Il Quaternario
Italian Journal of Quaternary Sciences
***18**(1), 2005 - Volume Speciale, 79-91*

GEOMORPHOLOGICAL SITES IN THE NORTHERN MARCHE (ITALY). EXAMPLES FROM AUTOCHTHON ANTICLINE RIDGES AND FROM VAL MARECCHIA ALLOCHTHON

Olivia Nesci, Daniele Savelli, Antonio Diligenti & Diego Marinangeli
Istituto di Geologia, Università degli Studi di Urbino "Carlo Bo",
Campus Scientifico, Località Crocicchia, 61029 Urbino, Italy; email: o.nesci@uniurb.it

ABSTRACT: O. Nesci *et al.*, *Geomorphological sites in the northern Marche (Italy). Examples from autochthon anticline ridges and from Val Marecchia allochthon*. (IT ISSN 0394-3356, 2005).
Two areas are proposed as representative of as many quite different geological and structural domains of the Marche region, namely the autochthon Umbria-Marche Apennines and the allochthon Val Marecchia Nappe. These two areas comprise several meaningful landforms - both active and relict, low Pleistocene-Holocene in age - which are worth emphasising as geomorphosites. Although during their geomorphologic evolution the two areas underwent similar morphoclimatic conditions, many landforms are quite different from one area to the other because of major geological and structural constraints. Thus, the two areas are suitable for highlighting interrelationships between geology and landforms both from scientific and educational standpoint. Significant karst, glacial and mass-movement derived landforms in which the structural control is subordinate, also occur in the studied sites and have been reported in this paper.

RIASSUNTO: O. Nesci et al.*,* Siti Geomorfologici nelle Marche settentrionali (Italia): esempi dell'autoctono umbro-marchigiano e della Colata della Val Marecchia*. (IT ISSN 0394-3356, 2005).*
Vengono proposte due diverse aree come esempi rappresentativi di due domini geologici e strutturali del territorio marchigiano piuttosto differenti fra loro, cioè l'autoctono umbro-marchigiano e la Coltre della Val Marecchia. Le due diverse aree contengono numerose e varie forme significative, in parte attive e in parte relitte, sviluppatesi fra il Pleistocene inferiore e l'Olocene. Sebbene in questo arco di tempo le due aree siano state soggette a condizioni climatiche molto simili, parecchie forme del rilievo sono molto differenti fra un sito e l'altro a causa del forte controllo strutturale. Pertanto, sia dal punto di vista scientifico che da quello didattico-divulgativo, le due aree prescelte si prestano ottimamente a mettere in risalto i rapporti fra lito-struttura e forme del paesaggio. Nei siti presentati compaiono anche importanti forme carsiche, glaciali e legate a movimenti di massa per le quali il controllo litostrutturale è subordinato; queste, dato il loro interesse, sono state ugualmente prese in considerazione nella presente nota.

Key words: Geomorphosites, Carbonate anticlines, Val Marecchia Nappe, Apennines, Marche.

Parole chiave: Geomorfositi, Anticlinali carbonatiche, Coltre della Val Marecchia, Appennino, Marche.

1. INTRODUCTION

The Marche regional territory is characterised by a hilly coastal zone, where often slightly deformed Plio-Quaternary terrains prevail. These ones merge to the southwest into a mountain chain area, mostly corresponding to Meso-Cenozoic intensely folded and thrusted formations, which can be subdivided into two different geological domains, the autochthon Umbria-Marche Apennines and the allochthon Val Marecchia Nappe – this latter pertaining to the Romagna Apennines - corresponding in their turn to as many geomorphological domains.

The Umbria-Marche Apennines are characterised, from SW to NE, by two main ridges (Fig. 1), the Umbria-Marche and the Marche Ridges *Auct*., respectively separated from each other by a broad topographic depression (*cf*. Bisci & Dramis, 1991a and references therein). The two ridges, made up of Mesozoic-Paleogene mainly carbonate and marly-calcareous units of the Umbria-Marche Succession, are characterised by an arcuate shape and correspond to asymmetric, mostly thrusted, NE-vergent more or less complex anticlines (*cf*. Deiana & Pialli, 1994 and references therein). The internal ridge, southerly merging with the external one, consists of an anticlinorium extending northwards to include Monte Catria and Monte Nerone. This ridge includes both brachyanticlines and wide asymmetric anticlines with a characteristic right-hand en-echelon arrangement. The anticlines represent box folds with often vertical or overturned forelimbs affected by thrust faults; these elements override the Tertiary units outcropping between the two main ridges (Calamita & Deiana, 1987). The external ridge consists of a less complex regional anticlinorium extending from Monti Sibillini northwards to Monte Pietralata. Minor calcareous ridges, corresponding with faulted anticlines, are located between the main ridges (e.g. Acqualagna anticline) and, more externally, at the boundary with the foothill area (e.g. Monti della Cesana).

The Umbria-Marche Apennines are bounded to the north by the Val Marecchia Nappe, embedded in lower Pliocene clays (*cf*. Ruggeri, 1970; Conti, 1989) thus indicating an emplacement dating back to the same age. The Nappe is formed by Ligurian Units overlain by Epi-Ligurian ones (*cf.* Ruggeri, 1970, Conti, 1989). The Epi-Ligurian Units (Langhian-Messinian) consist of a wide variety of lithotypes ranging from conglomerates, sandstones and biocalcarenites, to gypsum, marls and clays. The Ligurian Units, in turn, are represented by the Pietraforte-Alberese succession (Maastrichtian-Eocene), where chaotic varicoloured shales are associated with more competent lithotypes such as limestones, marly mudstones, and sandstones to form a melange. In any case, whatever the mechanism of the emplacement (*e.g.*, gravitational olisthostrome, Flores, 1955; gravitational slide, Merla 1951; De Feyter, 1991; resulting of a shortening within the context of an active roof duplex, Bettelli et al., 1987; Conti, 1989), from a geomorphological standpoint, Nappe structure is so complex that the overall geologic assemblage can be regarded as "chaotic".

Although the two different geological-geomorphological domains of the autochthon Umbria-Marche fold-and-thrust chain and of the allochthon Val Marecchia Nappe experimented the same climatic conditions and underwent similar morphogenetic agents and processes, quite different landforms were produced because of a strong structural constraint. Hence the two domains yield significantly different landscapes which, besides impressive natural sceneries and amazing landforms, are matters of great scientific and educational significance. Specifically, a strong response to differential erosion by various processes is markedly stressed in both domains. The autochthon is characterised by well developed anticline ridges, bearing outliers and structural surfaces of different kinds, flanked by series of "flatirons" and cross-cut by deep gorges. Conversely, the landscape of the Val Marecchia Nappe area is characterised by isolated rocky relieves and spurs protruding from badlands and gentle hillslopes shaped by mass movements.

