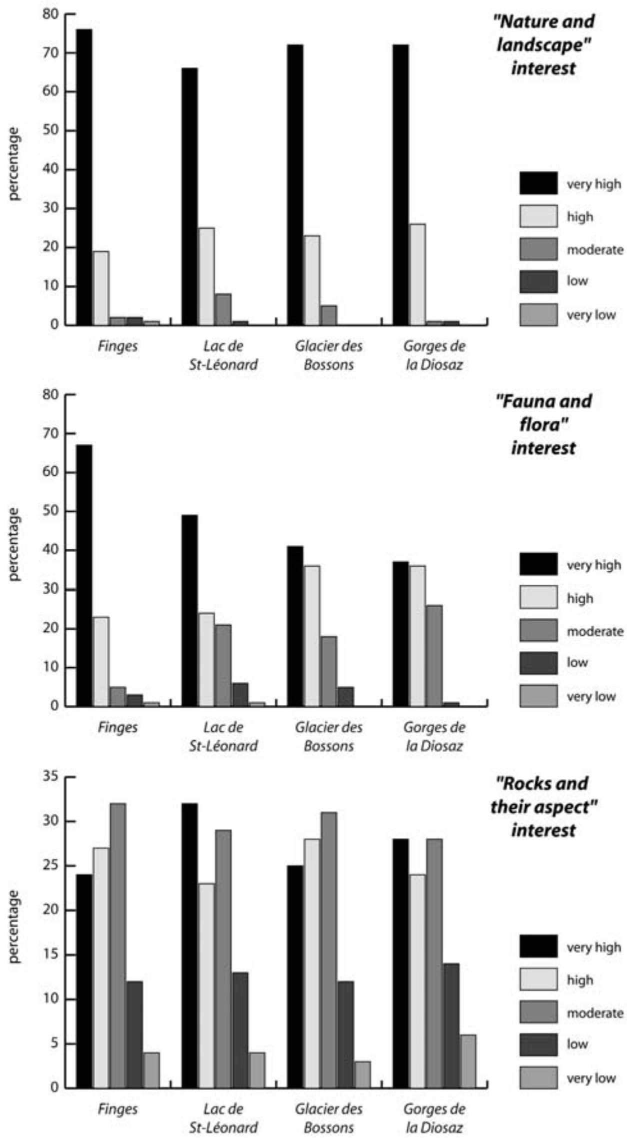

Fig. 3 – "Nature and landscape", "fauna and flora" and "rocks and their aspect" interests according to the visitors questioned (adapted from Pralong, 2006).
— *"Natura e paesaggio", "Fauna e flora" e "rocce e loro aspetto" sono gli interessi dei visitatori come emerso dai questionari (adattato da Pralong, 2006).*

(2) In that case, the terms of "geology" and "geomorphology" were avoided, in order not to assess the interest of visitors for these scientific domains, but only for rocks and forms of the Earth's surface. The simple expression "rocks and their aspect" was been also preferred.

new place are in each case more often mentioned than understanding the natural factors or the dynamics of the sites.

However, the demand for explanations is really significant, especially for Earth science. When didactic goods and services exist in a particular site, the percentage of demand is around 90%. For the *Diosaz* gorges, this rate is only 10% lower, but remains pertinent (3). In relation to the themes to optimise, the geological and geomorphological aspects (4) are mentioned in first position (fig. 4), with the exception of *Finges*. In comparison with TOMMASI (2002), it is also obvious that "*there is a strong demand for translating the geological knowledge into more explicit popular initiatives. These needs come from the education world, tourist operators and civic, cultural and trekking and climbing organisations (which would like to further develop mountain activities not only for competitive sport purposes but also for cultural and scientific ones)*".

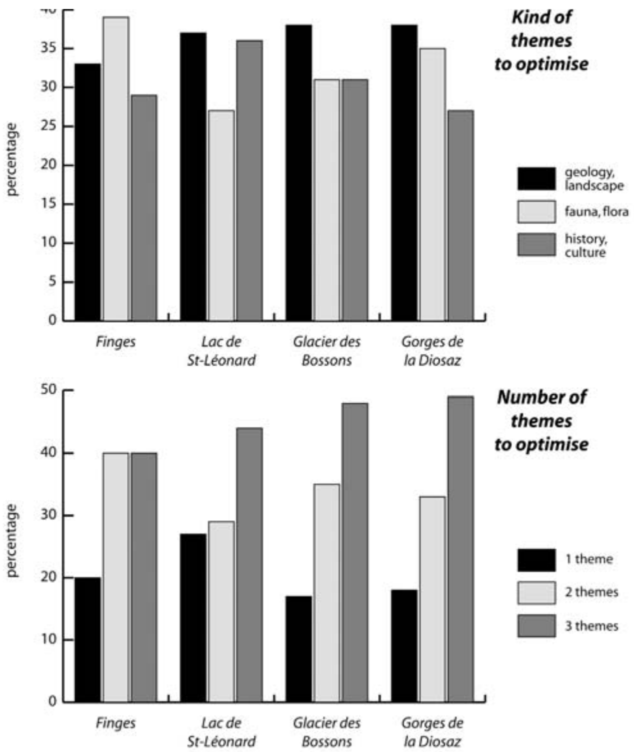

Fig. 4 – Kind and number of themes to optimise with didactic explanations according to the visitors questioned (adapted from PRALONG, 2006).
– *Tipi e numeri di tematiche da ottimizzare con le spiegazioni didattiche secondo quanto emerso dalle indicazioni dei visitatori (adattato da PRALONG, 2006).*

Otherwise, only low differences in percentage exist between the three proposed categories of themes. In this way, these results indicate that visitors wish a geosite interpretation which takes all kinds of heritage into account. This demand for explanation is clearly expressed in a sense of "geohistory" and "cultural integrated landscapes" (PANIZZA & PIACENTE, 2003). Moreover, a transdisciplinary and integrated approach seems to be wanted by the majority of visitors, as shown by the second chart of figure 4. In which case, "geohistory" is implicitly recognised as the best way to optimise the different interests of a site. Other results indicate that ensuing didactic goods and services must be developed with a basic level of popularisation.

Indeed, figure 5 shows that the aims of such tools should be to provide an introduction to a site as well as to allow day-trippers and tourists to obtain new knowledge (more than 50% of all the answers), in order to learn some aspects about the environment visited. In this way, the people surveyed apparently think that developing prior knowledge must be done in another manner (e.g. literature, course). To achieve the mentioned goals, traditional tools, such as didactic panels, guided tours, books, booklets or displays, are preferred, on the contrary to interactive computer tools or lectures. Finally, in relation to the sites investigated – with the exception of *Diosaz* gorges –, the demand partially corresponds to the offer, although the links between the different kinds of heritage should be more strongly optimised and the level of popularisation adapted more to the second and third categories of visitors (see last chapter).

4. – CONCLUSIONS

This paper demonstrates the usefulness of questionnaire surveying as well as the necessity of producing didactic goods and services based on the wishes and the needs of the different target groups. In the context of tourist and recreation utilisation of geological and geomorphological sites, the assessment of popularised tools – before and after putting them in place – allows geoscientists to really satisfy the demand of the various target publics and to develop appropriate goods and

(3) For this site, the lack of information and explanation is the most relevant element of disappointment for visitors. The lack of geological explanations regarding its formation is the third one.
(4) In that case, Earth science is taken into account by the terms "geology" and "landscape", in order to specify that the natural and physical features of the landscape are considered.
(5) "Marketing activities are all those associated with identifying the particular wants and needs of a target market of customers, and then going about satisfying those customers […] This involves doing market research on customers, analyzing their needs, and then making strategic decisions about product design, pricing, promotion and distribution". iws.ohiolink.edu

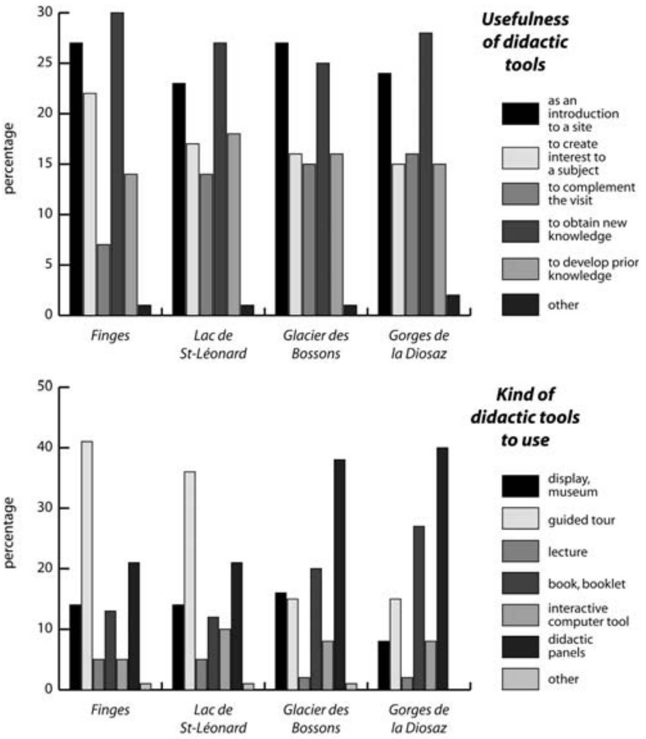

Fig. 5 – Usefulness of didactic tools and kind of tools to use for providing explanations according to the visitors questioned (adapted from PRALONG, 2006).
– *Utilità degli strumenti didattici e tipo di strumenti da usare per fornire spiegazioni secondo quanto emerso dalle indicazioni dei visitatori (adattato da* PRALONG*, 2006).*

services in terms of content and method. In summary, each kind of visitor has specific motivations and expectations and therefore requires specific didactic tools.

For that, the typology of the different target groups proposed by ORIGET DU CLUZEAU (1998) for cultural tourism is an interesting way to consider the effective demand for Earth science. Three categories are also distinguished:

specialists of a topic, people genuinely motivated (e.g. for fossils, minerals or glaciers); already interested in Earth science, they may be satisfied by the existing literature;

people genuinely motivated, but for any cultural topics; cultural and historical geosites as well as "geohistory" may be the right way to "conquer" them;

occasional visitors, simply inquiring – these make up the majority of visitors to cultural sites found in tourist areas. They prefer emotions, sensations and entertainment rather than acquiring knowledge; fascinating stories that Earth science may tell can be used to produce the desired experience.

Taking into account of the environmental sensitivity as well as the opinions on didactic tools of the different kinds of day-trippers and visitors, this study shows that interest in Earth science is, at first sight, quite moderate in comparison with biology and especially nature and landscape. Furthermore, the objectives of the visit highlight the fact that the particular characteristic of the objects concerned (e.g. cave, glacier, gorges), the wish to visit a natural site or to discover a new place are each time more often mentioned than the motivation to gain an understanding of the natural factors explaining the existence or the dynamics of the sites. However, the demand for explanations is really important, especially in Earth science; it can be observed that visitors older than 50 years of age have the largest interest in this.

In this way, the obtained results prove that day-trippers and visitors wish a geosite interpretation which takes all kinds of heritage into account. This demand for explanation is clearly expressed in a sense of "geohistory" and "cultural integrated landscapes". But the proposed didactic goods and services must be developed with a basic level of popularisation, because the aims of such tools are recognised as providing an introduction to a site and allowing visitors to obtain new knowledge. To achieve the mentioned goals, traditional tools, such as educational signs, guided tours, books, booklets or displays, are preferred. Finally, in relation to the investigated sites, the demand partially corresponds to the offer, although the links between the different kinds of heritage should be more strongly optimised and the level of popularisation adapted more to the second and third categories of visitors.

5. – PERSPECTIVES

After this first approach of the demand, studies on target groups' ideas and questions regarding Earth science should be encouraged, because a better understanding of the needs and wishes of the different kinds of visitors will allow geodidactic tools to be created that make sense for all. According to RIVARD (1999), ensuing goods and services have firstly to use references in relation to the experience of the day-trippers and tourists, secondly to "play" with their own conceptions in Earth science and finally to propose new issues and questions about geology and geomorphology. This statement shows that people interested in the popularisation of the discipline have to work not only on what content to transmit, but also on what methods to utilise with the different target groups. Therefore, it is not sufficient – but clearly necessary – to use illustrations, simple words and not too much text.

From a tourist's point of view, this kind of marketing studies (5) may allow geoscientists as well as tourist stakeholders to develop geotourist activities further, because the success of any form of tourism depends on the knowledge of specific markets – such as seniors, families or students for geotourism – and the best way to communicate to them. For that reason, new partnerships between geoscientists and tourist stakeholders have to be encouraged, notably with experts in marketing and product developers. In this sense, the sustainable optimisation of regional potentials, such as geological, biological or historical resources, may generate long term economic benefits and social advantages for day-trippers and tourists as well as for local and regional inhabitants.

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figg. 4 - tab. 1

Relationships between archaeology and landscape in two preandean valleys from northwest Argentina

Rapporti tra archeologia e paesaggio in due valli preandine dell'Argentina nordoccidentale

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NEDER L. (**)

ABSTRACT – The purpose of this research was to compare prehispanic settlement patterns as a response to geomorphological landforms. Two preandean valleys from northwest Argentina (Tafí and La Ciénega) were studied from the geomorphological and archaeological point of view. The prehispanic human occupation of these areas were belonging to Tafí Culture (360 B.C. to 800 A.C.), and the most significant difference are their altitudinal locations together with the geomorphological characteristics of each area. After to make a systematic photointerpretation of both areas, we construct a GIS using archaeological, geomorphological, and topographic information. We conclude that prehispanic settlements were adequate to different use preferences. La Ciénega valley, which dominant geomorphological landforms are erosion glacis were mostly used as cattle area, while Tafí valley was used for residential settlement as well as for agricultural exploitation.

KEY WORDS: Prehispanic settlement; Geoarchaeology; Northwest Argentina; Tafí Culture; GIS.

RIASSUNTO – Lo scopo della ricerca illustrata in questo articolo è quello di evidenziare la relazione tra la distribuzione degli insediamenti pre-ispanici e le forme del rilievo. A questo scopo è stata studiata la geologia e la geomorfologia di due valli pre-andine dell'Argentina nord-occidentale (Tafi e La Ciénega). L'occupazione antropica pre-ispanica di queste aree risale alla Cultura Tafi (da 360 B.C. a 800 A.C.), e le differenze più significative sono la loro quota e le caratteristiche geomorfologiche. A seguito di sistematica fotointerpretazione di entrambe le aree, le informazioni archeologiche, geomorfologiche e topografiche sono state inserite implementate in ambiente GIS. È apparso chiaro che le due valli, per le loro caratteristiche fisiche, erano adatte a differenti usi: la valle La Ciénega, in cui le forme del rilievo predominanti sono i glacis d'erosione, fu utilizzata prevalenetemente come area per il pascolo, mentre la valle del Tafi per uso residenziale e per uso agricolo.

PAROLE CHIAVE: Insediamenti pre-ispanici; Geoarcheologia; Argentina Nord-occidentale; Cultura di Tafi; GIS.

1. – INTRODUCTION

Tafí and La Ciénega valleys are located on the northwest of Tucumán Province – Northwestern Argentina (fig. 1). They are rich archaeological areas from the northwest of Argentina. They present one of the earliest agricultural settlements of the region and they had a long occupational period dated between 360 B.C. and 800 A.C. These occupations belong to Formative period. This period is defined by the appearance of permanent village settlements and the development of agriculture. After that, Tafí valley was scarcely occupied by Santa María Culture (about 1000 to 1400 A.C.).

The typical houses of Formative period are central circular patios (15 to 20 meters diameter) rounded by other circular smaller rooms (6 to 2 meter diameter). Tafí valley has also agricultural terraces while La Ciénega only has circular structures.

As these archaeological settlements were belonged to the same prehispanic culture, and they represent a long occupational and contemporaneous period, the purpose of this research is to compare prehispanic settlement patterns as a response to geomorphological landforms.

2. – STUDY AREAS

Tafí and La Ciénega valleys are located in the pre-Andean region of northwest Argentina. The first between 26º 45' and 26º 58' S, and between 65º 39' and 65º 48' W. And the second between

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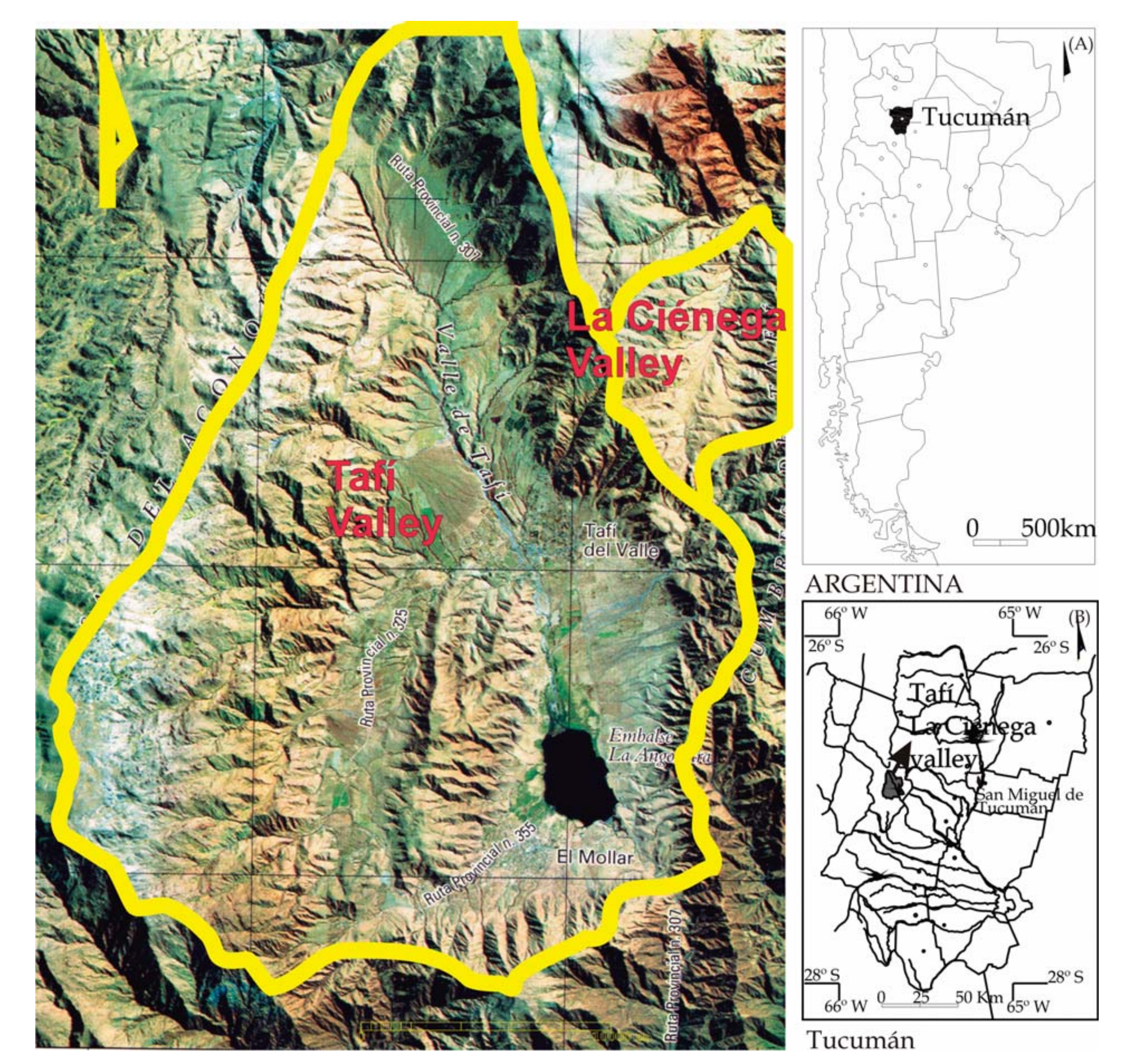

Fig. 1 – Location of Tafí and La Ciénega valley. Tucumán province, Argentina.
– Ubicazione delle valli Tafi e La Ciénega. Provoncia di Tucumán, Argentina.

26º 45' and 26º 50' S, and between 65º 38' and 65º 41' W (fig. 1). They are intermontane valleys which environmental conditions oscillate during Quaternary period. According to the research results obtained at Tafi valley, from the beginning of the Holocene until 7500 yr B.P., the climate was subhumid and warm. During the middle Holocene, it became cold and dry, but temperate and subhumid conditions were established around 3000 yr B.P. (Sayago & Collantes, 1991).

The Tafí valley is an elongated basin 1800–2300 m above sea level (m a.s.l.), with a median (N-S) floor slope of 18.8% (Bolsi *et alii*, 1992). The present climate is semiarid, with annual precipitations between 400 and 550 mm. Annual average temperature is about 13.1°C (Sesma, 1987). Most of the valley surface is covered by grass, which makes archaeological structures easily visible on aerial photographs.

La Ciénega valley is and elongated valley (28 km^2) formed by two river basins one that drains through the north and east until Tucumán plains, and the second one through the south and finished on Tafí river basin at Tafí valley. The bottom valley is located between 2500 and 2900 m a.s.l. As Tafí valley, it has a semiarid climate but they are not precise data on rain and temperature averages (fig. 2).

3. – CONCEPTUAL FRAMEWORK

To avoid conceptual problems related to different scholar formations we decided to introduce some definitions.

We understand by Formative Period the space of time comprised between 1000 B.C. and 1000 A.C. (according to Tartusi & Núñez Regueiro, 1993; Núñez Regueiro, 1994). It is culturally characterized by the establishment of a disperse settlement pattern where each residential unit is formed by rooms related with a central or lateral patio. The economy was based on agriculture, the production was extensive. Communities were formed by gourp of 100 members where the structure was done by extensive families. Some groups show the development of copper and bronze metallurgy (Sempé, 1994).

For the geomophological analysis we follow morphogenetic criteria (Viers, 1973; Verstappen, 1977; van Zuidam, 1985) because we consider that it is better to our classifications. Especially considering that using these criteria each landform unit implies a specific formational process, dominant climate, and relief as fundamental modelling factors (Sayago & Collantes, 1991).

On the other hand, all concepts about genesis and geomorphological classification of piedmont landforms presented by Viers (1973) were developed over the Argentinean Andean piedmont. So, it appears very useful to use it in a region with similar morphogenetic characteristics.

We distinguish according to their origins: a) structural denudational forms: integrated by denudational slopes; b) denudational forms: includes erosion, cone glacis and covered glacis; c) fluvial-alluvial forms: represented by alluvial fans, fluvial terraces, and river bed and alluvial plain.

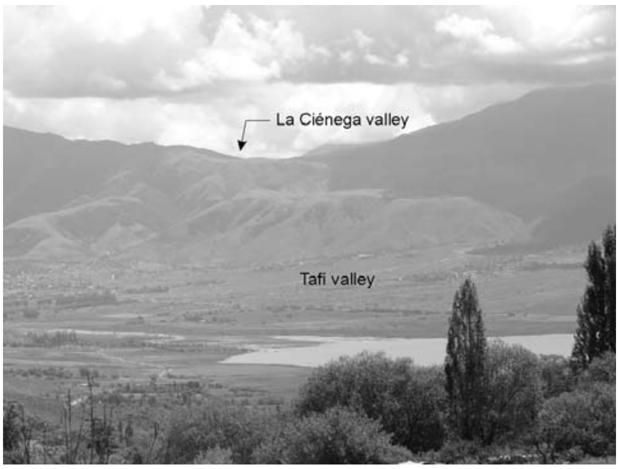

Fig. 2 – Panoramic view of both areas.
– *Vista panoramica delle valli oggetto di studio.*

Denudational slopes are defined as all slopes of contrary sense that limits a valley or a mountain affected by endogenous geological processes, as lithology and structure, and exogenous processes that produce the elimination of superficial weathered materials (Collantes, 2001).

Viers (1973) defines erosion glacis as a sort of planed surface with a gradient between 2 to 8 %. According to van Zuidam (1976) it is a piedmont form characterized by being an extensive plane, gently undulating, affected by ravines and gullies. Normally it is developed on the foot of a structural relief.

Covered glacis are piedmont landforms relatively planes to undulating similar to erosion glacis but characterized by the presence of a clastic cover of approximately 15 m of thickness. This form was defined by Viers (1973) as an erosion surface covered by an alluvial mantle so thick that it covers absolutely all substrate. van Zuidam (1976) defined it according to its superficial characteristics, as a flattening surface with a slope of 1-2 to 7 %, with smooth undulations.

Cone glacis are accumulation landforms defined by van Zuidam (1976) as a kind of accumulation glacis, of media extension; slope between 3 and 7 %, and with the shape of a cone or fan. They are developed in a relative small basin by fluvial activity and overland flow. This author points that, in general, they are landforms developed in the past because they show inactivity under the present environmental conditions; they also show a layer of materials with fine texture that covers the surface of the cone; the landform used to appear dissected by gullies; and some cones are cut by lateral erosion of main rivers after a recent incision period.

Verstappen (1977) has related the forms of fluvial origin with accumulation areas, like valleys and alluvial plains. There are still some doubts about which are the environmental factors that control the development of these forms, nevertheless there is no doubt about their complex and polygenetic nature (van Zuidam, 1985).

The literature about the genesis of alluvial fans is very vast, but all researches agree that it is a kind of landform that could be developed in very different environments. There is also coincidence about that they are characterized by the dominance of the deposition. They are formed by channelled fluvio-alluvial currents (highly competent and with severe fluidity) that emerge from a mountainous area and flows into a plain. As a consequence of this change of slope, the sediments are deposited generating this landforms with characteristic shape (Collantes, 2001).

There are different hypothesis about the genesis of fluvial terraces, and in general its origin is related with tectonic influence (local or regional), climatic changes or eustatic adjustments (BROWN, 1997).

River bed and flood plain are constituted by the sector over which the river actually flows, together with the plain that border it, and has been formed by the deposition of the materials transported by such river (CALMELS & CARBALLO, 1991).

4. – ANTECEDENTS

The entire area contains some of the earliest settlements in northwest Argentina. These settlements are particularly important because they represent the transition from hunter-gatherer to agricultural economies. However, little is known about them, especially about the relationship between environmental analysis and cultural responses.

During the final decades of the 19th century, menhirs (single upright crude monoliths), from Tafí valley, were described (AMBROSETTI, 1897; QUIROGA, 1899). These sculptures allowed archaeologists to relate these sites to the Tiahuanaco culture. Later papers noted the Prehispanic buildings dispersed across both valleys, which were described as agricultural terraces and residential units for Tafí valley (BRUCH, 1913; CANALS FRAU, 1953) and some of the most representative residential settlements for La Ciénega (QUIROGA 1899).

About Tafí valley, GONZÁLEZ & NÚÑEZ REGUEIRO (1960) completed the first systematic description of the archaeological remains found. They determined that the existing structures belonged to a specific cultural entity with particular characteristics, and named it the Tafí Culture (GONZÁLEZ & NÚÑEZ REGUEIRO, 1960). The Tafí Culture is 14C dated between 2296 ± 70 yr B.P. (GONZÁLEZ, 1962) and 1140 ± 50 yr B.P. (BERBERIÁN *et alii*, 1988).

These Formative Period settlements are characterized by pirca walls that can still be seen on the surface. Each settlement was formed by one to three big stone circles that have 10–20 m in diameter, surrounded by one to six, and occasionally more, circles that have 2–5 m in diameter. Each of these units was separated from the others by several meters (GONZÁLEZ, 1962; 1980).

Based on macroscopic artifacts, GONZÁLEZ & NÚÑEZ REGUEIRO (1960) established that the big central circles were places of daily domestic activities, such as milling, and also the place where the dead were buried. The small circles were rooms to sleep and to storage (GONZÁLEZ & NÚÑEZ REGUEIRO, 1960).

Using aerial photographs of the whole valley, SAMPIETRO VATTUONE (2002) simplified the building classification into two major categories: agricultural structures and circular rooms. The first category includes "despedres" (elongated mounds, with the same direction than slope, formed by stones removed from agricultural fields) and agricultural terraces (solid walls constructed perpendicular to slope). The second category could be divided into: simple circular rooms (one isolated structure), double circular rooms (two rooms with the same shape and dimensions constructed together), composite units (one big circle surrounded by smaller ones forming a household unit), and complex units (two or more big circles together with smaller ones forming a network where it is impossible to define restricted units).

By using geomorphological criteria to determine discrete sample units feasible for comparison, it was possible to identify landscape settlement preferences (SAMPIETRO VATTUONE, 2002). Cone glacis and alluvial fans were used for agricultural terraces and houses. Covered glacis and, in a lesser extent, erosion glacis were used exclusively for circular structures.

According to this settlement pattern, Tafí people had a segmentary society whose subsistence was based on cultivated plants and domesticated animals. The settlements were arranged according to some landscape preferences inside the Tafí valley area (SAMPIETRO VATTUONE, 2002). Apparently, no structure dominated any other. Houses were isolated and permanently occupied, with a dispersed settlement pattern. There is little evidence of centralization or specialization with the exception of the menhirs, agricultural terraces (BERBERIÁN *et alii*, 1988; SAMPIETRO & SAYAGO, 1998; SAMPIETRO VATTUONE, 2002), and a small ceremonial mound found in the valley (GONZÁLEZ & NÚÑEZ REGUEIRO, 1960).

There are little research antecedents about La Ciénega. Some archaeological excavations showed that, according to settlement pattern and recovered materials, the constructions present on this valley were also belonging to Tafí Culture and had relationships with other culture from the Tucumán plain (Candelaria Culture) (BERNASCONI DE GARCÍA & BARAZA DE FONTS, 1981-82).

Finally, CREMONTE (1996), by a visual interpretation of some aerial photographs, made a distribution map of the archaeological structures over landscape units. According to her, La Ciénega valley could be divided into five geomorphological areas: floodplain, alluvial zone, piedmont, colluvial levels, and high mountains.

According to her, floodplain corresponds to the bottom valley, its sediments are inundated each summer season. Alluvial zone is the intermediate terrain area between floodplain and the sediments accumulated over piedmont. Piedmont level is a big area of gently slope formed by peneplained deposits. Into this piedmont there are also colluvial levels, defined as deposits of sediments dragged by pluvial waters that were accumulated on depressions and then peneplained forming almost horizontal surfaces (CREMONTE, 1996).

Unfortunately, the characterization of each geomorphological unit does not have uniform criteria. So, their limits are not easily established, and also there is not clearly established which were the formational factors. Using this classification together with the calculation of the X^2 test, CREMONTE (1996) established that archaeological units are not randomly distributed over the valley; they tend to be located on the areas with deeper soils, on the south and central area of the study area.

5. – MATERIALS AND METHODS

For the study of landscape appropriation and archaeological structure distribution we started by the systematic photointerpretation of altitude, geomorphology, hydrology, and archaeology. Aerial photographs at 1:50,000 and 1:10,000 scales were used. All maps were controlled by pedestrian survey of both areas.

Geomorphological studies of areas with archaeological settlements are important to understand the natural processes that took place on the settlement surface generation. Furthermore, it gives evidences about the natural resources potentially available for the past populations that could condition settlement distribution. Finally, it provides paleoenvironmental information that is fundamental to understand the dynamic of archaeological formation processes.

Geomorphological analysis was performed following the methodology proposed by VAN ZUIDAM & VAN ZUIDAM-CANCELADO (1979).

Archaeological structures were categorized according to their constructive characteristics and shape, following SAMPIETRO VATTUONE (2002).

Then, archaeological maps were associated with geomorphological maps trough the construction of a GIS using ILWIS 3.4 software (ITC).

In order to compare the distribution of the different kind of circular units identified in both valleys we performed some statistical analysis. After the characterization of each archaeological unit, according with their architectural shape (following SAMPIETRO VATTUONE, 2002), and assuming that all ancient structures were nearly contemporary, we calculated the distance to nearest neighbors (DNN). In all cases geomorphological units where taken as discrete sampling units.

The DNN method involves the analysis of the spatial distribution of points using distance characteristics between individual points on the map. The pattern is analyzed by calculating distances between individual points and between their first to sixth nearest neighbor points in the pattern. The results are tested against the expected distances in complete spatial randomness (CSR) (ITC, 2001).

This technique was used to examine the spatial pattern of the points on our maps. When the individual points are closer to each other they would be in CRS, a cluster pattern is indicated. If this is not the case, the pattern is more regular, or uniform (ITC, 2001).

6. – RESULTS

As we started by the comparison of the geomorphology of both areas, we established that the vegetal formation of both them is highland grasses. The visibility of surface traits is optimal for a good photointerpretation.

As we set on the introduction, both areas have important altitudinal differences. The bottom part of Tafí Valley is located between 1800 and 2300 m a.s.l., while La Ciénega has between 2500 and 2900 m a.s.l. The first region has the exposition to wet south winds, while the north part of La Ciénega Valley has south exposition, and the south part has north exposition (fig. 2).

In both cases, the landforms over which archaeological structures were lying were geomorphologically stable when the settlement started, that means that the landscape has had a great stability for at least the last 3000 years. During this time soil development processes were dominant. This is also evident by the visibility and degree of conservation of the standing buildings, dated between 360 B.C. and 800 A.C.

Geomorphologically, dominant landforms of Tafí valley are covered glacis, cone glacis, erosion glacis, alluvial fans and fluvial terraces (fig. 3). At La Ciénega, geomorphological units are mostly erosion glacis together with covered glacis, alluvial fans and inactive fluvial terraces (fig. 4).

Prevailing archaeological structures from Tafí valley are residential units on both categories (complex and composed units), accompanied by double units. These units are distributed mainly over covered glacis and in some degree over cone glacis and alluvial fans. There are some geomor-

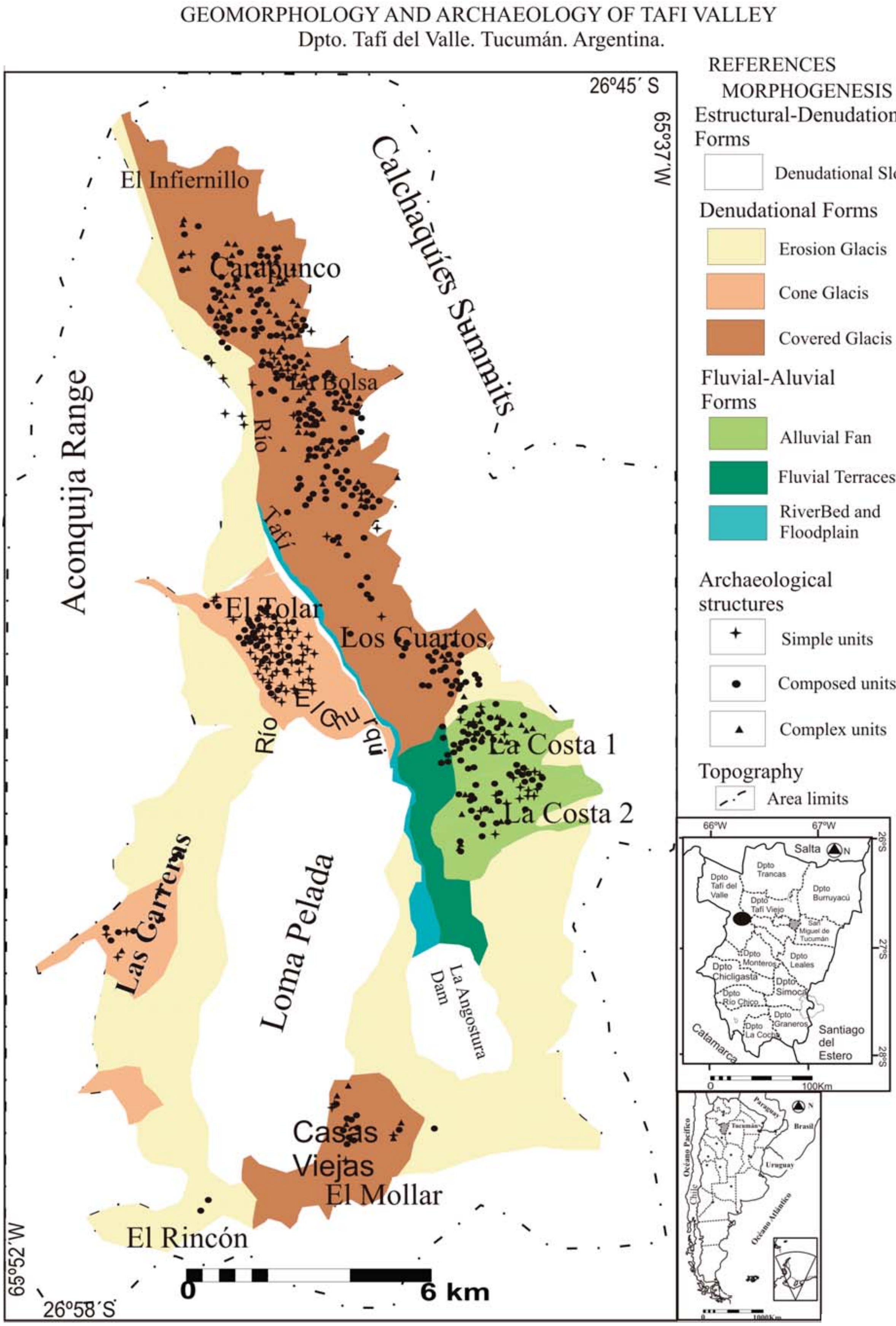

Fig. 3 – Geomorphology (simplified from COLLANTES, 2002) and archaeology from Tafí valley.
– Geomorfologia (semplificato da COLLANTES, 2002) e archeologia della valle di Tafí.

phological units used for agricultural purposes (alluvial fans and cone glacis), even both them have also residential units. Simple units, when they are present, are associated with agricultural fields and rise just 2 m of diameter (fig. 3).