The two different domains also show other meaningful geomorphologic peculiarities, such as the evidence of glacial processes, little known in these areas as yet, although recently documented in the Monte Catria massif (Savelli *et al*., 1995). The occurrence of karst topography and of several, often spectacular caves (e.g. the well-known Frasassi caves), is also notable; moreover, since these phenomena occur on different lithotypes, such as limestones, dolomitic limestones and gypsum, they assume a main significance both for educational and scientific aims.

This paper is set in the framework of the MIUR co-financed project, "*The geosites of the Italian landscape: research, evaluation and enhancement*". It is intended to deal with issues concerning the study and improvement of sites of special geomorphologic interest (i.e. *geomorphosites*, Panizza, 2001) in two different geological-geomorphological domains such as the northern Umbria-Marche Apennines and the sector of the Val Marecchia Nappe pertaining to the Marche region.

2. GEOMORPHOSITES IN THE NORTHERN MARCHE APENNINES

A large number of geomorphologically relevant areas pertains to the Umbria-Marche autochthon. Among these, we have selected the Monte Catria-Monte Nerone mountain ridge as one of most representative areas. Indeed, this mountain area as a whole can be considered a "*landscape unit*" (cf. Panizza & Piacente, 2003, pag. 264) characterised by a remarkable concentration and abundance of significant forms and landscapes, i.e. *geomorphosites* sensu Panizza (2001).

2.1 Monte Catria - Monte Nerone Ridge

This mountain area represents the northernmost sector of the Umbria-Marche Ridge (Fig. 1). Its principal geomorphological characteristic (Fig. 2) is a so strong morphostructural imprint that, as a matter of fact, it must be regarded as one of the best examples of carbonatic anticline ridges in the Central Apennines. The ridge is cross-cut by deep transverse gorges (*cf*. Bu and Bo in Fig. 2), forms of undoubted beauty and scientific significance, whose origin has been the object of a long-lasting debate and different interpretations (e.g. Mazzanti & Trevisan, 1978; Alvarez, 1999 and references therein). Recently, Mayer *et al*. (2003) assert an overall local effectiveness of each of the previous evolution models, emphasising that both superposition and stream-piracy phenomena could have played a significant control in the drainage network development and, in places, complex mechanisms involving antecedence cannot be ruled out for stream bypassing of anticlinal ridges. The main sectors of the ridge (i.e. Monte Catria massif, Monte Petrano and Monte Nerone) separated from each other by the major gorges (i.e. Sentino, Burano and Bosso rivers), perfectly display both the

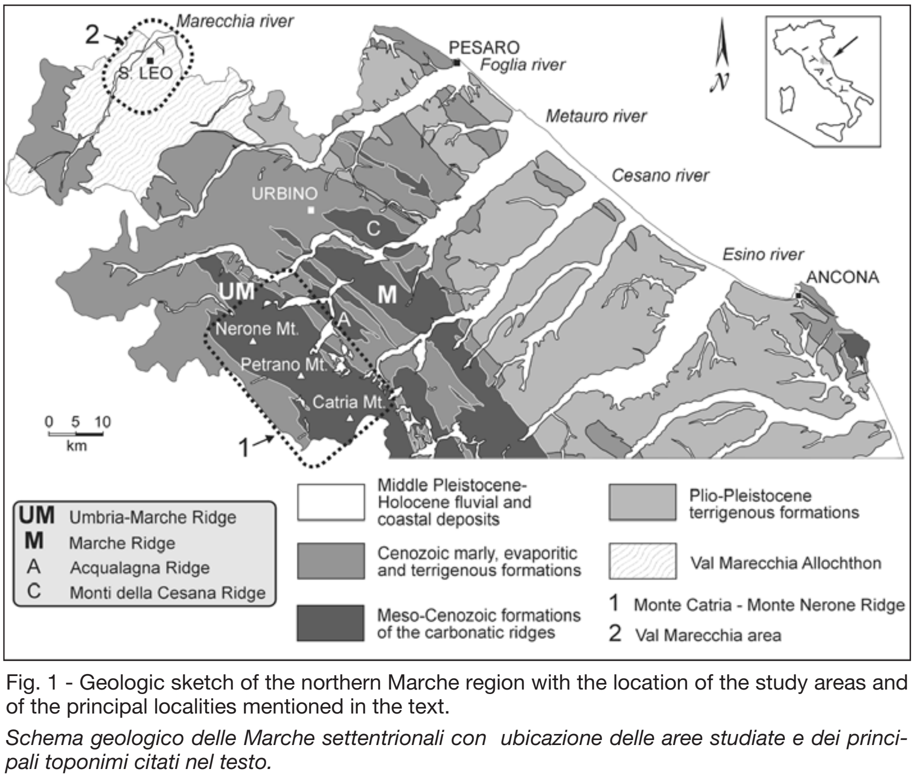

Fig. 1 - Geologic sketch of the northern Marche region with the location of the study areas and of the principal localities mentioned in the text.

Schema geologico delle Marche settentrionali con ubicazione delle aree studiate e dei principali toponimi citati nel testo.

rounded geometry of the anticline and its culminations (*e.g.*, A on Fig. 2), often related to transversal faults. This peculiar form has been shaped by different geomorphic processes, from weathering and mass movements to slope-wash and frost-shattering, often with selective behaviours able to highlight both lithologic contrasts and structural features, such as fault-zones and bended strata surfaces. The erosion of the anticline has been more effective under Pleistocene cold climatic conditions, thus several important landforms in the modern ridge are relicts of past morphogenetic stages. Other landforms, such as those related to mass-wasting or karst, are still more or less active, even though they can have experimented stages of more intense activity in the past (Bisci & Dramis, 1991b).

Our work focuses on a few significant landforms - which we are going to improve as geomorphosites - among the many ones occurring on the ridge. Namely, we will take into account landforms strictly related to the structure on Monte Petrano, landforms produced by Pleistocene glacial and cryogenic processes on the south-western side of Monte Catria, and forms related to karst processes on the southern side of Monte Nerone.