The archaeological structures from La Ciénega are composed and complex residential units mainly lying over denudational slopes, erosion glacis and covered glacis. Simple units are over the same geomorphological units than the previous ones but they have different shape than the simple units from Tafí valley, they oscillate between 10 to 20 m diameter, and they are not associated to agricultural systematizations of the landscape. This is clearly showing that they have a different functionality as the landform over which they are settled (fig 4).

Statistically, it was observed that there exist tendencies about the internal arrangement of the circular structures inside each geomorphological unit. These results are resumed on table 1.

For Tafí valley, as it was observed by the occurrence of stone circles, on the case of landforms used for agricultural purposes little simple units tend to have regular distribution, while where the emphasis was focused on residential purposes composed structures have regular distribution.

We believe that the uniform distribution of simple units at cone glacis and alluvial fans is the intrasite expression of regional patterns described by SAMPIETRO VATTUONE (2002) for Tafí valley. Their distribution is a response to the agricultural function of the sites. If we accept that these units were directly associated with crop raising, they must be positioned to minimize travel distance and maximize the use of space. The distribution of other types of structures is subordinate to the agricultural function of the area. The same interpretation could be done for residential structures on the case of covered glacis.

On the case of La Ciénega valley, big simple units were specially located over denudational slopes and erosion glacis, while residential structures (composed and complex units) are mainly distributed over covered glacis. We believed that this is related to the facility to direct water to the settlements.

Statistically, covered glacis reached a regular distribution of residential and simple units. On the case of denudational slopes, just simple units are regularly distributed. The regular distributions is denoting the preferences of use of each landform, being the covered glacis equally used to residential and cattle purposes, while over denudational slopes grazing activities were prevailing.

7. – CONCLUSIONS

Comparing both valleys we established that the most significant difference was its altitudinal location together with the geomorphological characteristics of each area (fig. 2).

At Tafí valley cone glacis and alluvial fans were occupied with agricultural settlements, while covered glacis were mainly used for residential purposes. None important structures were distinguished over erosion glacis.

Tab. 1 – *Statistic results of distribution tests.*
– Risultati statistici dei test di distribuzione.

TAFÍ VALLEY				
Geomorphological unit	Structure type			
	Simple	Double	Composed	Complex
Cone glacis	Regular	Grouped	Random	-
Covered glacis	Grouped	Grouped	Regular	Grouped
Alluvial fan	Regular	Grouped	Grouped	Regular
LA CIÉNEGA				
Geomorphological unit	Simple	Double	Composed	Complex
Cone glacis	Regular	-	Grouped	-
Covered glacis	Grouped	-	Grouped	Random
Alluvial fan	Regular	-	Regular	-

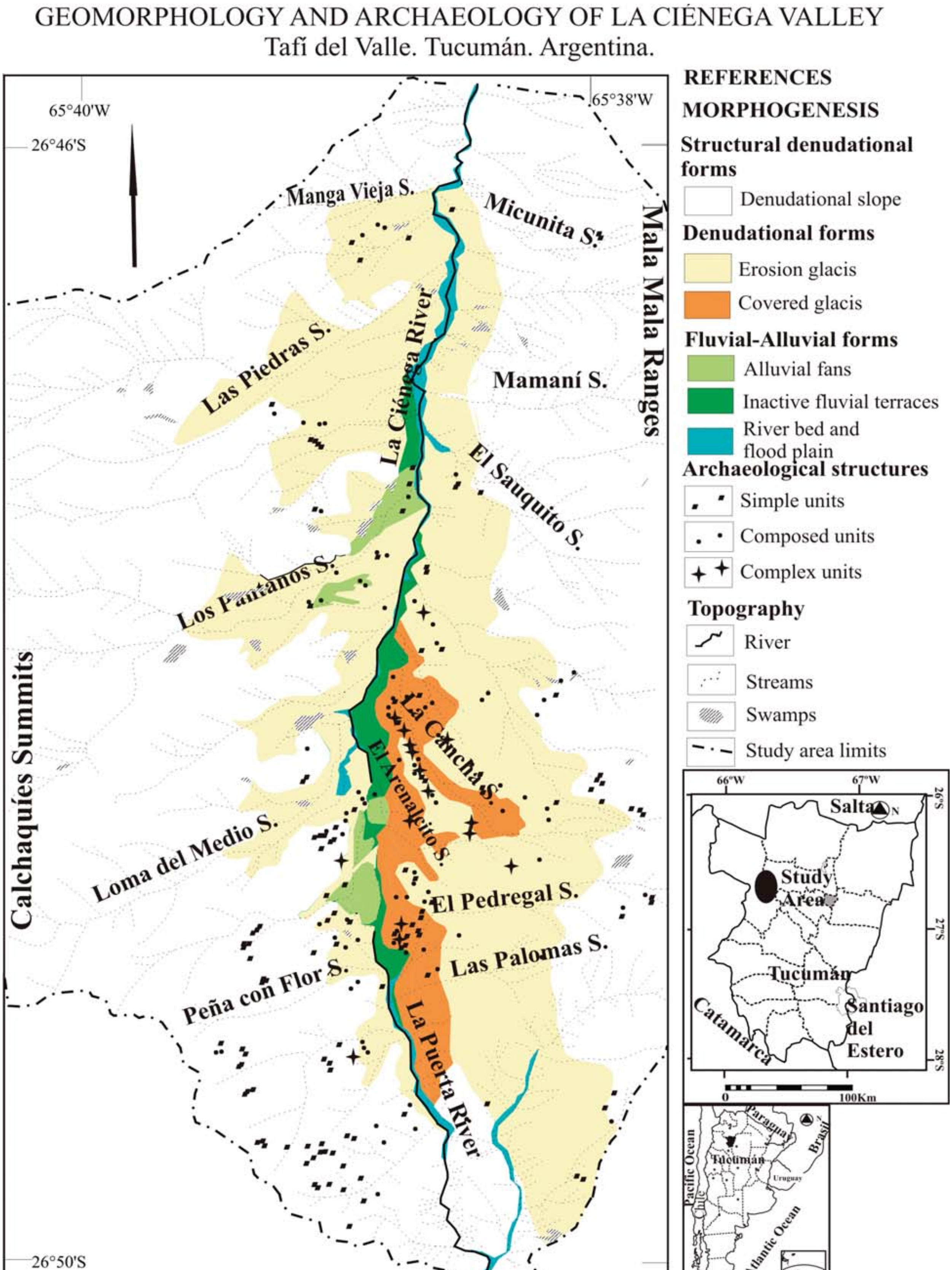

Fig. 4 – Geomorphology and archaeology from La Ciénaga.
– *Geomorfologia e archeologia della valle La Ciénaga.*

On the contrary, at La Ciénega valley the dominant landform is erosion glacis and the simple round structures settled there were very abundant.

Statistical analysis reinforced these ideas of landform characteristic – use preference, not just by the dominant shape of archaeological structures but also by the distribution of them on the landscape.

We conclude that prehispanic settlements were adequate to different use preferences. La Ciénega valley, which dominant geomorphological landforms are erosion glacis were mostly used as cattle area. The kinds of structures together with its distribution over landforms were oriented on this sense. While Tafí valley spatial appropriation was oriented to an intensive profit of agricultural soils.

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A method for the identification and assessment of significance of geomorphosites in Vorarlberg (Austria), supported by Geographical Information Systems

Un metodo supportato dal GIS per l'identificazione e la valutazione del significato dei geomorfositi nel Vorarlberg (Austria)

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DE GRAAFF LEO W.S. (**)

ABSTRACT – Using 1:10,000 full-area covering analogue geomorphological maps as the basis for our geoconservation work in the State of Vorarlberg (Austria), we define geomorphosites as the smallest coherent landforms which can be delineated, weighted and ranked, based on these maps. In our approach the term 'geomorphosite' is not restricted to unique or spectacular geomorphological objects or a group of objects, but it also includes 'common' sites in which people, animals and plants live. Therefore, the total landscape is valued on the basis of detailed geomorphological information. This means that not only individual landforms, but also associations or groups of landforms are assessed. A method has been developed for assessing the degree of significance ('value') of geomorphosites, with the objective of identifying potential geoconservation sites, within a frame of reference of choice. In a first step landform boundaries are identified, digitized in polygons and color-coded in a Geographical Information System (GIS) using a morphogenetic classification scheme. The degree of significance of the units is rated in a second step with a set of weighting and ranking criteria which include scientific relevance, frequency of occurrence, intactness and vulnerability. The assessment of significance combines expert knowledge and GIS-analyses which results in three ranks of significance of geomorphosites: low, moderate and high. The descriptive factors land use, scenery, status of protection, and additional criteria capture additional information in a third step, which may influence the final ranking for the degree of significance of the geomorphosites. In a fourth step, the ranking leads to the selection of potential geoconservation sites. The results are presented in a GIS and are hyperlinked to additional information, such as site descriptions, landscape photos and other thematic information. The method is illustrated in two case studies.

KEY WORDS: Geoconservation, Geomorphosites, Geomorphological mapping, Austria, GIS.

RIASSUNTO – Utilizzando le carte geomorfologiche digitali a scala 1:10.000 come base per il lavoro di geoconservazione nello stato del Vorarlberg (Austria), i geomorfositi sono stati definiti come le più piccole forme del rilievo coerenti, che possono essere individuate, pesate e classificate, basandosi su queste carte. Secondo questo approccio di lavoro il termine 'geomorfosito' non è utilizzato in modo restrittivo per indicare oggetti geomorfologici unici o spettacolari o gruppi di oggetti, ma include anche siti 'comuni' nei quali persone, animali e piante vivono. Quindi, il paesaggio nel suo complesso viene valutato sulla base di dettagliate informazioni geomorfologiche. Questo significa che non solo forme singole, ma anche associazioni o gruppi di forme possono essere valutate. È stato sviluppato un metodo per valutare il valore dei geomorfositi, con l'obbiettivo di individuare siti potenziali per la geoconservazione. Nella prima fase vengono definiti i limiti delle forme del rilievo e vengono digitalizzati i poligoni, utilizzando colori codificati in un sistema GIS per indicare la morfogenesi. Il grado di importanza delle unità è valutato in una seconda fase utilizzando un insieme di criteri che includono l'importanza scientifica, l'abbondanza, il grado di conservazione e la vulnerabilità. La valutazione del significato (valore) del geomorfosito combina la conoscenza dell'esperto e l'analisi GIS ed è stata classificata come bassa, moderata e alta. Elementi descrittivi come l'uso del suolo, la spettacolarità, lo stato di protezione e valori aggiunti aggiungono informazioni addizionali nella terza fase, che può influenzare il risultato finale del valore del geomorfosito. In una quarta fase, i valori ottenuti guidano nella selezione di siti potenziali per la geoconservazione. I risultati vengono presentati in ambiente GIS e sono collegati ad informazioni aggiuntive, come la descrizione dei siti, fotografie ed altre informazioni. Il metodo sviluppato viene illustrato in due casi studio.

PAROLE CHIAVE: Geoconservazione, Geomorfositi, Cartografia geomorfologica, Austria, GIS.

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1. – INTRODUCTION

Governments, inhabitants and visitors of mountain regions nowadays realize that mountain landscapes have vital functions and that overexploitation should be avoided to ensure sustainable landscape management. As a result of the interference by man, original mountain landscapes become fragmented or may even disappear.

Therefore, the conservation of such landscapes is of prime importance, now and in the future. Geodiversity plays a crucial role and is defined by GRAY (2004) as 'the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, processes) and soil features. It includes assemblages, relationships, properties, interpretations and systems'. Slightly different definitions have been proposed by EBERHARD (1997) and SHARPLES (2002). In central Europe the term 'geotope' is often used, e.g. by STÜRM (2005) who refers to "distinct components of the landscape with an outstanding geological, geomorphological or geoecological value. They are relics of, or give good insight into the Earth history, the evolution of life, climate or landscape". According to the IAG Working Group on Geomorphological Sites (2005), geomorphological sites (or geomorphosites) are portions of the geosphere that present a particular importance in the comprehension of the Earth history.

In our approach, the term 'geomorphosite' is not restricted to unique or spectacular geomorphological objects or groups of objects, but also includes 'common' sites in which people, animals and plants live. Such sites can be identified as being worth conservation (protection) on the basis of a set of objective weighting and ranking criteria, applied within and depending on a frame of reference of choice (cf. EMBLETON, 1984). Once a geomorphosite has been officially elevated by the authorities to the status of being protected, it is called a geoconservation site. Our method has been developed within the context of plans to make a complete inventory of potential geomorphosites in the State of Vorarlberg at a level of detail which is required for planning purposes, based on a full-area-covering evaluation of all landforms. This is different from the methods developed in some other countries, where the assessment often focuses on direct validation of individual geomorphosites (compare e.g. STÜRM, 1994; SHARPLES, 2002; GRAY, 2004; PRALONG 2005; GONGGRIJP, 2005). The method presented here seeks to a) define geomorphosites boundaries in a consistent manner using geomorphological information and b) assess the degree of significance and ranking of geomorphosites using well-defined weighting and ranking criteria in GIS as presented in table 1.

Tab. 1 – *Scheme outlining the method of identifying geomorphosites and assessing their significance in selecting geoconservation sites in Vorarlberg.*
– Schema che illustra il metodo di identificazione e valutazione dei geomorfositi nel processo di selezione dei siti per la geoconservazione nel territorio di Vorarlberg.

Steps	**Input**	**Action**	**Output**	
			Landforms	**Geomorphosites**
1	Geomorphological maps (1:10.000) and morphogenetic classification scheme (table 2)	Identification of homogeneous units	Landform boundaries	Geomorphosite boundaries
		Digitizing of unit boundaries	Digital Landform boundaries	Digital Geomorphosite boundaries
		Coding and coloring of polygons	Digital geomorphological maps	Digital geomorphosite maps
2	Weighting and ranking scheme	Quantitative weighting and ranking of primary criteria	Degree of significance for geomorphosites (low, moderate, high)	
		Quantitative weighting and ranking of secondary criteria		
3	Additional assessment criteria	Qualitative weighting and ranking of additional criteria	Final degree of significance for geomorphosites (low, moderate, high) = ranked geomorphosites	
4	Ranked geomorphosites	Selection of potential geoconservation sites	Potential geoconservation sites	
5	Potential geoconservation sites	Application of legislation by authorities	Geoconservation sites	

2. – A FRAMEWORK FOR GEOCONSERVATION IN VORARLBERG

The first inventory of potential geoconservation sites in Vorarlberg was initiated by the nature museum in the city of Dornbirn (formerly called 'Vorarlberger Naturschau', now 'inatura'), in cooperation with the University of Amsterdam (UvA). It resulted in a first description of "valuable" geomorphosites (at the time called geotopes) for Vorarlberg, based on geomorphological information. It is electronically published on the internet (De Graaff *et alii*, 1988). The objective of the inventory was to provide geoconservation information to be considered in local planning. The set of evaluation criteria used in that study forms the building stones for the new ranking method.

At present, 35 field-based full-area covering geomorphological maps at scale 1:10,000 are available in the public domain, which cover approximately 750 km^2 of Vorarlberg (De Graaff *et alii*, 1987; Seijmonsbergen, 1992; Van Noord, 1996). More maps are available in manuscript format. These maps inform on the distribution of and relations between landforms of a certain appearance, size, origin, and age; they also include morphographic, morphometric, morphogenetic and morphochronological data (Klimaszewski, 1982; Seijmonsbergen, 1992). They form the basis for identifying, delineating, digitizing, coding and coloring of digital map units, i.e. the geomorphosites of our approach of assessing geoconservation potential. A digital geomorphosite map unit can be assessed for its significance on the basis of a set of objective criteria, which guarantees the reproducibility of results. After ranking as a potential geoconservation site it can be officially elevated by the authorities to the status of being protected, and be integrated in geoconservation. The necessary legislation for this step is available in the State of Vorarlberg.

GIS processing is an essential tool for the method of weighting, ranking and visualization of geomorphosites and potential geoconservation sites. It is anticipated that the GIS-based ranking maps will be integrated into the GIS of the State of Vorarlberg (VOGIS), which can be consulted through a web-based interface via the internet.

3. – A METHOD FOR IDENTIFICATION AND RANKING OF GEOMORPHOSITES IN VORARLBERG

Based on the legend of the detailed geomorphological maps at 1:10,000 scale available in Vorarlberg, a morphogenetic classification scheme was designed (tab. 2). The scheme is used to identify, delineate, and code basic digital geomorphosites from the geomorphological maps. Eight main geomorphological classes are recognized in the scheme (Glacial, Fluvial, Mass Movement, Periglacial, Organic, Karst, Aeolian, and Anthropogenic), to which 'Water' is added as a separate class. Twenty-four 'Landforms and Deposits' classes are defined at the most detailed level, each with a distinctive color and GIS code.

A protocol for weighting and ranking geomorphosites in Vorarlberg, consisting of a quantitative and a qualitative part, has been developed (tab. 1;

Tab. 2 – *Morphogenetic classification scheme of 'Processes' and 'Landforms and Deposits'.*
– Schema di classificazione morfogenetica per "processi" e "forme e depositi".