2.1.1 The Bevano glacial valley, Monte Catria

The Monte Catria massif, made up of Jurassic to Eocene carbonates, is a sector of the Umbria-Marche anticline ridge where two important axial culminations, related to transversal fault systems, give rise to as many peaks reaching heights of 1668 m (Monte Acuto) and 1701 m (Monte Catria) and separated from each other by a broad saddle (*cf*. Fig. 3). In correspondence with this latter, the inner flank of the massif is cut by the Bevano valley, where Pleistocene glacial landforms have been recognised (Savelli et al., 1995, Savelli & Pergolini, 1999) (Figs. 3, 4). A glacial shaping of this valley is suggested at a

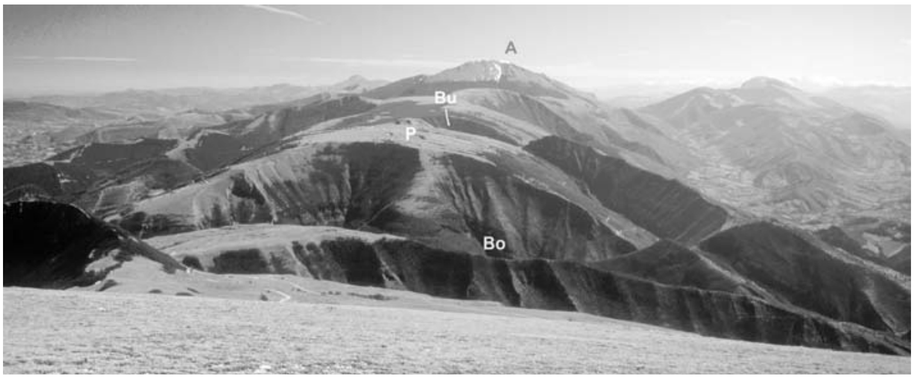

Fig. 2 - The Monte Catria-Monte Nerone anticline ridge, view from the southern side of Monte Nerone. A = Monte Acuto, Catria Massif. P = Monte Petrano. Bo = Bosso Gorge. Bu = Burano Gorge.

La dorsale anticlinalica Monte Catria-Monte Nerone vista dalle pendici meridionali di Monte Nerone. A = Monte Acuto, massiccio del Catria. P = Monte Petrano. Bo = Gola del Bosso. Bu = Gola del Burano.

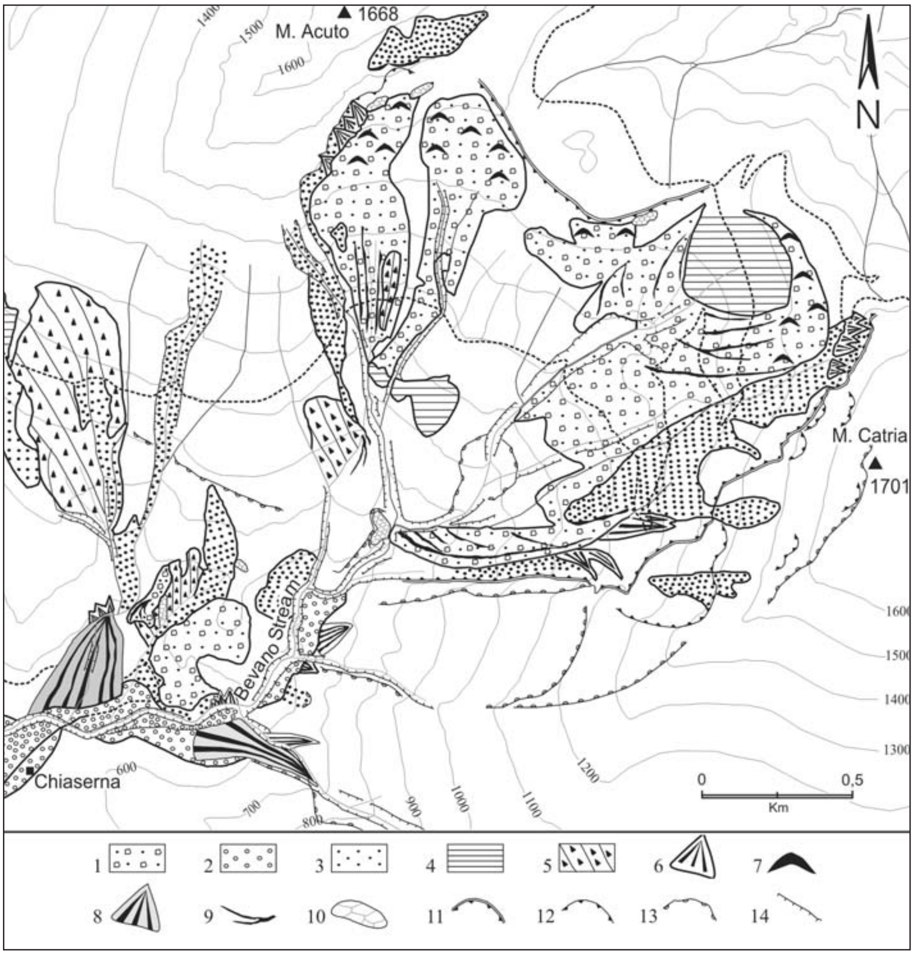

Fig. 3 - Geomorphologic sketch of the Bevano glacial valley, Monte Catria massif. 1= Upper Pleistocene lodgement and ablation till, at places slightly reworked. 2 = Upper Pleistocene and Holocene fluvial and fluvioglacial deposits. 3 = Holocene slope-waste debris. 4 = Inclined structural surface partially shaped by glacial erosion. 5 = Upper Pleistocene slope-waste stratified deposits. 6 = Talus cone. 7 = Hummocky kettled topography. 8 = Alluvial fan. 9 = Latero-terminal dump moraine. 10 = Landslide. 11 = Edge of glacially shaped scarp. 12= Edge of scarp shaped by nivation processes. 13 = Indifferentiated scarp. 14 = Scarp shaped by stream erosion.

Schema geomorfologico della valle glaciale del Bevano, massiccio di Monte Catria. 1= Depositi glaciali di fondo e di ablazione, a luoghi parzialmente rimaneggiati in superficie. 2 = Depositi fluvio-glaciali e fluviali del Pleistocene superiore e Olocene. 3 = Detrito olocenico. 4 = Superficie litostrutturale in parte di modellamento glaciale. 5 = Detriti stratificati del Pleistocene superiore. 6 = Cono detritico. 7 = Topografia a dossi e depressioni. 8 = Conoide alluvionale. 9 = Argine morenico. 10 = Frana. 11 = Orlo di scarpata di modellamento glaciale. 12 = Orlo di scarpata modellata da processi crionivali. 13 = Orlo di scarpata poligenica. 14 = Scarpata torrentizia.

glance by the morphology of the valley heads, even though other evidence of exaration -as striated rocks- cannot be observed; on the contrary, in places, rounded rocks reminding whale-back forms are detectable. The valley does not display a deep entrenchement because of a significant lateral erosion by the glacier itself on soft terrains interbedded with hard limestones. On the SE flank of Monte Acuto (right valley-side), the steep valley slopes shaped by glacial erosion merge into a wide cirque. The occurrence of glacialism, rather than by erosional landforms is emphasised by depositional landforms (Fig. 5). In fact, in some places, well preserved morainic ridges sub-parallel to the valley sides can be observed. The more external ridges lying near the foothills of the Monte Catria carbonatic massif, near the village of Chiaserna, stresses the extension of the upper Pleistocene glacier (Fig. 6) The debris covering the floor of highest valley parts, display a significant hummocky topography, probably related with the latest ablation stages. Broad Richter slopes (Fig. 7) associated with slope-waste stratified debris occur close to the valley trough, thus underlining the strong impact of upper Pleistocene periglacial processes all around the glaciated area.

2.1.2 The Monte Petrano anticline mountain

Monte Petrano (Fig. 8) is a 1163 m high relief standing out in the landscape because of its almost flat top-surface visible from long distances. It is separated southerly from Monte Catria and northerly from Monte Nerone respectively by the Burano and Bosso gorges transversally cutting the mountain ridge. Monte Petrano is a excellent example of anticline ridge, where the geological structure is perfectly reflected by the relief topography (P on Fig. 2, Fig. 9). No axial culminations, such as those of Monte Nerone and Monte Catria sectors,

Fig. 4 - The Bevano glacial valley.

La valle glaciale del Bevano.

Fig. 5 - Lateral dump moraine in the lower sector of the Bevano valley, Monte Catria massif.

Argine morenico nel settore inferiore della valle del Bevano, massiccio di Monte Catria.

Fig. 6 - Artistical reconstruction showing the maximum extent of the Bevano glacier (Monte Catria massif) in the upper Pleistocene. Same viewpoint of Fig. 4; after Savelli & Pergolini, 1999, modified.

Ricostruzione mostrante la massima estensione del ghiacciaio del Bevano (massiccio del Catria) nel Pleistocene superiore. Stessa prospettiva di Fig. 4; da Savelli & Pergolini, 1999, modificato.

Fig. 7 - Richter slope on the right side of the Bevano valley. Cherty limestones of the *Maiolica Formation*, Monte Catria massif.

Versante "di Richter" sul fianco destro della valle del Bevano. Calcari selciferi della formazione della Maiolica*, massiccio del Catria.*

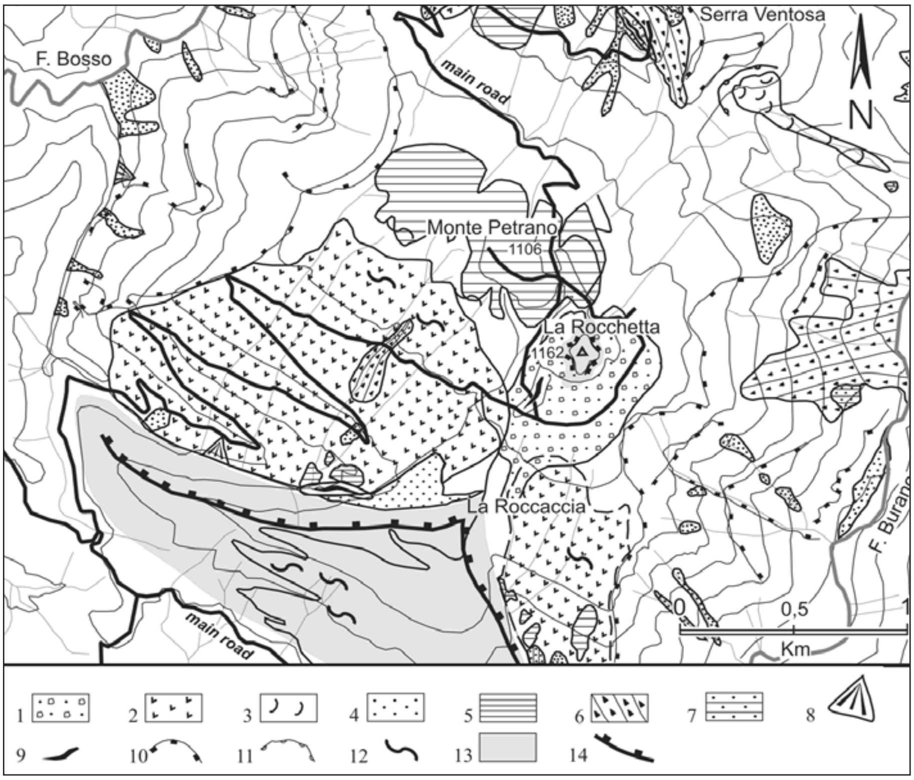

Fig. 8 - Geomorphologic sketch of Monte Petrano anticline relief. 1 = Upper Pleistocene and Holocene heterogeneous debris partially reworked by mass-flow processes. 2 = Rock-slide. 3 = Earth-flow. 4 = Holocene debris. 5 = Structural surface. 6 = Upper Pleistocene stratified slope-waste deposits. 7 = Talus. 8 = Talus cone. 9 = Debris ridge. 10 = Edge of undifferentiated scarp. 11 = Edge of landslide scarp. 12 = Landslide trench. 13 = Flatiron and related outlier. 14 = Edge of flatiron scarp.

Schema geomorfologico del rilievo anticlinalico di Monte Petrano. 1 = Detriti eterogenei del Pleistocene superiore e Olocene, in parte interessati da processi di colamento. 2 = Scorrimento in roccia. 3 = Frana di colamento. 4 = Detrito olocenico. 5 = Superficie strutturale. 6 = Detriti stratificati del Pleistocene superiore. 7 = Falda detritica. 8 = Cono detritico. 9 = "Cordone" detritico. 10 = Orlo di scarpata poligenica. 11 = Orlo di scarpata di frana. 12 = Trincea di frana. 13 = Flatiron e relativo outlier. 14 = Orlo di scarpata di flatiron.

occur to disturb the simple regularity of the tectonic folding, so that the relief is really an amazing natural model of an exhumed anticline, fit for appearing on a textbook (*e.g*. Bartolini & Peccerillo, 2002). The anticline crest corresponds with a wide smooth and almost flat top-surface, shaped by differential erosion in correspondence with the boundary between the soft *Marne a Fucoidi Formation* and the underlying hard limestones of the *Maiolica Formation*. On the flanks of the mountain three well developed flatirons are found (Figs. 2, 8, 9, 10), testifying the erosional removing of younger formations. The same indication is given by the outlier of La Rocchetta, a small hill elevating from the top-hill flat (Figs. 2, 9, 11). The anticline ridge has been shaped by

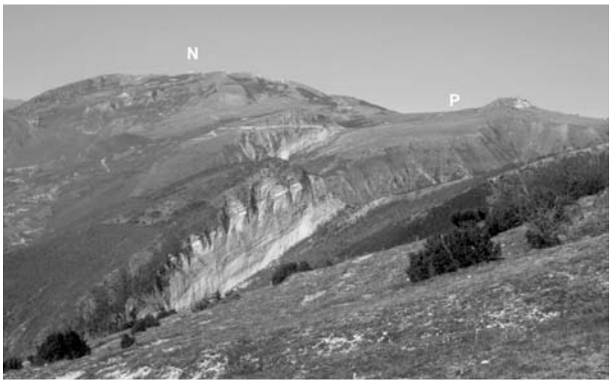

Fig. 9 - The southwestern flank of the Monte Catria-Monte Nerone anticline ridge; view from the northern side of the Catria massif. P = Monte Petrano. N = Monte Nerone. Please note “La Rocchetta” outlier on the top of Monte Petrano and the series of flatirons on its left.