Processes	**Glacial** (1000)							**Fluvial** (2000)					**Mass Movement** (3000)				**Periglacial** (4000)		**Organic** (5000)	**Karst** (6000)		**Aeolian** (7000)	**Human** (8000)	**Water** (9000)
	Erosion (1100)		Accumulation (1200)					Erosion (2100)	Accumulation (2200)				Degradation (3100)		Accumulation (3200)		Disintegration (4100)	Accumulation (4200)	5100	Karst in carbonates (6100)	Karst in sulphates (6200)	Accumulation (7100)		9100
	(1110)		Subglacial (1210)	Ice marginal (1220)				(2110)	(2210)				(3110)		(3210)		(4110)	(4210)	(5110)	(6110)	(6210)	(7110)	(8110)	(9110)
Landforms and deposits	Glacially eroded bedrock	Glacially eroded Quaternary deposits	Landforms underlain by subglacial till s.l.	Landforms underlain by ablation till s.l.	Erosional landform	Landform underlain by fluvial deposits	Landform underlain by lake fill deposit	Incision: slope subject to fluvial erosion	Recent streambed	Fluvial terrace	Alluvial fan, debris fan	Landform underlain by lake fill deposits	Slope with deep seated mass movement	Slope with shallow mass movement	Landforms underlain by fall deposits	Landforms underlain by flow and/or slide deposits	Terrain subject to disintegration	Rock glacier	Landform underlain by peat deposits	Slope surface strongly affected by karst	Slope surface strongly affected by karst	Landform underlain by aeolian deposits	Graded or leveled land; pits, quarries etc.	Lake
GIS code	1111	1112	1211	1221	1222	1223	1224	2111	2211	2212	2213	2214	3111	3112	3211	3212	4111	4211	5111	6111	6211	7111	8111	9111

tab. 3A-C). The frame of reference for the assessment is the State of Vorarlberg, rather than the world, Europe, a country or a certain region within Vorarlberg (cf. EMBLETON, 1984). Each digital geomorphosite unit is assessed for its degree of significance according to primary and secondary evaluation criteria, which have been quantified in the attribute table using a weighting and ranking scheme. The weighting and ranking forms the basis for the selection of potential geoconservation sites. The assessment is best done by an experienced earth scientist who either has been working in the region or has access to sufficiently detailed geological and geomorphological maps and literature.

Worthwhile to refer to in this context are the following studies. CORATZA & GIUSTI (2005) proposed to assess scientific quality as a major factor, by weighting the expert knowledge factors, area, rareness, degree of conservation, exposure and added value. Some of these factors or qualities are difficult to 'measure', something which was also stressed by BRUSCHI & CENDRERO (2005). They proposed to use indicators that can be expressed on a continuous scale. The weighting system designed by SERRANO & GONZÁLEZ-TRUEBA (2005) is strongly based on geomorphological mapping and the use of three assessment scoring criteria: scientific value, cultural value and use value. Geomorphosite description cards are used to assess the importance of landform and processes. PRALONG (2005) used criteria and scoring tables that focused on scenic, scientific, cultural and economic values with the aim to assess tourist potential and other use of geomorphological sites.

We use four factors in the quantitative part of the weighting and ranking protocol: scientific relevance, frequency of occurrence, intactness and vulnerability. Various criteria are applied to weight the scientific relevance. A landform or deposit can be a 'textbook example' of a certain geomorphological process or of a group of processes and as such be scientifically relevant. A certain landform or deposit may bear value in the reconstruction of landscape history. The frequency of occurrence is a measure for the uniqueness of a landform or deposit. The more frequent a landform or deposit occurs, the less unique it is. It is context-dependent, i.e. it depends on the size of the study area.

A landform may be unique in a certain community, but not in the State of Vorarlberg. Scientific relevance and frequency of occurrence of digital geomorphosite units are the primary quantitative parameters in the weighting and ranking protocol (tab. 1; tab. 3A), of which the former is considered the most important. Scientific relevance is rated from no (0), low (1), some (3), high (5) to very high relevance (7). The frequency of occurrence can be rated as: high (1), normal (2) or low frequency (3). Combination of scientific relevance and frequency of occurrence results in a matrix (tab. 3A), of which the cells are ranked into 'low rank', 'medium rank' and 'high rank', according to the combined scores in the table.

Intactness and vulnerability are secondary weighting and ranking parameters. Intactness refers to the degree in which a landform or deposit has already been destroyed by human activity. It does not refer to an 'ideal' or 'textbook' condition of a landform or deposit. Vulnerability refers to the effect human activity will have on a landform or deposit. Questions to be answered are: is human activity likely to adversely affect a potential geomorphosite? Will it be partly or completely destroyed even at low levels of human activity? The adverse effect of human activity on geomorphosites varies, certain ones are likely to be completely destroyed by small-scale human activity (i.e. high vulnerability), whereas other ones will still preserve their essential nature at larger scale activity (i.e. low vulnerability). The scores for intactness (undisturbed, score = 5; <10% disturbed, score = 3; 10-30% disturbed, score = 1; >30% disturbed, score = 0) and vulnerability (low, score = 1; medium, score = 3; high, score = 5) are combined in a matrix and are ranked in three classes (tab. 3B). The geomorphosites which are classified as 'low rank' in the combination of scientific relevance and frequency of occurrence (tab. 3B) are not included in the weighting and ranking of the secondary factors, for the sake of efficiency.

The matrices of table 3A and table 3B are then combined into a new matrix. The geomorphosites with scores from 7 through 10 have a 'low degree of significance' and do not deserve specific attention. The geomorphosites with scores from 11 through 15 are considered as having a 'moderately degree of significance' and deserve attention. A score of 16 and higher indicates a 'high degree of significance' and deserve prime attention in terms of becoming a potential geoconservation site. The weighting and ranking of primary and secondary factors has been automated in GIS.

Decision-making usually requires further characterization and assessment of significance of valuable geomorphosites identified in the forementioned protocol. Additional descriptive factors provide additional characterization. These are *status of protection*, *scenery*, *land use*, and *additional criteria*. The status of protection is indicated when an area already has a specific status of protection. This information can be obtained from local or regional authorities. Scenery refers to visual appreciation of a landform – which is rather subjective. An additional complication is that a certain appreciation is usually for a group of landforms, in combination with other fragmented parameters, such as vegetation and pasture. Nevertheless, it is considered useful to include information on the scenic value of individual geomorphosites in the attribute table. The scenic value is differentiated in low (1), medium (2) and high value (3). The land use classes differentiated in Vorarlberg are: deciduous forest, coniferous forest, mixed forest, grassland, bare land, urban land and agricultural land. Additional criteria, such as hydrological features and soil development, can be entered as text in the attribute table.

The additional descriptive criteria capture information which may lead to a revision of the degree of significance of a given geomorphosite as determined in the quantitative part of the weighting and ranking protocol. In most cases the revision will be an upgrade of the geomorphosite to a higher rank of significance. If so, the new ranking will be entered in the attribute table as the final ranking. This is illustrated in the example of the Lech area below. Once the weighting and ranking is completed, a selection of geomorphosites can be made to become potential geoconservation sites.

The GIS geo-database contains files to which hyperlinks can be made from the various maps or tables (compare CARTON *et alii,* 2005). A clickable

Tab. 3 – *Weighting and ranking scheme used for assigning the degree of significance to geomorphosites.*
– Schema dei pesi utilizzati per assegnare un valore ai geomorfositi.

A: Primary factor weighting and ranking			**Scientific relevance**				
			no	**low**	**some**	**high**	**very high**
			0	1	3	5	7
Frequency	**high**	1	1	2	4	6	8
	normal	2	2	3	5	7	9
	low	3	3	4	6	8	10

	1-4 low rank		6-7 medium rank		8-10 high rank

B: Secondary factor weighting and ranking			**Intactness**			
			>30%	**10-30%**	**<10%**	**Intact**
			0	1	3	5
Vulnerability	**low**	1	1	2	4	6
	medium	3	3	4	6	8
	high	5	5	6	8	10

	1-4 low rank		6-7 medium rank		8-10 high rank

C: Final weighting and ranking		**Medium and high primary factors**				
		6	7	8	9	10
Secondary factors	1	7	8	9	10	11
	2	8	9	10	11	12
	3	9	10	11	12	13
	4	10	11	12	13	14
	5	11	12	13	14	15
	6	12	13	14	15	16
	8	14	15	16	17	18
	10	16	17	18	19	20

	7-10 low degree of significance		11-15 moderate degree of significance		16-20 high degree of significance

point file may bring up a photo, whereas a hyperlinked text document may be opened upon clicking the geomorphosite polygon. This technique also allows the capturing of special geomorphological features, such as small exposures, which are 'overlooked' in the polygon-based evaluation. GIS presentation and visualization of geomorphosites allows easy interactive access for the non-scientific public in a web based environment.

In the next sections the application of the method is illustrated by two case studies.

4. – EXAMPLES

4.1. – The Bürserberg area

The first area is situated near the village of Bürserberg (fig. 1) and is composed of landforms and deposits which reflect the deglaciation phases of the Würm glaciation. The interactions that existed between the trunk Ill glacier and the tributary Brandner glacier have been locally preserved in ice-marginal fluvial and deltaic terraces and moraine ridges which indicate invasion of the larger Ill glacier into the lower reaches of the smaller Brandner Valley. Limestone and marl of the East Alpine Lechtal nappe (Muschelkalk, Arlbergschichten and Partnachschiefer Formations, Oberhauser, 1998) underlie the Quaternary deposits and are locally exposed as glacially eroded ridges. Postglacial denudation and erosion have degraded the glacial s.l. landscape to some extent. Apart from agriculture and forestry, human influence is restricted to an abandoned gravel pit (excavation of sand and gravel from ice-marginal deposits) and to some hamlets and roads on the level parts of the ice-marginal terrace remnants. Refer to Simons (1985), Keller (1988), De Graaff & Seijmonsbergen (1993) and Van Noord (1996) for more details on the geomorphological history of these surroundings. The area has no current protection status. Due to local population pressure, especially recreation, the Late Glacial landscape elements are exposed to further disturbances.

The method described in the previous sections has been applied and the results are depicted in figure 2. Spatial information is presented in 6 layers. The basic layer is formed by the digital geomorphological map, whereas the spatial distribution of the primary (scientific relevance and frequency of occurrence) and secondary (intactness and vulnerability) weighting and ranking factors is displayed as overlays. The final step of assessment, i.e. degree of significance, is the combination of the four factors. It can be displayed separately or in combination with other layers. The photos are from the GIS database and show scenery (A), a local karst depression (B) and a small, but informative roadside exposure in ice-marginal deposits (C).

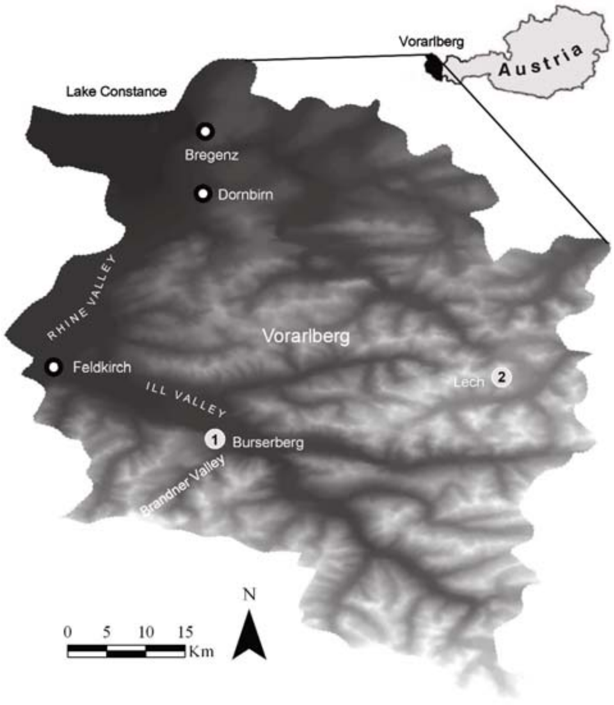

Fig. 1 – Location of the two example areas in Vorarlberg, western Austria. – *Inquadramento geografico delle due aree campione in Vorarlberg, Austria occidentale.*

4.2. – The Lech area

The second area is located between the villages of Schröcken and Lech in the Lechquellen Mountains of eastern Vorarlberg, on the divide between the catchments of the rivers Bregenzerach and Lech, at altitudes above 1500 m (fig. 1). Bedrock is formed by the formations of the East Alpine 'Kalkalpen' of the Allgäu and Lechtal nappes (Oberhauser, 1998). Geologically speaking, the area is significant because of the occurrence of tectonic klippes and a tectonic half-window, and because of outcrops of the Upper Cretaceous Branderfleck Formation, which are rare in Vorarlberg (Von Eynatten, 1996). From a geomorphological point of view, the area is remarkable because of its rather 'open' topography in a high-alpine setting. Situated between the peaks of the Juppenspitze-Mohnenfluh and Auenfelder Horn-Karhorn, the area is characterized by a wide valley floor and a plateau-like high with a field of glacially moulded humps, which are underlain by the Branderfleck Formation. Such morphology usually occurs at lower altitudes. In figure 3 an overview of the Lech area is seen. An inventory of the geomorphology of the area was made in 2002 (De Graaff *et alii*, 2003). Using the criteria of De Graaff *et alii* (1988), landforms with significant geoconservation value were then identified at three levels: individual landforms; groups of landforms; and the area as a whole.

A part of the original study area has been selected to show how a first ranking of significance based on the quantitative weighting and ranking criteria is modified by including one qualitative parameter (i.e. bedrock geology). For the sake of simplicity only scientific relevance and frequency of occurrence have been used for the quantitative ranking. The method is visualized in a series of 6 maps (fig. 4).

The map of figure 4A shows the digital geomorphological map with geomorphosite boundaries and the original analogue geomorphological field map as a backdrop image. Refer to De Graaff *et alii* (1987) for the legend of the geomorphological field map. A simple geological map (modified from De Graaff *et alii*, 2003) is shown

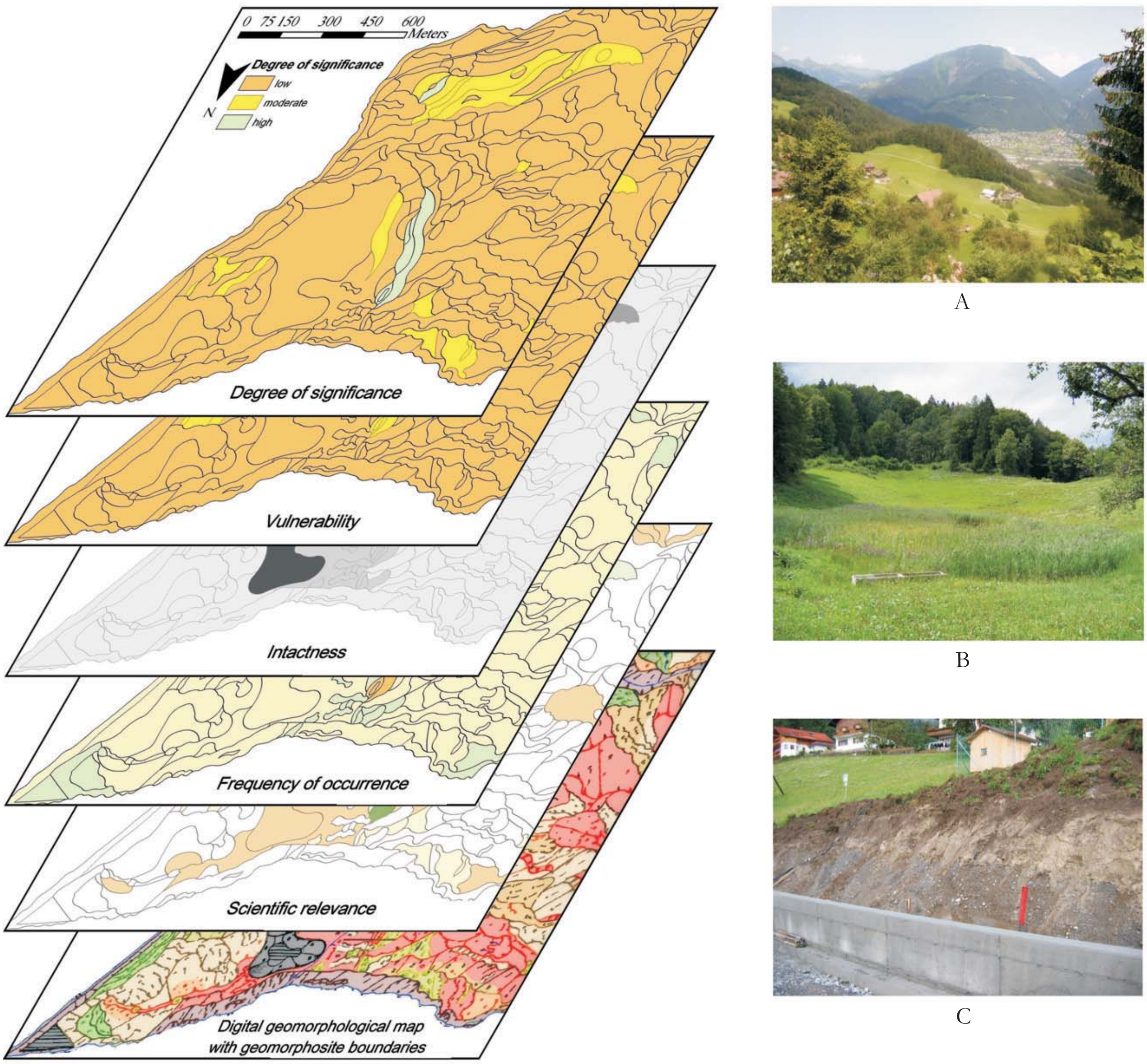

Fig. 2 – Representation of GIS layers depicting the spatial distribution of landforms with geomorphosite boundaries, the weighting and ranking factors and the final degree of significance for the Bürserberg area. Three examples of terrain situations are shown: A. Scenic view of the Bürserberg area (centre of photo), B. Karst depression and C. Exposure in ice-marginal deposits.

– Rappresentazione dei livelli informativi della distribuzione spaziale delle forme con indicazione dei confini dei geomorfositi, dei criteri utilizzati per la valutazione e del valore finale per l'area di Bürserberg. Vengono illustrati tre esempi differenti: A. Vista panoramica dell'area di Bürserberg (al centro nella fotografia), B. depressione carsica e C. Affioramento di deposti glaciali marginali.