Versante sud-occidentale della dorsale anticlinalica Monte Catria-Monte Nerone vista dal versante settentrionale del massiccio del Catria. P = Monte Petrano. N = Monte Nerone. Si notino l’”outlier” de La Rocchetta sulla sommità di Monte Petrano e la serie dei flatiron sulla sinistra.

Fig. 10 - “La Roccaccia” flatiron, Monte Petrano.

Il flatiron de La Roccaccia, Monte Petrano.

Fig. 11 - “La Rocchetta” outlier, Monte Petrano. Please, note the mass-flow lobes at the foot of the outlier, where clayey terrains of the *Marne a Fucoidi Formation* outcrop.

L’outlier de La Rocchetta, Monte Petrano. Si notino i lobi prodotti da processi di colamento sui litotipi argillosi della formazione delle Marne a Fucoidi *al piede dell’outlier stesso.*

Fig. 12 - Trench on a wide rock-sliding along bedding planes in the cherty limestones of the uppermost *Maiolica Formation*, Monte Petrano.

Trincea su un ampio rock-slide lungo superfici di strato dei calcari selciferi della parte sommitale della formazione della Maiolica*, Monte Petrano.*

different agents and processes, but certainly the role of mass movements has been in the past and is still today one of the most effective. Diffuse bed-on-bed rock-slide phenomena are recognisable on the flanks of the anticline ridge (Fig. 12), where still contribute to maintain the adjustment of topography on fold geometry; moreover, several small earth-flows are active all around the relief in correspondence with the *Marne a Fucoidi Formation* clayey terrains. The morphogenetic role of upper Pleistocene cryonivation phenomena has been important too, as pointed out by thick relict stratified slope-waste deposits widespread all over the flanks of the relief (Fig. 13).

Fig. 13 - Upper Pleistocene periglacial slope-waste stratified deposits supplied by the limestones of the *Scaglia Rossa Formation*, southwestern flank of Monte Petrano.

Detriti stratificati di ambiente periglaciale prodotti dai calcari della formazione della Scaglia Rossa *sul versante sud-occidentale di Monte Petrano.*

2.1.3 The Pieia karst area, Monte Nerone

This geomorphosite (Figs. 14, 15), displaying a remarkable karst morphogenesis, stresses on the south-west side of Mount Nerone. Here, Jurassic limestones of the *Calcare Massiccio Formation* crop out astride an important fault system representing the southern margin of the Jurassic structural high of Monte Nerone (*cf.* Jacobacci *et al*., 1974). The upper Pleistocene-Holocene lowering of the hypogean spelaeogenetic level is responsible for many relict karst landforms and for partially collapsed fossil caves (*e.g*. Pipistrelli Cave, Fig. 14) recognisable throughout the almost whole site of Pieia. Namely, the area is split by wide karst depressions, such as the so-called "Pieia blind valley" and "Fosso del Breccione" valley. The first is a remarkable wide trough (Figs. 14, 16) running along the southern Monte Nerone foothill, lacking in any surface drainage and filled up by slope debris and alluvial deposits likely upper Pleistocene-Holocene in age. The latter is a broad valley joining downhill the Pieia blind valley and sided by two high rock spurs, i.e, Sasso della Rocca and Sasso del Re (Figs. 14, 17). An occasional stream run through the valley carrying downstream large amounts of debris, hence the name of "*Fosso del Breccione*", *i.e*. "*dale overwhelmed with coarse debris*". At the foot of the hillslope, just near the downstream end of the Pieia blind valley, an intermittent karst resurgence (*i.e.* Resurgence of Torrente Giordano, Figs. 14, 18) connected to unexplored cave systems is noticeable, pointing out a remarkable subterranean circulation. Finally, this area

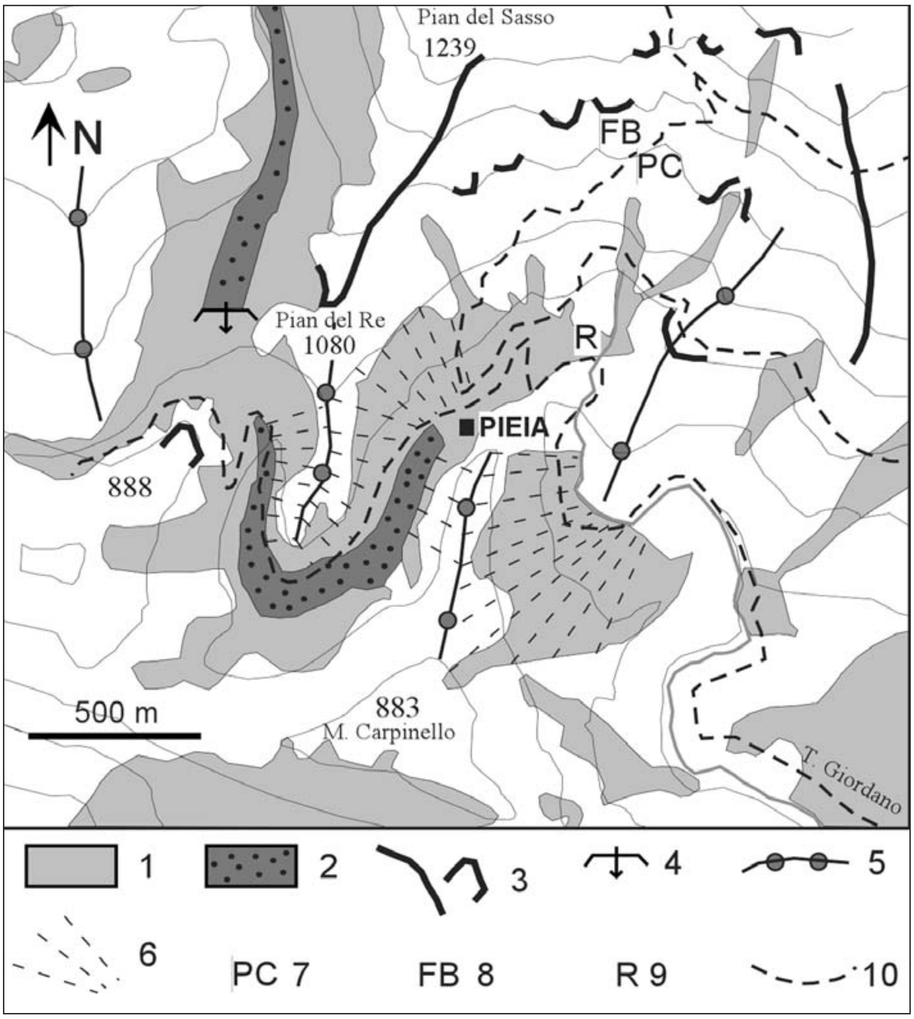

Fig. 14 - Geomorphologic sketch of the Pieia karst area, southern side of Monte Nerone. 1 = Upper Pleistocene-Holocene slope-waste debris. 2 = Upper Pleistocene-Holocene alluvium. 3 = Karst spur and wall. 4 = Hanging valley. 5 = Crest. 6 = Richter slope. 7 = Pipistrelli Cave. 8 = Fondarca natural bridge. 9 = Resurgence of Torrente Giordano. 10 = Road.

Schema geomorfologico dell'area di Pieia, sul versante meridionale di Monte Nerone. 1= Detrito di versante del Pleistocene superiore-Olocene. 2 = Depositi alluvionali del Pleistocene superiore-Olocene. 3 = Sperone e muro carsico. 4 = Valle sospesa. 5 = Cresta. 6 = Versante di Richter. 7 = Grotta dei Pipistrelli. 8 = Ponte naturale di Fondarca. 9 = Risorgiva del Torrente Giordano. 10 = Strada.

bears one of the most striking landforms of the Monte Catria-Monte Nerone site, namely the natural bridge of *Fondarca* (Figs. 14, 19), more than 30 m high and c.ca 15 m wide, connected to a deep collapse-sinkhole.

Fig. 15 - Panoramic view of the Pieia site, southern flank of Monte Nerone.

Veduta panoramica del sito di Pieia, versante meridionale di Monte Nerone.

Fig. 16 - The Pieia blind valley, southern flank of Monte Nerone.

La valle cieca di Pieia, sul versante meridionale di Monte Nerone.

Fig. 17 - The *Sasso del Re*, a rock-spur on the southern flank of Monte Nerone.

Il Sasso del Re*, uno sperone roccioso sul fianco meridionale di Monte Nerone.*

Fig. 18 - The karst resurgence of Torrente Giordano (southern flank of Monte Nerone) during a stage of maximum flood.

La risorgiva del Torrente Giordano (versante meridionale di Monte Nerone) durante una fase di massima attività.

3. GEOMORPHOSITES IN THE VAL MARECCHIA NAPPE

The Val Marecchia Nappe displays a lot of forms of geomorphologic relevance. Since a peculiar concentration of spectacular and interesting landforms is found in an area enclosing the famous San Leo cliff and the relief of Rocca di Maioletto, we have chosen this area as the best representative of the whole domain of the Val Marecchia Nappe (Fig. 1). Similarly to the already described Monte Catria-Monte Nerone area, this "*landform unit*" gathers several interesting and peculiar geomorphosites.

3.1. The area of San Leo and Rocca di Maioletto

This geomorphosite is located on the right side of the middle reach of the Marecchia River valley (Fig. 1). Most of the landforms of this site reveals a strong control by the litho-structural arrangement of the Nappe, stressing both the lack of simple geometric arrangements in the geologic structure itself and the effect of rocks of quite different resistance to degradation and erosion processes (*e.g*. clays vs. arenites or limestones). As a matter of fact, the presence of resistant rock plates embedded in clayey terrains advantage the pro-

Fig. 19 - Fondarca natural bridge, southern flank of Monte Nerone.

L'arco naturale di Fondarca, sul versante meridionale di Monte Nerone.

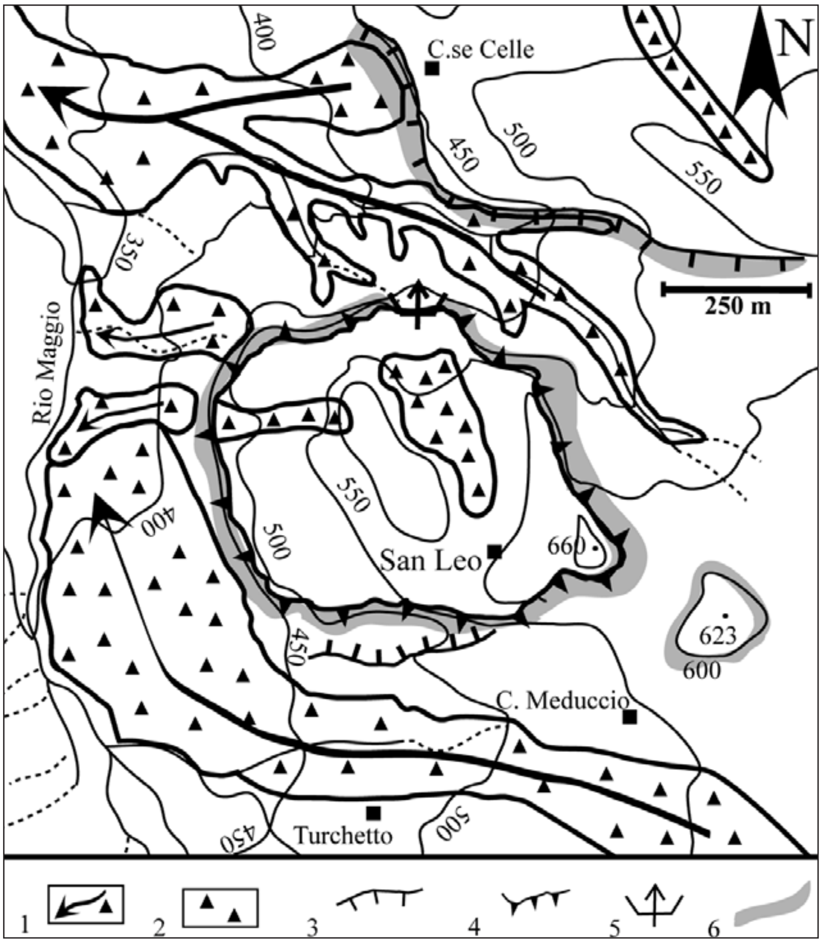

Fig. 20 - Geomorphologic sketch of San Leo site. 1 = Earth-flow. 2 = Holocene slope-waste debris. 3 = Badland edge. 4 = Edge of undifferentiated scarp. 5 = Hanging valley. 6 = Outlier margin.

Schema geomorfologico del sito di San Leo. 1 = Frana di colamento. 2 = Detrito di versante olocenico. 3 = Orlo di calanco. 4 = Orlo di scarpata poligenica. 5 = Valle sospesa. 6 = Bordo di outlier.

cesses of selective erosion responsible for the shaping of steep cliffs at the margin of rock relieves and spurs. The occurrence of clayey bedrocks, in turn, lead to undermining of resistant rock-plates - with consequent retreat of their borderline-cliffs - as well as to extensively shaping of hillsides by mass-movements and to wide badlands growth.

3.1.1 San Leo rock-plate

An isolated rock-plate, towering up to the height of 639 m a.s.l. on the right side of the mid Marecchia River valley (Fig. 20), is one of the most famous sites of central Italy for being the place where the village of San Leo and his celebrated, impressive castle rise (Fig. 21). The cliff bordering the rock-plate (*cf.* Figs. 21, 22) con-

Fig. 21 - Aerial view of the San Leo rock-plate.
Veduta aerea della rupe di San Leo.