Fig. 3 – View to the north of the area near Lech. The area of figure 4 is in the centre-foreground and centre-left of the photo. – *Panoramica dell'area vicino a Lech. L'area illustrata in figura 4 corrisponde alla zona in primo piano al centro e a sinistra rappresentata in fotografia.*

in figure 4B. Scientific relevance and frequency of occurrence are shown in figures 4C and 4D, respectively. Figure 4E shows the results of the quantitative weighting and ranking, i.e. degree of significance. As mentioned before, the Branderfleck Formation (see figure 4B) is rare in Vorarlberg. Landforms underlain by this formation, therefore, gain significance. This has been implemented by upgrading the relevant geomorphosites one rank, i.e. the geomorphosites of 'low degree of significance' are included in the 'medium degree of significance', those of 'medium degree of significance' are included in the 'high degree of significance', and the 'high degree of significance' geomorphosites remain 'high degree of significance' (fig. 4F).

Grouping of geomorphosites is also illustrated in figure 4. A group of adjoining geomorphosites has been hatched in figure 4F. Together they represent a highly diverse geomorphological association in a very small area. The grouping has been done by the expert; tests are ongoing to automate the grouping procedure in GIS. The geomorphosites within the group are all upgraded to the rank of the highest-ranking individual geomorphosite of the association. This is, however, not shown in figure 4F, for the sake of clarity.

5. – DISCUSSION AND CONCLUSIONS

The method here presented for the identification and assessment of geomorphosites has been developed for Vorarlberg. Evaluation at a degree of detail necessary for small-scale planning purposes is possible due to the availability of geomorphological maps at scale 1:10,000. It is concluded that this method is also applicable at larger scales by making groups or associations of geomorphosites.

Grouping of geomorphosites may also be required for reasons of efficiency. Applying the method at scale 1:10,000 to large areas is, for obvious reasons, time-consuming. The method as presented here is considered robust; further work focuses, among other things, on improving efficiency. Experiences with the selection of boundaries indicate that some generalizations can already be made during the process of digitization: adjoining landforms and deposits of similar nature can be grouped. Tests are being done to see if the weighting and ranking of factors such as frequency of occurrence and intactness can be automated in GIS, e.g. by using buffering techniques and by using geodiversity indicators. It is considered logical that expert knowledge will always remain a necessary input for the selection of boundaries and for assessing the scientific relevance of geomorphosites.

The morphogenetic classification scheme of landforms and deposits (tab. 2) is a 'box of bricks'. New geomorphologic features can be added. It may contribute to fill the 'lack of classification systems for landforms' already noted by Gray (2004).

Text descriptions and photos of terrain situations have been hyperlinked in the GIS to the digital maps. A further point of interest is to link the geoconservation geodatabase to external sources of digital information or hyperlinked documents.

We believe that the here presented method is applicable to other mountainous areas. We also believe that in areas without detailed geomorpholog-

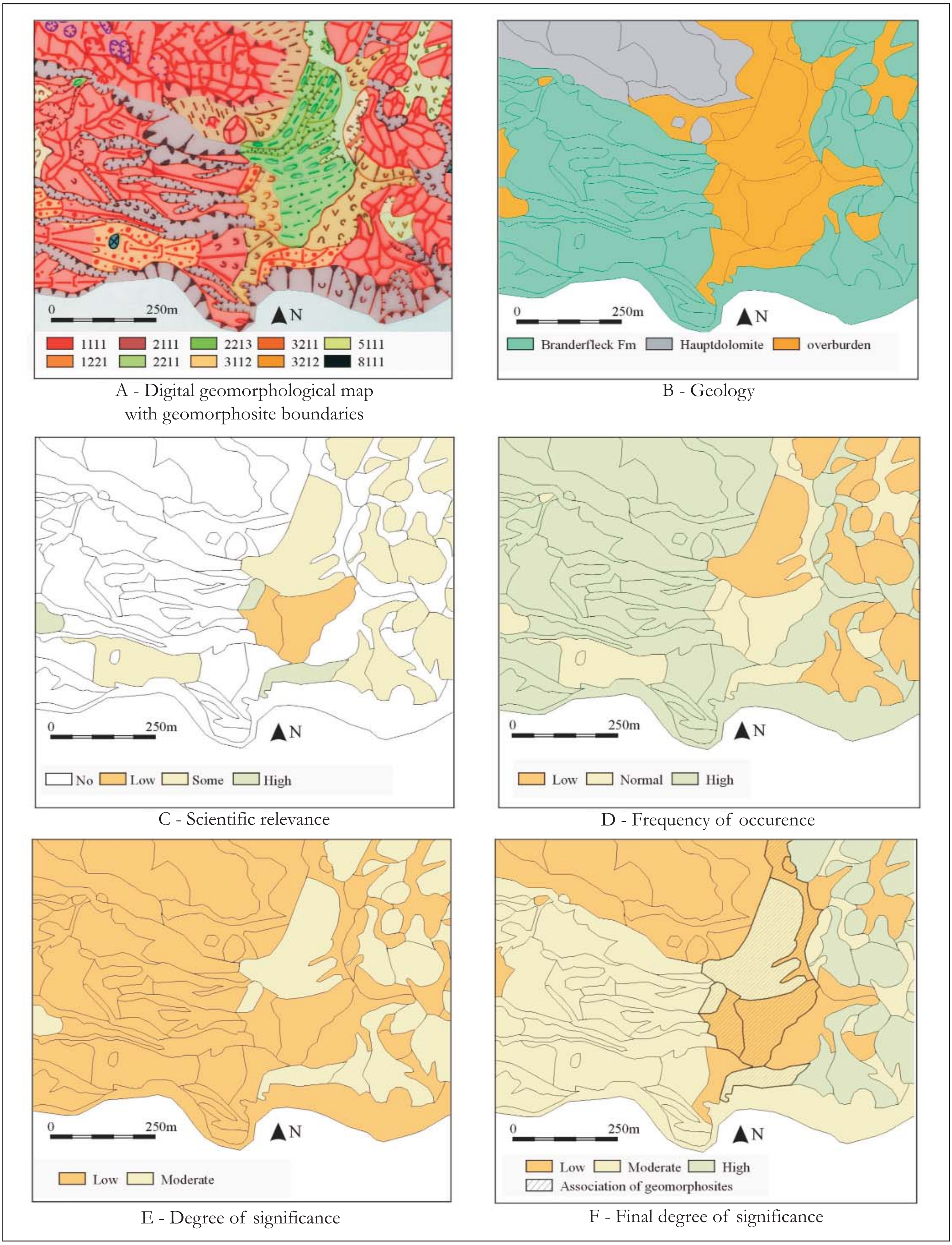

Fig. 4 – Representation of GIS layers depicting the sequence from identification of geomorphosite boundaries to the assessment of their final degree of significance. See text for further explanation.
– *Rappresentazione dei livelli tematici che illustrano la sequenza dall'identificazione dei limiti del geomorfosito fino alla valutazione del suo valore. Confronta il testo per ulteriori spiegazioni.*

ical maps expert knowledge can be applied to extract the relevant information from other (scale) available maps, such as geological maps, soil maps or geomorphological overview maps and additional information such as excursion guides.

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Geodiversity assessment in a rural landscape: Tiermes-Caracena area (Soria, Spain)

Valutazione della geodiversità del paesaggio rurale: l'area di Tiermes-Caracena (Soria, Spagna)

SERRANO E. (*), RUIZ-FLAÑO P. (*), ARROYO P. (*)

ABSTRACT – In this paper an index is developed to assess geodiversity, which can be applied to territories with different characteristics. The first step is to make a geomorphological map and to delimit the morphological units where the geodiversity index is to be calculated. The relationship between the physical elements, the surface and roughness are established by means of the index. The physical elements, taken from the geomorphological, geological and soils map, field work and the bibliography, are geological structures, morphostructures, erosional and accumulation features, morphogenetic systems, erosional processes, micro-landforms, soils and hydrological elements. Roughness is calculated from the slope map. Five types of geodiversity enable us to classify the units. This method is applied to a rural landscape of southern Duero basin (Soria Province, Spain) and a map of geodiversity is made.

KEY WORDS: Geodiversity assessment; Geoconservation; Geomorphology; Tiermes; Spain.

RIASSUNTO – In questo articolo viene presentata la metodologia utilizzata per ottenere un indice di geodiversità applicabile a territori con differenti caratteristiche. La prima fase consiste nella realizzazione di un carta geomorfologica e nella delimitazione delle unità moorfologiche per le quali viene calcolato l'indice di geodiversità, che mette in relazione gli elementi fisici, la superificie e la rugosità dell'unità. Gli elementi fisici, desunti dalle carte geomorfologiche, geologiche, pedologiche, da rilevamenti di campagna e da indagine bibliografiche, sono: strutture geologiche, morfostrutture, forme di erosione e di accumulo, sistemi morfogenetici, processi attivi, microforme, suoli ed elementi idrologici. La rugosità viene calcolata a partire dalla carta del pendio. Sono stati individuati cinque diversi gradi di geodiversità che consentono di classificare le diverse unità morfologiche. Il metodo qui presentato è stato applicato al paesaggio rurale del settore meridionale del bacino del Duero (Provincia di Soria, Spagna) ed è stata realizzata una carta delle geodiverità.

PAOLE CHIAVE: Valutazione della geodiversità; Geoconservazione; Geomorfologia; Tiernmes; Spagna.

1. – INTRODUCTION

Owing to its recent invention the term geodiversity is found in few references but within them it has a double viewpoint - theoretical and applied. From the theoretical point of view the term geodiversity began as a synonym of "abiotic diversity", to differentiate it from biological diversity or biodiversity (DUFF, 1994). The first definitions of the term identify geodiversity with "geological diversity", and it is still used frequently at the present-day (DIXON, 1996; EBERHARD, 1997; JOHANSSON, 2000; NIETO, 2001). Later the concept gained a wider meaning and recently it has been defined by GRAY (2004) as *"the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems"*. KOZLOWSKI (2004) widened the concept to include the effect of human activity on geodiversity at the same level as natural processes. In GRAY's (2004) and PIACENTE's (2005) works it is possible to find wider definitions of geodiversity.

As it is linked to other very recent concepts such as geoconservation and geomorphosites, the applied aspect of geodiversity has been evident from the beginning. All authors are in agreement on the need to safeguard geodiversity, so it has become a decision tool for planning and management, and also for education. KOZLOWSKI (2004) gives good reasons for its conservation in an important paper concerned with the development and increase of biodiversity. For SERRANO (2002), geodiversity and biodiversity are the constituents

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of Natural Diversity, and are both necessary elements in the territorial assessment of Natural Protected Areas. By the same token, geodiversity is the main aspect and aim of geoconservation (Gray, 2004). Undoubtedly its importance will increase in the future due to its practical usefulness and also because of its ease of comprehension for technicians and territory managers. This resource makes it easier to use and relate different scientific disciplines (geography, geology, geomorphology, pedology, hydrology or topography).

The effectiveness of its incorporation into territory management depends on the availability of useful methods to estimate geodiversity. Theoretical thinking has not been accompanied by a methodological effort to establish geodiversity assessment methods. There has recently been a great development of assessment methods for geomorphosites (Panizza, 1992; Panizza, 2001; Panizza & Piacente, 1993; Serrano & González-Trueba, 2005), but very little has been done for geodiversity assessment (Serrano & Ruiz-Flaño, 2007). Gray (2004), for example, suggests the possibility of using spatial geodiversity measurements and geoindicators but he does not indicate how to do so. Kozlowski (2004) has applied a qualitative scale of five sorts of geodiversity in Poland at a regional level and proposed its application to different states of the European Union.

2. – OBJECTIVES AND LOCATION OF STUDY SITE

The aim of this work is to develop a method to estimate, as objectively as possible, the geodiversity of a territory, and to quantify the geodiversity of different units to permit comparison both between units of a territory and between different geographical areas. Geodiversity is assessed by land units and work is applied on a local scale, in this case to a rural landscape of the southern area of the region of Castile and Leon to provide a geodiversity map that will be of use as a tool for planning and management.

The study area is located in the foothills of the Spanish Central System, on the south side of the Duero basin. The Tiermes-Caracena area is a marginal territory defined by heavy depopulation, an ageing population and land use abandonment without a functional replacement by other land uses (tourism, industry, and so on). In the study area there are 24 villages containing 700 inhabitants (population density of 2,3 inhab/km^2). The area has an important cultural heritage (Roman city of Tiermes, Medieval villages and castles; Romanesque churches, Islamic remains) together with the natural value of the landscape. It is a rural landscape characterised by the alternation of broad valleys and highlands crossed by fluvial gorges (fig. 1).

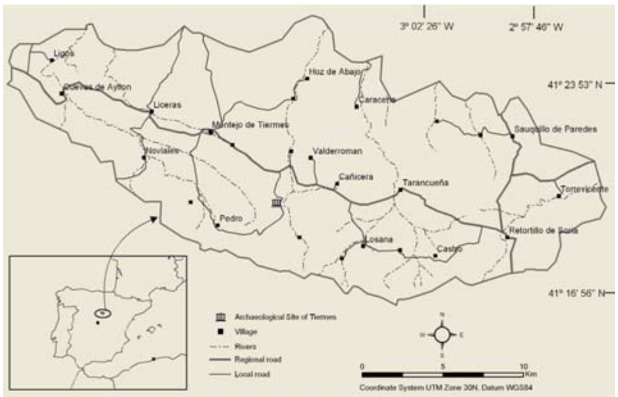

Fig. 1 – Location of Tiermes-Caracena area.
– *Inquadramento dell'area di Tiermes-Caracena.*

3. – METHODOLOGY

The procedure, used to establish the degree of geodiversity, is based on delimitation by geomorphological units and an inventory of the physical elements of each unit by means of the following:

- Analysis of abiotic elements: Study of geological, geomorphological, hydrological and pedological elements of the study area and drawing up a detailed geomorphological map.
- Establishment of units: The geomorphological units are the basis for the assessment of geodiversity and are delimited from the geomorphological map, aerial photography and field work. An inventory of the main physical characteristics of the units is made and summarised on cards (tab. 1).
- Assessment of units: an index which relates the variety of physical elements with roughness and surface of the units is created by assessing geodiversity. We began from the assumption that if there are more elements, geodiversity is greater, and the greater the roughness the greater will also be the micro and topo-climate complexity. Thus, the elements and roughness affect the increase in geodiversity. Accordingly, the following formula is applied:

$$Gd = Eg\, R / \ln S$$

Gd = Geodiversity index.

Eg = Number of different physical elements (geological, geomorphologic, hydrological and pedological) of the units;

R = Coefficient of roughness of the unit;

S = Surface area of the unit (km^2).

Tab. 1 – *Example of unit card for inventory of abiotic elements.*
– Esempio di scheda per l'inventario degli elementi abiotici.

<table>
<tr><td colspan="2">Name:
Liceras-Retortillo Depression</td><td colspan="2">Coordenates: 41º 18´N
3º 7´ W</td><td>Altitude:
Max.:1250</td></tr>
<tr><td colspan="2">Number: 1.a</td><td colspan="2">Surface: 73 km²</td><td>Roughness: 1.2</td></tr>
<tr><td colspan="5">**ELEMENTS**</td></tr>
<tr><td colspan="3">Lithology</td><td colspan="2">- Conglomerate - Sandstone
- mudstone - Limestone
- Marls - Dolomites</td></tr>
<tr><td colspan="3">Geological structures</td><td colspan="2">- Monocline
- Faults with relief representativeness
- Synclines</td></tr>
<tr><td colspan="3">Morphostructures</td><td colspan="2">- Monocline ridges: backs, frontal scarp
on Jurassic limestone, frontal scarp
on Triassic conglomerates and sandstones
- Orthocline depression</td></tr>
<tr><td colspan="3" rowspan="2">Morphogenetic system</td><td>**ACTIVES**</td><td>**RELICTS**</td></tr>
<tr><td>- Fluvial
- Slopes
- Weathering.</td><td>- Slopes
- Fluvial
- Weathering</td></tr>
<tr><td rowspan="3">Macro and
meso landforms</td><td colspan="2">Erosional landforms</td><td>- Rills, badlands
- Landslides
- Escarpements</td><td>- V-shaped valleys
- Flat bottom valleys
-Torrential Downcutting
- Palaeovalleys</td></tr>
<tr><td colspan="2">Acummulation landforms</td><td>- Debris talus
- Rock fall
acummulations</td><td>- Fluvial terraces
- Holocene infill
- Glacis
- Aluvial fans</td></tr>
<tr><td colspan="2">Anthropic landforms</td><td>--</td><td>--</td></tr>
<tr><td colspan="3">Micro-landforms</td><td>--</td><td>--</td></tr>
<tr><td colspan="2">Present-day processes</td><td colspan="3">- Soil erosion and Badlands - Rock fall
- Torrential streams - Landslide</td></tr>
<tr><td colspan="2">Represented Ages</td><td colspan="3">-Triassic -Jurassic - Pleistocene - Holocene</td></tr>
<tr><td colspan="2">Hydrographical elements</td><td colspan="3">- Rivers - Sinkhole - Torrents</td></tr>
<tr><td colspan="2">Soils</td><td colspan="3">- Inceptisol - Entisol</td></tr>
</table>

The parameter Eg is calculated from a recount of physical elements such as lithology, geological structures, geomorphology, morphostructures, erosional landforms and the presence of micro-landforms of interest. This data was obtained from the geomorphological, geological and soils maps (tab. 2). Only the different elements are counted and any repetitions are not taken into account. In the same way, only the processes that are not included in any landform are considered. Finally, the presence of hydrological and pedological elements are also included.

The topography and micro and topo-climate variations are represented by the roughness coefficient. Its incorporation is supported by the important role of both parameters on the energy flows (exposure to sunlight, humidity) and material flows (water, sediments on the slopes), and, in consequence, on the diversity and distribution of landforms and processes. It is an integrative parameter introduced to take account of the smaller variations and the complex relations between the elements and processes of the abiotic natural system. The roughness value is established from the dominant slopes in each unit. We have made a map of slopes using five intervals. The roughness coefficient of each unit corresponds to the dominant interval in the unit, according to the following scale.

roughness values	1	2	3	4	5
Slopes °	0-5	6-15	16-25	26-50	>50

If there are two dominant slope intervals very different to the other groups, a roughness value proportional to the surface area occupied by each interval is allotted.

Once the algorithm is applied the geodiversity of the unit is obtained. The following thresholds have been established:

Geodiversity	Very Low	Low	Medium	High	Very high
Values	<15	15-25	25-35	35-45	>45

4. – THE GEODIVERSITY IN TIERMES-CARACENA AREA: RESULTS

The Tiermes-Caracena area is characterised by folded relief formed by conglomerates, sandstones and clay of the Triassic Age, limestones, sandstones and marbles of the Jurassic and Cretaceous Ages, and conglomerates and sandstones of the Miocene Age. The area has extended anticline folds, where the Triassic rocks outcrop, and smaller folds affecting the Jurassic and Cretaceous cover.

The structural organization has formed a structural relief to the south characterised by the existence of "combes" next to the Sierra de Pela, with mixed ortocline valleys and monocline ridges. To the north a wide planation surface forms the extended highlands with fluvial palaeovalleys and karst features (Birot & Solé, 1954; García de la Vega, 2001; Rodríguez & Pérez, 2005). The highlands are divided by fluvial gorges, incised to 50-100 metres, which drain into the structural valleys and "combes". In the wider valleys shaped on soft rocks, two families of glacis and terraces have been formed (fig. 2).

In the study site 14 geomorphological units have been defined with different sizes and properties (figure 3 and table 3). Compared with the wide planation surface, with almost 200 km^2 of surface, there are units, like Pozo Moreno Gorge, of 1 km^2 of surface. This surface area has been deemed the minimum size for a unit in our scale of work. Seven units are fluvial valleys and several of them, Caracena and Talegones Gorges for example, are sharply incised on highlands. In these units the roughness reaches values as much as or even higher than 3. The Sierra de Pela has the steepest slopes, with a roughness coefficient value of 3.3. The least correspond, logically, to the planation surface and the ortocline valleys, and in second place the valleys formed in the pericline fold, which have a roughness coefficient value of 1. The other fluvial valleys and gorges have intermediate values.

The number of different elements hardly varies between units. The minimum values are located in the valleys, with values between 8 in the Madruédano Valley and 18 in the Talegones Gorge. The other units have values of between 20 and 42. The maximum values have been observed in the Liceras Retortillo depression (42) and in the Caracenas Gorge (30).

Figure 4 and table 3 show the geodiversity values calculated for the Tiermes-Caracena area. In general terms, geodiversity is low. In 75% of the surface (three units) geodiversity is very low due to the low values of slopes and wide surfaces. Five units (10,4% of the surface) have low values related to medium roughness and lesser surfaces.

Medium values are found in four units (9,7% of the surface). They are related to the high roughness of fluvial valleys and the range Sierra de Pela. Only one unit has a high value, the Caracena Gorge, where the diversity of constituent elements and roughness is higher. Only in one unit are very high values reached, which is more due to the small surface (hardly 0,3% of the study area) than by his abiotic constituents.

Tab. 2 – *Elements used to calculate the geodiversity index.*
– Elementi utilizzati per calcolare l'indice di geodiversità.

Geology	Lithology	Structure	
Geomorphology	Morphostrucures	Morphogenetic systems	Processes
Hydrology	Erosional landforms	Accumulation landforms	Micro-landforms
Soils	Water states	Hydrological elements	
	Orders	Sub-orders	

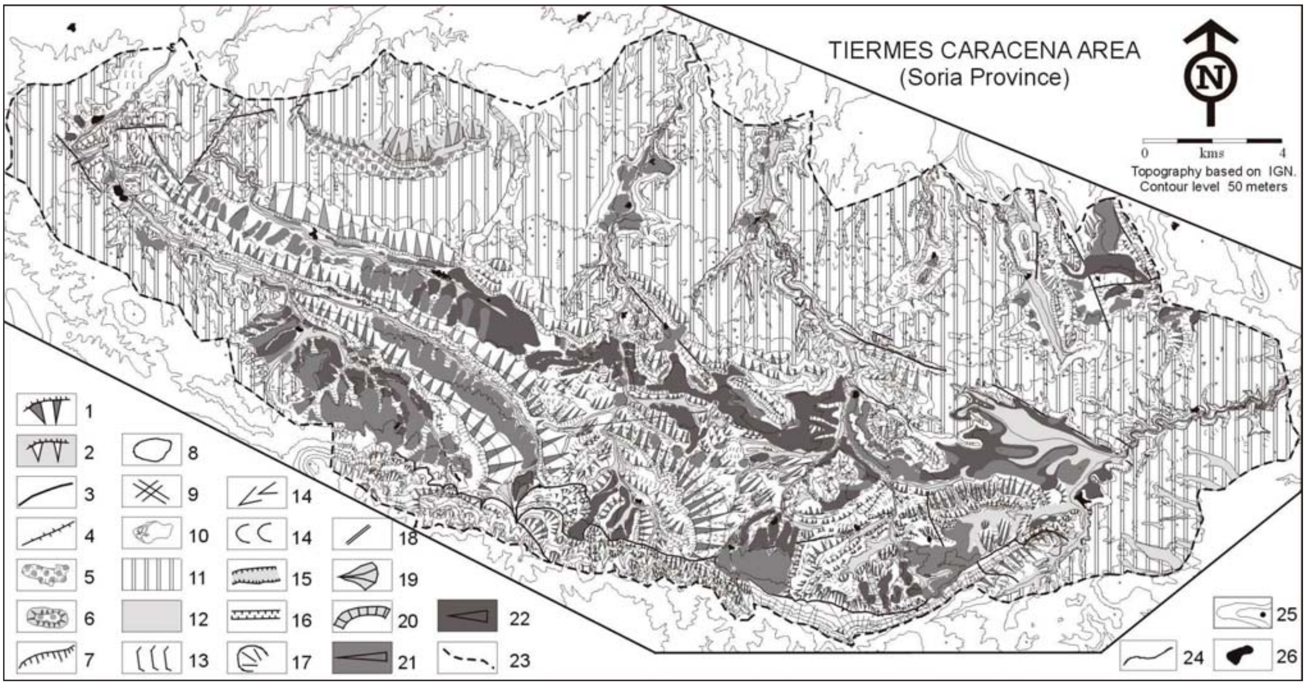

Fig. 2 – Geomorphological scketch of Tiermes-Caracena area. Legend: 1) Monocline ridge. 2) Monocline ridge on sandstones. 3) Faults. 4) Hog backs. 5) Orthocline valley. 6) Structural valley, Combe. 7) Structural scarp. 8) Dolines. 9) Karren. 10) Tufa. 11) Planation surface. 12) Fluvial terraces. 13) Fluvial flat bottom valley. 14) V-shaped fluvial valley. 15) Fluvial gorge. 16) Fluvial incision. 17) Erosional head. 18) Hanging valley. 19) Alluvial fan. 20) Fluvial palaeovalley. 21) Glacis, level 1. 22) Glacis, level 2. 23) Limit of study area. 24) River. 25) Contour level and peaks. 26) Villages.
— Schema geomorfologico dell'area di Tiermes-Caracena: Legenda: 1. Monoclinale nell'arenaria. 3) Faglie. 4) Hog backs. 5) Valle ortoclinale. 6) Valle strutturale, Combe. 7) Scarpata strutturale. 8) Doline. 9) Karren. 10) Tufi. 11) Superficie di pedeplanazione. 12) Terrazzi fluviali. 13) Valle fluviale a fondo piatto. 14) Valle fluviale con profilo a V. 15) Forra torrentizia. 16) Incisione fluviale. 17) Area in erosione. 18) Valle sospesa. 19) Cono alluvionale. 20) Paleovalle fluviale. 21) Glacis, livello 1. 22) Glacis, livello 2. 23) Confini dell'area di studio. 24) Fiume. 25) Curve di livello e rilievi. 26) Centri abitati.

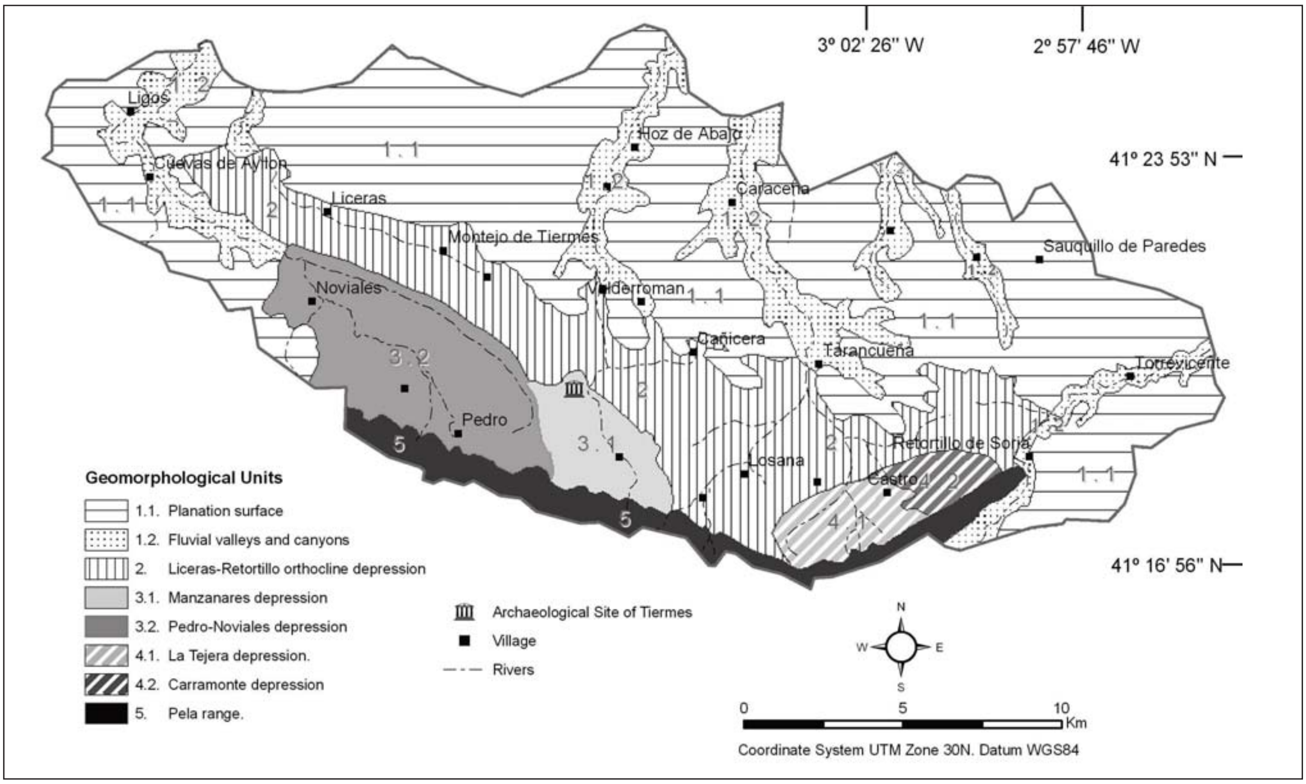

Fig. 3 – Geomorphological units of Tiermes-Caracena area.
— Unità geomorfologiche dell'area di Tiermes-Caracena.

Tab. 3 – *Geomorphological units and geodiversity index.*
– Unità geomorfologiche e indice di geodiversità.

Units	Unit name	Elements number	Surface (km2)	Roughness	Geodiversity Index	Geodiversity Value
1.1	Planation surface	23	184	1	4.4	Very low
1.2.1	Pedro Gorge	22	12	2.5	22.1	Low
1.2.2	Pozo Moreno Gorge	18	1	2.7	48.6	Very high
1.2.3	Tielmes Gorge	24	9	2.7	29.5	Middle
1.2.4	Caracena Gorge	30	15	3.2	35.4	High
1.2.5	Madruédano Valley	8	4	2.6	15	Low
1.2.6	Modamio Valley	14	3	2.5	31.8	Middle
1.2.7	Talegones Gorge	18	7	3	27.7	Middle
2	Liceras-Retortillo Depression	42	73	1.2	11.7	Very low
3.1	Pericline flank of Manzanares	24	11	2	20	Low
3.2	Pedro-Noviales Depression	26	32	1.7	12.7	Very low
4.1	Tejera Depression	20	8	1.8	17.3	Low
4.2	Carramonte Depression	20	5	1.5	18.6	Low
5	Pela Range	24	18	3.3	27.4	Middle

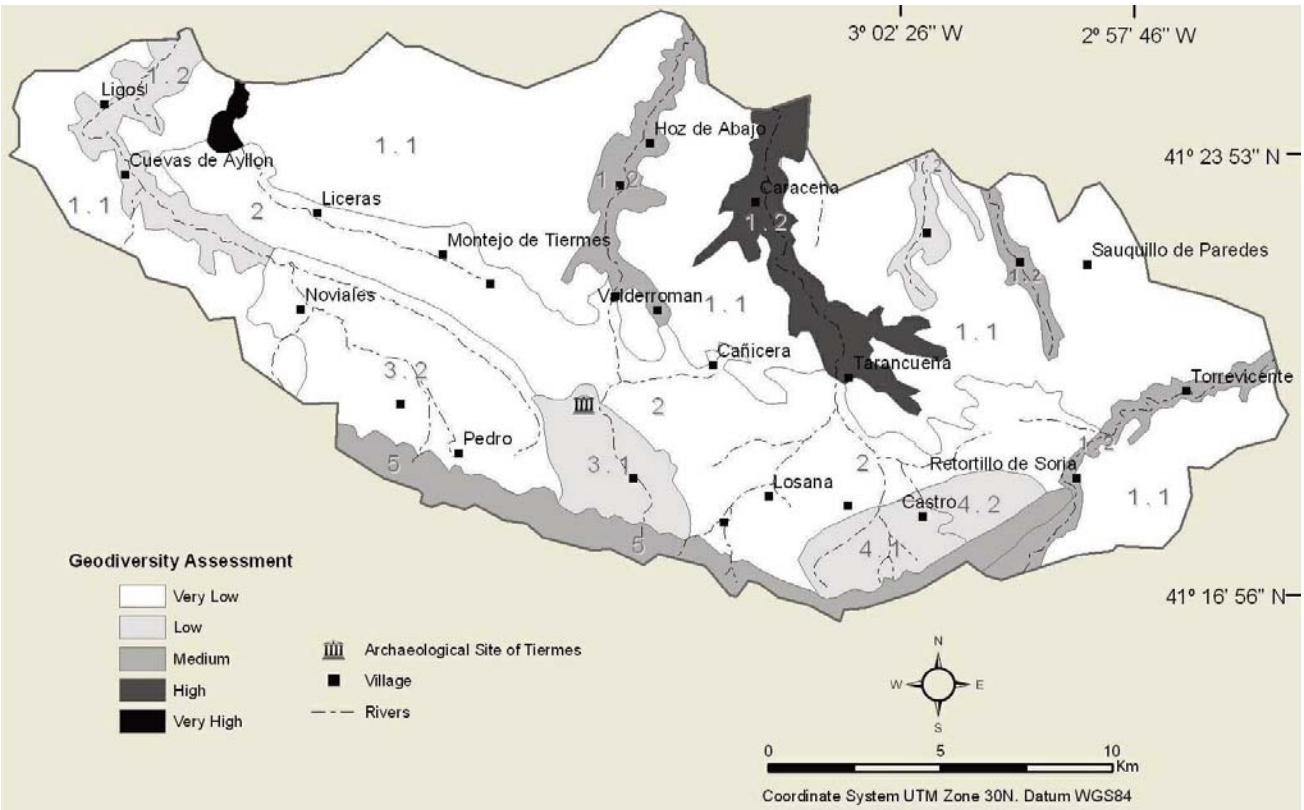

Fig. 4 – Geodiversity map of Tiermes-Caracena area.
— Carta della Geodiversità dell'area di Tiermes-Caracena.

5. – CONCLUSIONS

The assessment of geodiversity developed in this work has enabled us to establish five different classes from very high to very low. The methods used compound the physical elements (geology, landforms and processes, morphogenetic systems, hydrology and soils) with the roughness and surface area in a predetermined unit. The method can be applied to geomorphological or landscape units.

In the Tiermes-Caracena area the structural landforms, planation surface, and the fluvial and slope systems are dominant and have generated limited diversity of landforms, processes and soils. Once the index applied, it became clear that more than 75% of the territory had very low geodiversity, with wide surfaces and low numbers of elements and roughness. The results obtained reflect the internal homogeneity of the study area with low geodiversity but with areas (gorges and valleys) with higher values. All of them are close to the reality.

The index is easy to apply and enables comparisons to be made, on the same scale, between different territories. Nevertheless, the method must be confirmed in areas with more internal differences and until this is done the method must be used with caution. Some improvements should be included in further applications. We must point out the necessity to improve the calculation of roughness of units and of the relationships between surfaces and slopes. It is recognised that the index cannot be applied to small size units. Finally, the incorporation of other elements that increase geodiversity must be improved, such as palaeontology or micro-landforms. Regarding the latter, only its presence or absence has been considered in this work with a collective value, but in the future and in other areas or on other scales, it may be considered with individual values.

A quantitative approach to the assessment of geodiversity has been described, which may, in future, be used together with cultural, ethnographic and biological assessments by planners and managers for the better conservation of abiotic and geomorphologic values of the territory. The map of geodiversity, together with the indices, creates a useful tool for management.

Acknowledgements

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Assessment and promotion of cultural geomorphosites in the Trient Valley (Switzerland)

Valutazione e promozione di geomorfositi culturali nella Valle del Trient (Svizzera)

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ABSTRACT – Within the framework of three cultural projects developed in the Trient valley (Switzerland) – the "Cultural Routes in Switzerland" (ViaStoria), the Alposcope, and Vallis Triensis – several projects aimed at the promotion of the geocultural heritage are being carried out. An inventory of cultural geomorphosites of the Trient, Eau Noire and Salanfe valleys aims at developing a database that will constitute the base for further projects. 39 cultural geomorphosites are being assessed by using a method that considers the scientific (geomorphological) and cultural values independently. A second inventory, developed within a larger international project on the importance of Goethe's writings and observations for the development of Earth sciences, aims at comparing the German poet's views with the current situation of several geomorphosites in the area. Several geotourist products, aimed at promoting the geomorphological importance of glacial processes in the valley, are proposed for school children and tourists.