Fig. 22 - Northern cliff of the San Leo rock-plate.
Il versante settentrionale della rupe di San Leo.

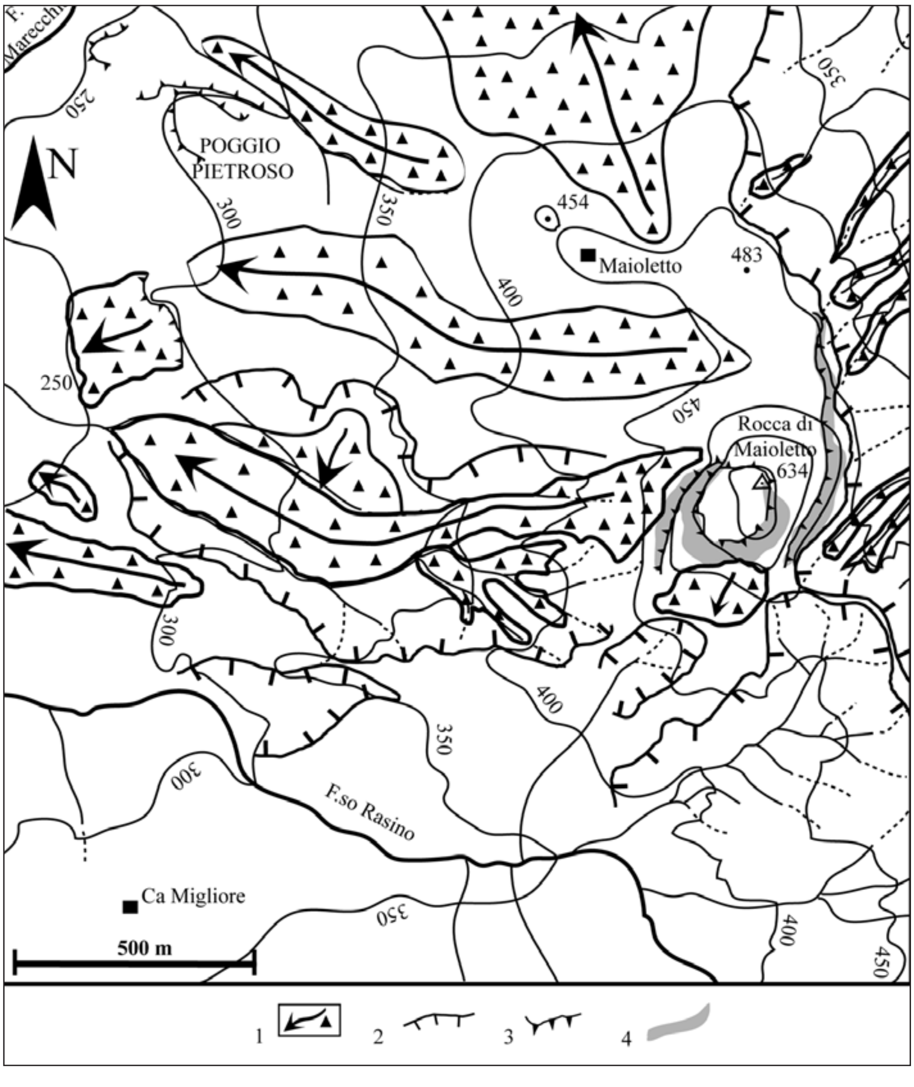

Fig. 23 - Geomorphologic sketch of the Rocca di Maioletto area. 1 = Earth-flow. 2 = Badland edge. 3 = Edge of undifferentiated scarp. 4 = Outlier margin.

Schema geomorfologico dell'area di Rocca di Maioletto. 1 = Colamento di terra. 2 = Orlo di calanco. 3 = Orlo di scarpata poligenica. 4 = Bordo di outlier.

sists of organogenic limestones forming the lower part of the *San Marino Formation* and of glauconitic sandstones belonging to the *Monte Fumaiolo Formation*, both belonging to the Epi-Ligurian units (*cf.* Conti, 1989; 1994). The plate of San Leo rests above the varicoloured clays of the *Argille Varicolori* (Conti, 1994), as shown both on an extensive outcrop on the western side of the rock slope (Fig. 22) and in the adjacent badlands. These clays are subject to rapid erosion as well as to unloading phenomena, thus landslide processes, such as slumping or earth- and debris-flows, concentrate both at the foot of the rock-plate and in the surrounding badlands. As a consequence, the rock-plate is so actively undermined that the stability of the bordering cliff is seriously compromised by ongoing rock-falls and topples, so that continuative and expensive maintenance and consolidation are requested to avoid damages to the old town and to the castle.

3.1.2. The Rocca di Maioletto outlier

Rocca di Maioletto corresponds with an isolated hill (Fig. 23) situated on the right hydrographic side of the Marecchia River valley, two kilometers to the west of the San Leo rock-plate. The top-hill is constituted by Pliocene sandstones and conglomerates overlying pelitic units of the same age. Pliocene terrains, in turn, overly overall clayey units of the Val Marecchia Nappe represented by messinian gypsy-clays (Epi-Ligurian units) and by varicoloured clays (Ligurian units) as well. From the geomophological standpoint, Rocca di Maioletto is an *outlier* boarded on two sides by remarkable badlands and by large landslides (Figs. 24, 25). The northern side of the *outlier*, whose top preserves an ancient fortress ruins, was affected on 29th May 1700 by a devastating landslide, presumably a rock-slide, which destroyed a village. The rock materials fallen downslope during this landslide fed (or perhaps gave origin to) an earth-flow which is still active today, and which has transported for more than 1 km downslope many large blocks coming from the Rocca di Maioletto cliff. The comparison of the positions of several blocks recognisable on aerophotographs taken at different times between 1978 and 1997 has allowed the calculation of the velocity of the earth flow for this span of time to be made at an average of 4.2 cm/day.

3.1.3. Gypsum karst, Rio Strazzano

Microcrystalline nodular gypsum belonging to messinian Epi-Ligurian units (*cf*. Conti, 1989) outcrops in the area of Legnanone, *c.ca* 2 km north of San Leo. This geomorphosite is crossed by Rio Strazzano (Fig. 26), a small right tributary of the Marecchia river originating from the Spring of San Francesco, close to the monastery of Sant'Igne, near San Leo. The approximately 3 km-long Rio Strazzano encounters the gypseous rocks in its early course, where it takes to flow between 10-15 m high walls of a narrow gorge. While flowing through the gorge, it disappears into numerous shallow karst holes, streaming out *c.ca* 1km downstream (Fig. 26). Therefore, midway through its course Rio Strazzano flows permanently underground, creating a suggestive hypogeal complex with alternating narrow underground passages and large caves. Along Rio Strazzano dale, distinctive small, medium and large-scale karst forms did develop (Fig. 26) on the surface also. Gypsum dissolution landforms of this area are quite similar to those usually formed on calcareous rocks, though the high solubility of gypsum implies a faster process as well as a shorter existence of karst forms. Gypsum dissolution along Rio Strazzano led to

Fig. 24 - Aerial view of Rocca di Maioletto site, mid Marecchia River valley.
Veduta aerea di Rocca di Maioletto, versante destro della media Val Marecchia.