KEY WORDS: Geomorphosites, Cultural sites, Heritage, Trient, Switzerland.

RIASSUNTO – Nell'ambito di tre iniziative culturali che hanno interessato la Valle del Trient (Svizzera) –"Vie Culturali in Svizzera" (ViaStoria), Alposcope, e Vallis Triensis – sono stati sviluppati numerosi progetti volti alla valorizzazione e promozione del patrimonio geoculturale della valle. L'inventario di geomorfositi culturali delle valli del Trient, Eau Noire e Salanfe ha lo scopo di sviluppare ed implementare un database che costituirà la base per progetti futuri. Sono stati così valutati 39 geomorfositi culturali utilizzando un metodo che considera il valore scientifico (geomorfologico) e quello culturale in modo indipendente. Un secondo inventario, sviluppato nell'ambito di un progetto internazionale più ampio sull'importanza degli scritti e delle osservazioni di Goethe per lo sviluppo delle Scienze della terra, ha lo scopo di comparare le osservazioni dello scrittore tedesco con la situazione attuale di molti geomorfositi nell'area. Vengono proposti numerosi prodotti geoturistici per turisti e ragazzi delle scuole, con lo scopo di promuovere l'importanza dei processi glaciali nella valle.

PAROLE CHIAVE: Geomorfositi, Beni culturali, Patrimonio, Trient, Svizzera.

1. – INTRODUCTION

Several scholars (PANIZZA & PIACENTE, 2003; PRALONG 2004; REYNARD & PRALONG, 2004) have demonstrated the potentialities of considering cultural heritage not only with respect to its human-made elements – archaeological vestiges, historical buildings, infrastructures, etc. -, but also in a broader sense, including the natural (biological and abiotic) elements of landscape. These studies open new opportunities in history education that is not restricted to the mere human history but covers longer periods, including the geological and natural history. New concepts such as geohistory (PANIZZA & PIACENTE, 2003), total history (PRALONG, 2004) or long history (P. Dubuis, oral com-

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munication) may open new collaboration between sciences that are generally not, or poorly, connected (geology, geomorphology, archaeology, history, ethnography, heritage sciences, etc.). The aim of this interdisciplinary approach is to consider landscape as the result a chain of natural and human processes as they are perceived by society (DROZ & MIÉVILLE-OTT, 2005; REYNARD, 2005).

Starting from this integrated approach, several initiatives have emerged in Switzerland. One is the recent modification (2006) of the Nature and Landscape Protection Act that evolves from a legislation aimed at protecting individual natural or cultural objects to a more territorial and integrated approach, with the creation of new parks, aiming at the sustainable management of the rural landscape. Another case is the project of the 3rd Rhone River Corrections (started in 2000) that was developed with the clear objective of co-ordinating the protection of the population against floods, the rehabilitation of the ecological functions of the watercourse, and the social use of the river. The project managers have developed a large participative process and in this context, historians have created a network of studies aimed at the reconstruction of the long history of the river and its appropriation by society. Specialists of both natural and cultural sciences are involved in this network.

The Trient valley, in the Swiss part of the Mont-Blanc massif, is another place where scientists have developed a similar process of integration involving natural, cultural and social sciences. In this case, geomorphologists have taken the initiative and several projects are being carried out in order to improve the common knowledge of the valley's natural and human history. The objective of this paper is to present the first results of three studies that are currently being developed in the valley by the Institute of Geography at the University of Lausanne within the framework of broader cultural projects co-ordinated by the *ViaStoria* local office. All three projects aim at obtaining better knowledge and promoting cultural geomorphosites.

2. – CULTURAL GEOMORPHOSITES

Geomorphosites are geomorphological objects to which a value can be given (PANIZZA, 2001). The importance of the site may be purely scientific (restrictive definition, REYNARD, 2004a; 2005) or may also include other ecological, cultural, economic or cultural values (broader definition, REYNARD, 2004a; 2005). We have proposed to distinguish two levels of value (REYNARD, 2005): a central one (the site's importance for the reconstruction of the Earth history; scientific value) and additional values that may be important in various contexts, such as, for example, tourism (see PRALONG, 2005).

In this sense, cultural geomorphosites are geomorphological objects that also have a cultural value. With respect to other geomorphosites, their use by Man gives them a higher value (LUGON & REYNARD, 2003). Examples of cultural geomorphosites are glacial locks supporting castles or defence infrastructures, archaeological findings linked with a specific geomorphological context (e.g. karstic caves, habitats in rockfall deposits) or particular landforms used for religious rituals (e.g. Uluru inselberg in central Australia, Lourdes karstic cave in Southern France).

3. – KNOWLEDGE AND PROMOTION OF THE TRIENT VALLEY HISTORY

Several projects are currently being carried out in the Trient valley. They have been launched after a Master's thesis study on the contribution of educational trails to sustainable development in the Alps (BENEDETTI, 1998). The first phase was dedicated to the development of several interpretative trails – supported by panels and brochures – in various parts of the valley and its surroundings, with the aim of contributing to the summer tourism in the area.

Currently, three more complex projects, all aiming at a better comprehension of the Alpine history, concern the valley: the "Cultural Routes in Switzerland", the *Alposcope* and the activities of *Vallis Triensis*.

Under the label "Cultural Routes in Switzerland", *ViaStoria* – Center for transport history research – is currently establishing a network of twelve historical routes (fig. 1) throughout Switzerland. "Cultural Routes in Switzerland" provides access to natural and cultural curiosities of the landscape, Swiss cultural historical peculiarities, spectacular evidence of the routes' landscape, known and less conventional historical means of transportation, the history of regional customs, and the products of the various regions. The entire program is led and co-ordinated by *ViaStoria* that collaborates with national, regional and local organisations for tourism, economy, and culture, and with the public services and transports. The project started in February 2004 and the twelve routes of national interest were opened in 2007 (www.viastoria.ch). One of them – the Via Cook – concerns the Trient valley.

Alposcope is a network linking natural and tourist sites together and aiming at describing the long history of the Alps (www.alposcope.ch). The project is viewed as a promotional instrument developed by and for the local communities. It aims at promoting the tourist infrastructures and the natural and cultural sites of the region situated between Chamonix (France) and Martigny (Switzerland) by following the principles of sustainable development. The Trient valley is the geographical core of the project. The long history of the Alps, from their geological formation to the hydropower scheme building (Emosson dam) at the end of the 20th century, constitutes the thematic core of the project. Geology and orogeny, landscape formation by glaciers and rivers, fauna and flora colonisation, prehistorical and historical development, the historical routes between Switzerland and France, as well as the development of tourism and alpinism, are the principal themes that are demonstrated by a transdisciplinary group of specialists of natural, historical and human sciences. The network links villages, natural and cultural sites, and communication means between Chamonix and Martigny, and aims at promoting a common tourist product.

Vallis Triensis is an association created in 1999 that aims at studying and promoting the value of natural, archaeological and historical sites of the Trient and Eau Noire valleys (www.vallistriensis.ch). The association organizes guided visits, field trips and conferences, and publishes a bulletin and thematic monographies concerning the region. To date, three books have already been published on the geology, geomorphology and archaeology of the area.

4. – INVENTORY OF CULTURAL GEOMORPHOSITES

In order to have a common view of the value and location of the geocultural heritage of the valley, an inventory of cultural geomorphosites has been carried out (KOZLIK, 2006). The aim was to select, describe and map the principal sites in the valley that have both a geomorphological and a cultural value. A first selection was made on the basis of precedent works on the geomorphology and the cultural heritage of the study area. 39 sites were selected (fig. 2) and each site was then described and assessed using a method developed at the University of Lausanne (REYNARD *et alii*, 2007).

A card is created for each site. It is divided in six parts (tab. 1): general data; description and morphogenesis; scientific value; additional values; synthesis; references. The assessment of the sites is based on two levels of values (REYNARD, 2004a): a central (scientific) value and several additional (cultural, aesthetic, ecological, social-economic) values. The scientific value is assessed using six different criteria (tab. 1): integrity, representativeness, rarity, paleogeographical, educational and geohistorical value. For each criterion, a qualitative evaluation is made, and numerical values (scores ranging from 0 to 1) may be added. The four additional values are assessed using simple criteria (table 1 presents only the cultural value). The fifth section (synthesis) is divided into three parts: a synthesis of the geomorphological value, a listing of potential threats by natural processes and/or human impacts, and finally, proposals of management measures. The inventory, which is currently implemented in an ArcGis application, is used by *Vallis Triensis* as a database for future actions and publications (KOZLIK *et alii*, 2009).

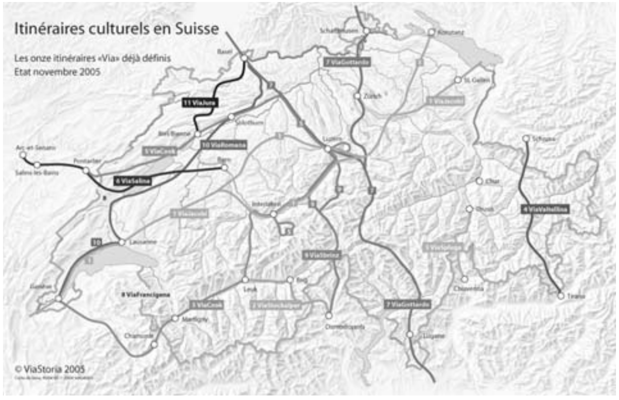


Fig. 1 – Map of the "Cultural Routes in Switzerland".
– *Carta delle "Strade Culturali in Svizzera".*

Table 1 presents the card of the erratic block called *Pierre Bergère* (fig. 3) that was used by Nobel Prize Guglielmo Marconi in 1895 for the first wireless experiments. The physician sent waves from the top of the block, while a local child working as an assistant moved around several parts of the surroundings and showed flags of different colors according to whether he could record the signal or not. In 2003, the Institute of Electrical and Electronics Engineers recognized the stone as a keyplace in the history of electrical sciences and placed a commemorative plaque on the stone. The historical value of the block and Marconi's experiments in Salvan have been recognized and promoted in recent years by an association, the Marconi Foundation (www.fondation-marconi.ch). A small museum and a cultural trail were created, and a brochure was published. Each year, events around Marconi's fame are organised. Nevertheless, the origin of the block, its integration in a

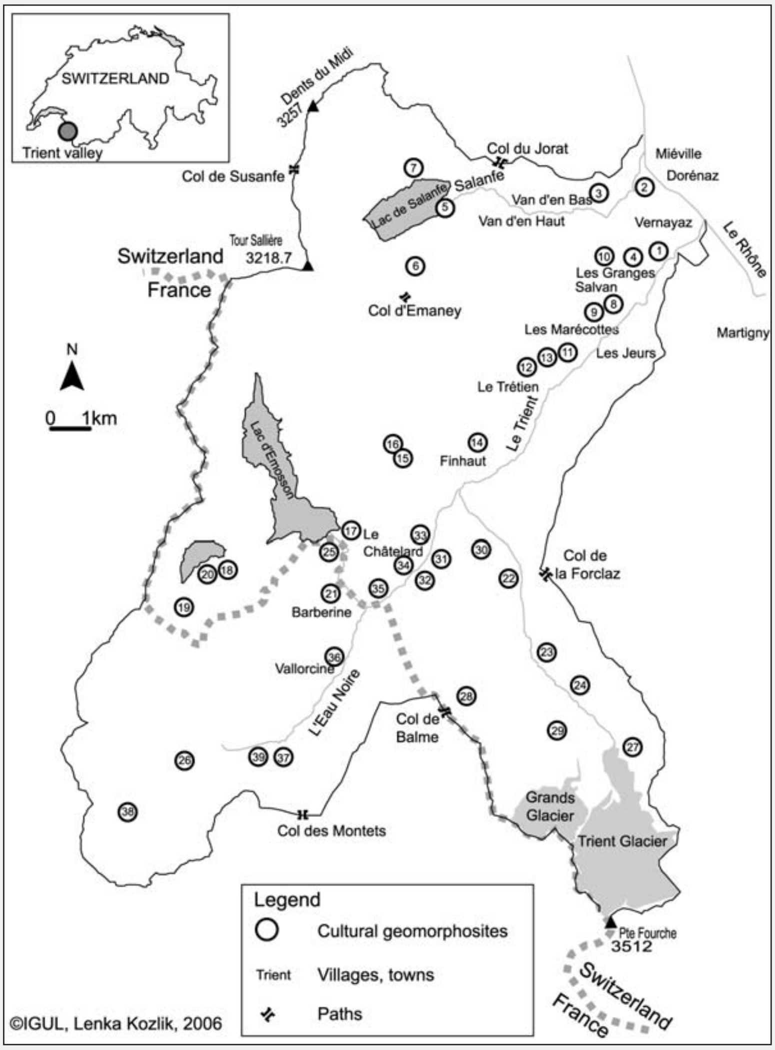


Fig. 2 – Map of the cultural geomorphosites of the Eau Noire, Trient and Salanfe valleys. 1. Trient gorges; 2. Pissevache waterfall; 3. Dailley gorge; 4. Stagecoach road Vernayaz-Salvan; 5. Salanfe glacial lock; 5. Salanfe mine; 7. Salanfe alp; 8. Pierre Bergère erratic block; 9. Salvan rupestral engravings; 10. Salvan shelter for plague victims; 11. Les Marécottes natural swimming-pool; 12. Triège gorge; 13. Stagecoach road Salvan-Finhaut; 14. Le They *roches moutonnées*; 15. Fenestral moraines; 16. Fenestral stele; 17. Emosson chapel; 18. Vieux-Emosson glacial lock; 19. Vieux-Emosson dinosaur tracks; 20. Vieux-Emosson landscape; 21. Barberine waterfall; 22. Trient moraines; 23. Trient irrigation channel; 24. Trient glacier path; 25. Emosson glacial lock; 26. Bérard natural reserve; 27. Trient glacier; 28. Herbagères alp; 29. Les Grands alp; 30. Tête Noire gorge; 31. Les Jeurs mill stone; 32. Les Jeurs cupule stone; 33. Le Châtelard Hässig factory; 34. Le Châtelard rockfall shelter; 35. Le Châtelard hole; 36. Stagecoach road Finhaut-Vallorcine; 37. La Poya cupule stone; 38. Bérard stone; 39. Bérard waterfall and cave.
– *Carta dei geomorfositi culturali delle valli Eau Noire, Trient e Salanfe. 1. Gole del Trient; 2. Cascata del Pissevache; 3. Gola del Dailley; 4. Strada per diligenza Vernayaz-Salvan; 5. Sbarramento glaciale di Salanfe; 5. Miniere di Salanfe; 7. Alpe di Salanfe; 8. Blocco erratico Pierre Bergère; 9. Incisioni rupestri di Salvan; 10. Ricovero per le vittime della peste; 11. Piscine naturali Les Marécottes; 12. Gola del Triège; 13. Strada per diligenza di Salvan-Finhaut; 14. Roches moutonnées Le They; 15. Morene di Fenestral; 16. Stele di Fenestral; 17. Cappella Emosson; 18. Sbarramento glaciale Vieux-Emosson; 19. Tracce di dinosauri di Vieux-Emosson; 20. Paesaggio di Vieux-Emosson; 21. Cascata di Barberine; 22. Morene del Trient; 23. Canale di irrigazione di Trient; 24. Sentiero glaciale di Trient; 25. Sbarramento glaciale di Emosson; 26. Riserva naturale di Bérard; 27. Ghiacciaio del Trient; 28. Alpe di Herbagères; 29. Alpe di Les Grands; 30. Cascata di Tête Noire; 31. Ruota di mulino di Les Jeurs; 32. Les Jeurs cupule stone; 33. Stabilimento Le Châtelard Hässig; 34. Difesa dai crolli a Le Châtelard; 35. Cavità a Le Châtelard; 36. Strada per diligenza di Finhaut-Vallorcine; 37. La Poya cupule stone; 38. Bérard stone; 39. Cascata e grotta a Bérard.*

larger glacial geomorphological system, with *roches moutonnées* and striated rocks, as well as the relationships between the glacial landforms and the presence of archaeological findings (cupule stones) were very poorly developed. Two interpretative panels on the valley morphogenesis and on the glacial history were, therefore, prepared (KOZLIK *et alii*, 2008) and added to the cultural itinerary in summer 2008.

5. – THE SCIENTIFIC VALUE OF GOETHE'S TRAVELS IN SWITZERLAND

Like many other intellectuals in his time, Wolfgang Goethe (1749-1832) travelled in the Alps and through Italy several times. Frequent travelling throughout Europe started in the 17th Century by the young aristocracy undertaking the *Grand Tour*, which brought them to European centres of cultural, political, economic and religious life (ASHWORTH, 1993). Later, alpine stays in the Swiss and French Alps were included (DEBARBIEUX, 1995).

The growing interest in natural sciences during the 18th century made the mountain environment one of the most praised sites of observation and experimentation (DEBARBIEUX, 1995) and the *voyage savant* (scientific travel) became a common form of travelling, especially for intellectuals (BRIFFAUD, 1994). Goethe's interest for geology developed in 1776, when he was charged with the supervision of a copper and silver mine in Illmenau (Thüringen, Germany) (GNAM, 2001). First, Goethe mainly took care of the legal and the economic aspects, but he also felt eager to inform himself about technical questions. As a result, his mineralogical and geological interest grew and he began to visit the mines and the ironworks in the surrounding area. Later, he undertook adventurous journeys in the surrounding areas and through Switzerland and Italy.

Tab. 1 – *Assessment card of the Pierre Bergère erratic block in Salvan (cultural geomorphosite n°8 on fig. 2).*
– Scheda di valutazione del masso erratico Pierre Bergère a Salvan (geomorfosito culturale n°8 in fig. 2).

Pierre Bergère	**TRIGLA003**	
1. General data Localisation Swiss coordinates Altitude Type Size Property	Salvan, Valais, CH 567.750/107.730 950 m a.s.l. PCT (punctiform) 95 cubic meters Terrain: private property Block managed by the Marconi foundation (but remains a private property)	
2. Description The site is situated NE of Salvan village, on a hill situated near the church. It is formed by two glacial landforms: the erratic block and an outcrop of abraded and striated *roches moutonnées*. The block is made of augen gneiss from the Mont-Blanc massif. It is 3.5 metres long at the base and 6 metres long at the top; it is 5 metres high and 4 metres large. Several human installations are present near and on the block: scale, orientation, table, barrier, and bench. The block is situated on a large area covered with *roches moutonnées* and locally known as *Rochers du soir* (Evening rocks). These are rocks from the Salvan-Dorénaz permo-carboniferous syncline that have been abraded by the Trient glacier. The block is situated on a high point and gives a large view of the area. It can also be viewed from various points. The *Pierre Bergère* is very close to the Salvan rupestral engravings (cultural geomorphosite n° 9) that are situated on the same *roches moutonnées* outcrop. **Morphogenesis** During the Quaternary, glaciers coming from the Mont-Blanc massif modelled the Trient valley shape. The glacier abrasion was more important in the South-eastern part of the valley, made of soft sedimentary rocks. Differential erosion has modelled several longitudinal ridges separated by depressions. The *Pierre Bergère* is located on one of the elongated hills of the area. During the glacier retreat, the Trient glacier has abandoned several erratic blocks (melt-out till); one of them is the *Pierre Bergère*.		
3. Scientific value	**Assessment**	**Score**
Integrity	The site is highly modified by human settlements, on the block itself (scale, panels) and around it (asphalted road, individual house).	0.20
Representativeness	The size and the position of the blocks on striated roches moutonnées is a good example of erratic blocks in the area.	0.80
Rarity	There are numerous other erratic blocks in the valley. Nevertheless, the size of the block and its location are relatively uncommon.	0.80
Paleogeographical value	The block does not give any information on a glacial stage.	0.20
Educative value	Possible explanations on glacial processes (abrasion, striation, melt-out) and landforms (roches moutonnées, striaes, erratic blocks, glacial locks and depressions).	0.80
Geohistorical value	The position of the block allowed the first wireless experiments by G. Marconi in 1895.	1.00
Scientific value	**The site is representative of ancient glacial processes, but the natural characteristics are poorly conserved.**	**0.63**
4. Cultural (additional) value	**Assessment**	**Score**
Religious importance	No known religious activities.	0.00
Historical importance	Legend: the first pasture place in Salvan (which explains the name Pierre Bergère: Shepherd Stone) 1895: first wireless experiments by G. Marconi	1.00
Literature and artistic importance	Several writings on Marconi and wireless experiments Presence in Salvan of Marconi Foundation and Museum	1.00
Cultural value	**Because of the block and Marconi's experiments, Salvan is known as one of the world's cradles of telecommunications**.	**0.67**
5. Synthesis		
Values	The natural environment is poorly conserved, but the block is a key-site in telecommunication history. The geomorphosite, therefore, has a high cultural importance	
Potential threats	The block is situated in Salvan village and could be damaged by human activities.	
Management measures	The value of the block should be formally recognised and the block should be protected. The management should be insured by the Marconi Foundation.	

6. References

FOURNIER Y. (1996/2000). *Salvan : sur les pas de Marconi - Following Marconi's footsteps*, Salvan (booklet).

COQUOZ L. (1899). *Salvan- Fins-hauts avec petite notice sur Trient*, Imp. Ch. Pache, Lausanne.

Website: www.fondation-marconi.ch

Fig. 3 – A view of the *Pierre Bergère* where Guglielmo Marconi made the first wireless experiments in 1895 before being awarded the Nobel prize (picture E. Reynard).
– *Panoramica di Pierre Bergère dove Guglielmo Marconi fece i primi esperimenti nel 1895 prima della vincita del premio Nobel (immagine E. Reynard).*

During his second journey to Switzerland in 1779 he met a professor of geology and physics, Horace Bénédict de Saussure in Geneva, who suggested visiting some interesting places. On de Saussure's recommendations, Goethe trained his awareness for geological phenomena and started collecting minerals (GNAM, 2001). For his third journey to Switzerland in 1797 Goethe had a clear scientific and encyclopaedic aspiration: to acquire information about the economic situation, local customs as well as climatic, geographic and geologic facts of the places he visited (CHIADÒ RANA, 2003). Therefore, a rich amount of letters, diary notes, poems and drawings concerning naturalistic observations cover his travels to Switzerland.

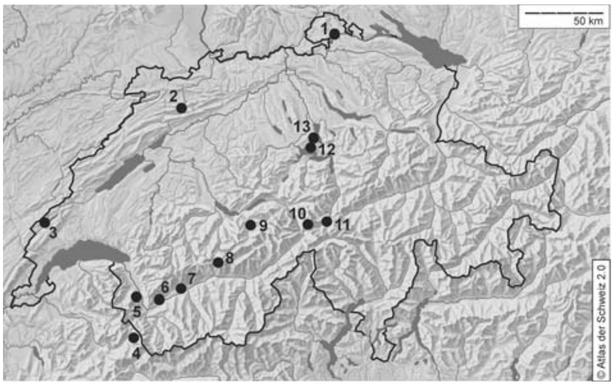


Fig. 4 – Map of the geomorphosites visited and described by Goethe during his travels in Switzerland. 1. Rhine waterfall; 2. Moutier cluse; 3. Joux syncline valley; 4. Mer de Glace glacier; 5. Pissevache waterfall; 6. Rhone meanders; 7. Sion glacial lock; 8. Leukerbad thermal spring; 9. Staubbach waterfall; 10. Rhone glacier; 11. Schölenen gorge; 12. Weggis landslide; 13. Küssnacht erratic block.
– *Carta dei geomorfositi visitati e descritti da Goethe durante i suoi viaggi in Svizzera. 1. Cascata di Rhine; 2. Moutier cluse; 3. valle a sinclinale del Joux; 4. Ghiacciaio Mer de Glace; 5. Cascata Pissevache; 6. Meandri del Rhone; 7. Sbarramento glaciale di Sion; 8. Sorgente termale di Leukerbad; 9. Cascata di Staubbach; 10. Ghiacciaio di Rhone; 11. Gola di Schölenen; 12. Frana di Weggis; 13. Masso erratico di Küssnacht.*

Within the framework of a German-Swiss-Italian project (GEYER *et alii*, 2007), a comparison of Goethe's views and the current aspect of several sites in Germany, the Czech Republic, Austria, Switzerland and Italy, is being carried out by researchers of various countries. The objective is to confront Goethe's views and theories with the current knowledge, in order to understand the German poet's importance in the development of Earth sciences, to assess the processes that have transformed the sites visited by Goethe, and finally to develop a virtual journey in Goethe's footsteps. In Switzerland, 13 sites have been selected (fig. 4); one of them, the *Pissevache* waterfall (tab. 2), is situated in the Trient valley area. The compilation of the scientific value of the site, the natural and human-forced waterfall evolution, and the listing of the main descriptions and paintings of the site are in progress. The information is organised in a database (tab. 2) and the results will also be used as material within the framework of the *Cultural Routes of Switzerland.*

6. - THE GLACIAL HISTORY FOR SCHOOLS AND TOURISTS

The third project has been developed within the framework of the *Alposcope* project. The aim is to combine geomorphological evidence of glaciations (erratic blocks, *roches moutonnées*), active glacial processes (Trient glacier) and glacial landforms showing the adaptation of the hydrographical network to the former glacial history to explain to school-children and tourists the importance of glaciers in the morphogenesis of the area.

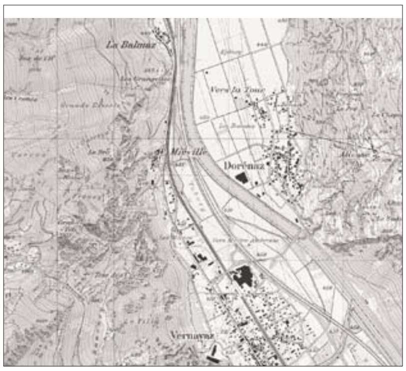
Two thematic itineraries were prepared within the framework of a Master's thesis (SCHNEIDER, 2009). The first one (fig. 5) is a cycling road from Martigny to Monthey (20 km in length). In Martigny, the Rhone valley makes a 90-degree change in direction and the river crosses the geological units perpendicularly. The crystalline basement, a permo-carboniferous syncline and sedimentary covers are successively crossed. Because of the alluvial deposits, the itinerary is almost flat. That is not the case of the bedrock that is about 600 meters below the current valley level in Martigny, where the glacial abrasion was quite important, whereas in St-Maurice the bedrock is visible and has created an impressive glacial lock that is currently cut by a gorge eroded by the Rhone River (REYNARD *et alii*, 2009). The itinerary allows the observation of different glacial and fluvial landforms clearly visible in the landscape (educational value). Seven stops are pro-

Tab. 2 – *Descriptive card of the Pissevache waterfall used within the Goethe project.*
– Scheda descrittiva delle cascate Pissevache utilizzata nel progetto di Goethe.

On Goethe's path

Index	**Name**	**Country**	**Region**	**Canton**
5	Pissevache	Switzerland	Western Switzerland	Valais

Localization **Illustrations**



- [ ] history of geology
- [ ] geology in general
- [ ] stratigraphy
- [ ] petrography
- [ ] mineralogy
- [ ] sedimentology
- [x] geomorphology
- [x] cultural geomorphology
- [x] geotourism
- [ ] meteorology
- [ ] natural sciences
- [ ] archaeology
- [ ] history
- [ ] history of art

Geoscientific value
The Pissevache waterfall is a site of high geocultural value. It was one of the most frequently visited spots in the Alps in 17th and 18th century tourism

Goethe's description
Wir wussten, dass wir uns dem berühmten Wasserfall der Pissevache näherten, und wünschten einen Sonnenblick, wozu uns die wechselnden Wolken einige Hoffung machten. An dem Wege betrachteten wir die vielen Granit- und Gneisstücke, die bei ihrer Verschiedenheit doch alle eines Ursprungs zu sein schienen. Endlich traten wir vor den Wasserfall, der seinen Ruhm vor vielen andern verdient.
In ziemlicher Höhe schiesst aus einer engen Felskluft ein starker Bach flammend herunter in ein Becken, wo er in Staub und Schaum sich weit und breit im Wind herumtreibt. Die Sonne trat hervor und machte den Anblick doppelt lebendig. Unten im Wasserstaube hat man einen Regenbogen hin und wieder, wie man geht, ganz nah vor sich. Tritt man weiter hinauf, so sieht man noch eine schönere Erscheinung. Die luftigen schäumenden Wellen des obern Strahls, wenn sie gischend und flüchtig die Linien berühren, wo in unsern Augen der Regenbogen entstehet, färben sich flammend, ohne dass die aneinanderhängende Gestalt eines Bogens erschiene; und so ist an dem Platze immer eine wechselnde feurige Bewegung. Wir kletterten dran herum, setzten uns dabei nieder und wünschten ganze Tage und gute Stunden des Lebens dabei zubringen zu können.

Saint-Maurice, den 7. November 1779, In: *Briefe aus der Schweiz* (1796)

Today's description
Being a major tourist attraction for travellers of the romantic epoch, the Pissevache waterfall is praised in the first *Récits de voyage*. It inspired, for example, Haller, Goethe, Rousseau and the Alpine poet Emile Javelle and is, furthermore, very much represented in the Alpine iconography.
Due to the implementation of the hydroelectric installation of Salanfe in 1953, the Salanfe River suffered from a strong reduction of its flows. As a result the Pissevache no longer resembles the waterfall of the romantic period. Nevertheless, the geomorphologic value of the waterfall is undeniable: it is one of the most beautiful examples of postglacial waterfalls in Switzerland.
Although the Pissevache appears in many publications concerning the Valais, the site lacks a real tourist and cultural promotion (no publication or tourist equipment). Its proximity to the gorges of Trient and the alluvial fan of the St-Barthélémy (see fig. 5) gives the site a great tourist and educational potential, which waits to be exploited.

Accessibility
- [ ] walk
- [x] car
- [ ] boat
- [ ] public trasport

How to get there
The Pissevache waterfall is visible from the A9 motorway and the railway, but can only be reached by the district road.

Bibliography
REICHARD, 1793 / ESCHASSERIAUX, 1806 / TÖPFFER, 1836 et 1842 / GAUTHIER, 1868 / COQUOZ, 1899 / REVAZ, 1983 / METTAN, 1991 / REICHLER & RUFFIEUX, 1998 / REYNARD, 2004

posed (fig. 5); they each propose explanations on one kind of glacial and postglacial process.

The first one is the Trient gorge (cultural geomorphosites n°1 in fig. 2) where postglacial fluvial erosion by a river charged with abrasive crystalline gravels has cut a profound and narrow gorge linking the tributary Trient River with the Rhone River valley. An interpretative trail has been available since 2004. The second stop is the Pissevache waterfall, already described in the last section (tab. 2). The third stop is an example of another type of tributary valley linking with the main valley: the alluvial fan. The St-Barthélémy alluvial fan is one of the most impressive in the Rhone River valley. It is fed with the debris of shales coming from the sedimentary Morcles nappe and it has pushed the Rhone River to the other side of the valley (REYNARD *et alii*, 2009). Stop number 4 is in St-Maurice, a historic town that is considered as the entrance to the Rhone River valley because of its strategic position in the narrowest part of the valley (glacial lock). This stop provides an opportunity to discuss the importance of the glacial erosion in the valley's shape, but also the links between geomorphology and human history. Stop number 5 is situated on the lee side of the glacial lock, where glacio-fluvial processes have been active. A glacial pothole, that was discovered and is managed by a local farmer, is visible. The sixth stop is also situated on the lee side of the glacial lock and shows impressive *roches moutonnées* and striated rock walls that are used for rock climbing. This stop is the occasion not only to present glacial landforms but also to discuss the issues concerning the management of geomorphosites and the possible conflicts with other recreational activities. The last stop is the *Pierre des Marmettes* erratic boulder in Monthey. This is the largest erratic block in Switzerland and Jean de Charpentier described it in his famous *Essai sur les glaciers* in 1841 that is considered as one of the first glaciology books in the world. Because of an important popular and scientific mobilisation against its destruction by an extraction company in 1905, it was bought and placed under the protection of the Swiss Natural Sciences Society in 1908 (SCHARDT, 1908). This is, therefore, one of the first protected geomorphosites in Switzerland (REYNARD, 2004b) and it gives a good opportunity to remember the importance of geology and geomorphology in the history of nature conservation movement in Switzerland.

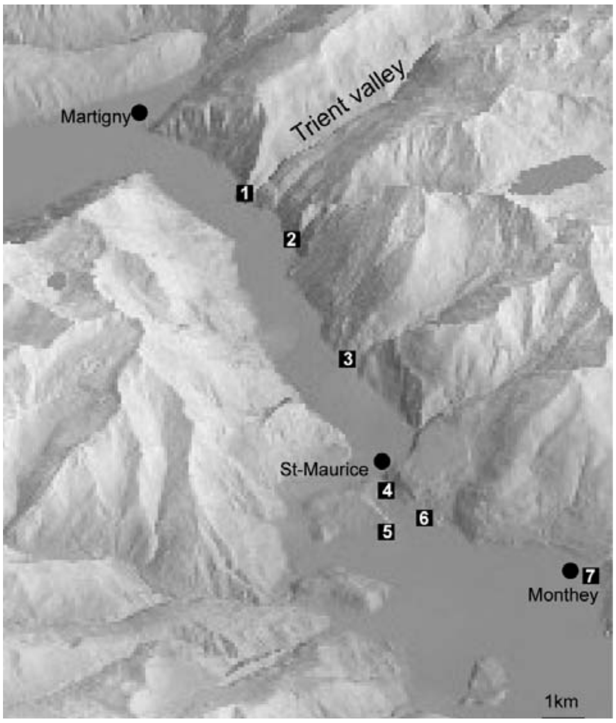


Fig. 5 - Map of the Geomorphosite Cycle Road Martigny-Monthey. 1. Trient postglacial gorge; 2. Pissevache waterfall; 3. St-Barthélémy alluvial fan; 4. St-Maurice glacial lock; 5. Bex glacial pothole; 6. Massongex *roches moutonnées* outcrops; 7. Pierre des Marmettes erratic block.
– *Carta dei Geomorfositi lungo la Pista Ciclabile Martigny-Monthey. 1. Gola postglaciale di Trient; 2. Cascata di Pissevache; 3. Cono alluvionale di St-Barthélémy; 4. Sbarramento glaciale di St-Maurice; 5. Marmitta dei giganti di Bex; 6. Affioramento di roches moutonnées di Massongex; 7. Masso erratico di Pierre des Marmettes.*

The second educational itinerary is a hiking trail along the Trient River valley, from the Trient glacier to mouth in the Rhone River. The itinerary, which is divided into 10 stages, may be done in two days, with a possible stop in Finhaut, where tourist accommodation is available (see figure 2 for location of visited sites). As for the first itinerary, the glacial history of the valley is the main topic and the importance of glaciers in the regional economy and history is also demonstrated. The beginning of the itinerary is situated at the Forclaz pass, accessible by public transportation from Martigny. The first two stops (n° 23 and 27 on figure 2) concern the Trient glacier from the Little Ice Age to the present. The Trient glacier is a very dynamic one and the tongue is evolving very fast with climate variations. During the Little Ice Age, the glacier was also used for ice production and a dynamic economy has been active for several decades. This makes it a good example of the possible use of geomorphology from an economic point of view. The village of Trient (stop 3, n° 22, figure 2) is built on and around a moraine ridge dating back to the Egesen stage. The itinerary continues with the Tête Noire gorge, which is a good example of a U-shaped glacial valley (stop 4, n° 22, figure 2). From Finhaut to Vernayaz, the itinerary follows the former *Route des diligences*. The hiker will stop to see several geomorphosites that present various traces of the local glacial history (Le They *roches moutonnées*, n° 14; Triège postglacial gorge, n° 12; Les Marécottes *roches moutonnées*, n° 11; Pierre

Bergère erratic boulder, n° 8; Salvan *roches moutonnées* covered with prehistoric paintings, n° 9) and finishes in the Trient gorge (n° 1, figure 2). All the visited sites are described using the assessment card presented in this paper (tab. 1) and both itineraries will be included in the *Alposcope* tourist offer.

7. – CONCLUSIONS

This paper aimed at presenting several initiatives developed in the Trient valley (Western Switzerland) with the objective of assessing and promoting the geocultural heritage of the area. An inventory of cultural geomorphosites was carried out. It constitutes the base for the preparation of various geotourist products (educational trails, panels and leaflets). A second inventory is being carried out within the framework of an international project on Goethe's importance for the development of Earth sciences in the 18th century. All these projects aim at promoting the idea of the integrative nature of landscape that is anchored both in the natural and cultural sciences.

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