Fig. 25 - Badlands on the southeast of Rocca di Maioletto, mid Marecchia River valley.
Calanchi sul versante sudorientale di Rocca di Maioletto, versante destro della media Val Marecchia.

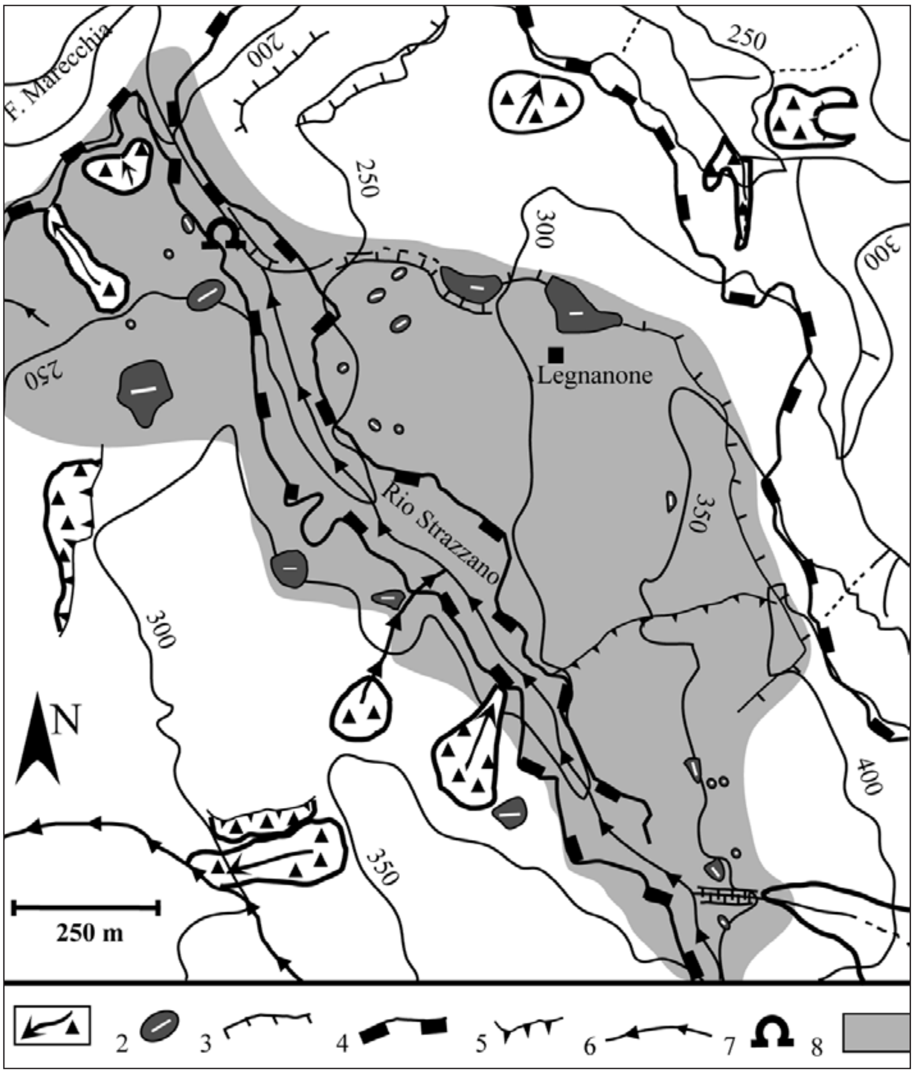

Fig. 26 - Geomorphologic sketch of the Rio Strazzano area. 1 = Earthflow. 2 = Sinkhole. 3 = Edge of structural scarp. 4 = Edge of fluvial scarp. 5 = Edge of landslide scarp. 6 = Karst canyon. 7 = Cave. 8 = Gypsum outcrops.

Schema geomorfologico del sito di Rio Strazzano. 1 = Frana di colamento. 2 = Dolina. 3 = Orlo di scarpata strutturale. 4 = Orlo di scarpata d'erosione fluviale. 5 = Orlo di scarpata di frana. 6 = Canyon carsico. 7 = Grotta. 8 = Area di affioramento dei gessi.

the creation of a characteristic dry valley-reach in correspondence with its underground streaming. The area is also characterised by other meaningful landforms such as a natural arc, several shallow-sinkholes, a karst canyon and potholes (Fig. 27). Microforms such as a microkarren, reversed kettles, calcareous crusts and travertine fragments occur as well.

This work was funded by MIUR project, "The geosites of the Italian landscape: research, evaluation and enhancement." to O. Nesci. Special thanks to Nicole Savelli for revising the English text.

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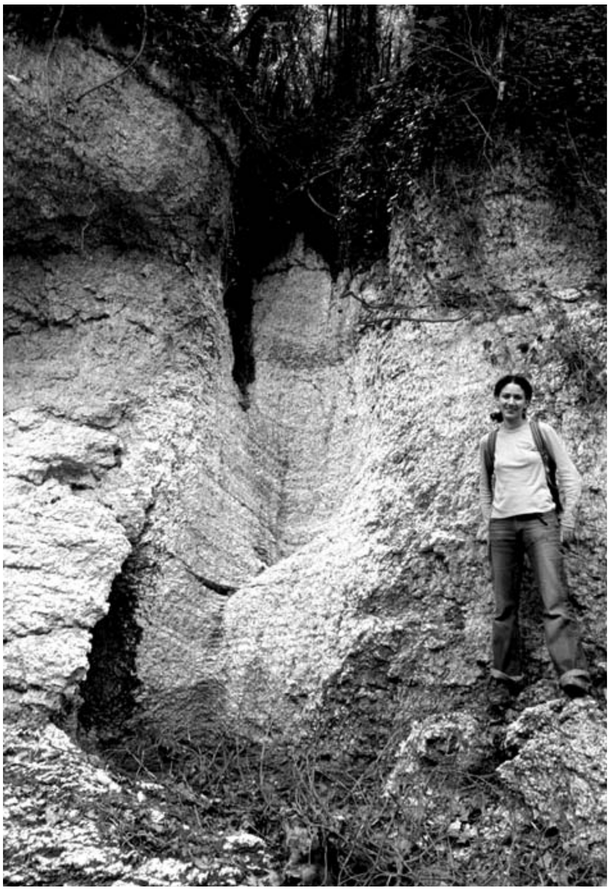

Fig. 27 - Pothole in the gypsum of Rio Strazzano area, mid Marecchia River valley.

Forma di evorsione nei gessi di Rio Strazzano, versante destro della media Val Marecchia.

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