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Carlo BARONI (*,**), Pierluigi PIERUCCINI (***), Monica BINI (*), Mauro COLTORTI (***),
Pier Luigi FANTOZZI (***), Giulia GUIDOBALDI (*), Daniele NANNINI (*),
Adriano RIBOLINI (*) & Maria Cristina SALVATORE (*)

GEOMORPHOLOGICAL AND NEOTECTONIC MAP OF THE APUAN ALPS (TUSCANY, ITALY)

Abstract: Baroni C., Pieruccini P., Bini M., Coltorti M., Fantozzi P.L., Guidobaldi G., Nannini D., Ribolini A. & Salvatore M.C. - *Geomorphological and Neotectonic Map of the Apuan Alps (Tuscany, Italy).* (IT ISSN 0391-9838, 2015)

Renowned since the Roman Period for the extraction of precious marble, the Apuan Alps (northern Tuscany) are an extraordinary region of natural and cultural heritage in the Mediterranean basin and contain a large number of geosites of international and national interest. The great variety of morphologic and topographic contexts, ranging from the coastal plain of Versilia to the rugged, harsh landscape in the interior, makes this region remarkable for its peculiar geologic and geomorphologic setting.

Two map sheets are appended to this paper: (1) a geomorphological map of Apuan Alps Regional Park and its immediate surroundings at a scale of 1:50,000 and (2) two thematic maps at a scale of 1:100,000 ('Neotectonic Map' and the 'Map of Selected Sites of Geomorphological Significance') and other four thematic maps at a scale of 1:200,000 that present the relief, slope aspects, drainage networks, and climatic elements of the region.

The preparation of the Geomorphological Map followed the principles adopted by the National Group of Physical Geography and Geomorphology and by the National Geological Survey, Working Group for Geomorphological Cartography and was updated using the guidelines for the fieldwork and preparation of the Geomorphological Map of Italy at a scale of 1:50,000.

The geomorphologic data were stored in a spatial database and managed using a GIS application (ArcGis™).

The high relief, complex geologic structure, and Pleistocene climate condition have deeply shaped the evolution of the Apuan landscape, which is characterized by great structural control of the landforms, an extensive and complex epigean and hypogean karst landscape, and impressive shaping by glaciers during the Late Pleistocene. In addition, gravity, frost shattering, marine action, and running water have played significant roles as active morphogenetic agents. The coastal belt has been the source of abundant valuable data regarding the Holocene coastal evolution. Finally, the present-day landscape has also been extensively shaped by a long history of anthropic activities, including agriculture, timber production, intense marble quarrying in the interior and widespread urban and productive settlements in the coastal plain.

Key words: Geomorphological mapping, Geographic information system (GIS), Geopark, Anthropogenic geomorphology, Geomorphologic hazard, Neotectonics, Apuan Alps.

Riassunto: Baroni C., Pieruccini P., Bini M., Coltorti M., Fantozzi P.L., Guidobaldi G., Nannini D., Ribolini A. & Salvatore M.C. - *Carta geomorfologica e neotettonica delle Alpi Apuane (Toscana, Italia).* (IT ISSN 0391-9838, 2015)

Conosciute fin dall'epoca romana per l'estrazione di preziosi marmi, le Alpi Apuane (Toscana settentrionale) conservano uno straordinario patrimonio naturale e culturale del bacino del Mediterraneo, che comprende numerosi geositi di interesse globale e nazionale. La coesistenza di contesti morfologici e topografici molto dissimili, che spaziano dalla pianura costiera della Versilia all'aspro e duro paesaggio montuoso nel cuore del massiccio, rendono questo territorio peculiare per l'estrema varietà geologica e geomorfologica. In questo lavoro vengono presentate due tavole, allegate al volume, relative la prima alla Carta Geomorfologica del Parco Regionale delle Alpi Apuane e delle aree limitrofe (alla scala 1:50,000), mentre la seconda contiene due carte tematiche alla scala 1:100,000 ('Schema neotettonico' e 'Schema delle principali emergenze geomorfologiche) e altre quattro carte tematiche alla scala 1:200,000, che sinteticamente illustrano le fasce altimetriche, l'esposizione, il reticolo di drenaggio e gli elementi climatici.

La struttura della legenda della Carta Geomorfologica segue le linee guida suggerite dal Gruppo Nazionale di Geografia Fisica e Geomorfologia e dal Servizio Geologico Nazionale, Gruppo di Lavoro per la Cartografia Geomorfologica, aggiornato con le Linee guida per il lavoro sul campo e per la rappresentazione della carta geomorfologica di l'Italia alla scala 1:50,000. Tutti i dati geomorfologici sono stati organizzati ed archiviati in un database spaziale e gestito in ambiente GIS (ArcGis ™).

(*) *Dipartimento di Scienze della Terra, Università di Pisa, Via S. Maria 53, 56126 Pisa, Italy (corresponding author: mariacristina.salvatore@unipi.it)*
(**) *Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse (CNR-IGG), Pisa*
(***) *Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Università di Siena, Via Laterina 8, 53100 Siena, Italy*

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La variabilità altimetrica, la complessa struttura geologica e i cambiamenti climatici pleistocenici, hanno profondamente guidato l'evoluzione del paesaggio Apuano che si caratterizza per un elevato controllo strutturale delle forme del rilievo, un diffuso e articolato paesaggio carsico epigeo ed ipogeo, un importante modellamento ad opera dei ghiacciai del Pleistocene superiore; non mancano, peraltro, significativi contributi di agenti morfogenetici quali la gravità, il crioclastismo, il mare e le acque di scorrimento superficiale, mentre nella fascia costiera sono conservate importanti testimonianze dell'azione marina olocenica. Infine, l'attuale paesaggio deriva anche dall'intensa e antica attività antropica che localmente lo ha modellato profondamente (uso del suolo agricolo e forestale, intensa e diffusa attività estrattiva, diffusi insediamenti urbani e produttivi nella pianura costiera).

TERMINI CHIAVE: Cartografia geomorfologica, Sistema informativo geografico, Geoparco, Geomorfologia antropica, Pericolosità geomorfologica, Neotettonica, Alpi Apuane.

INTRODUCTION

The Apuan Alps are located in northern Tuscany. Due to their geologic and geomorphologic peculiarities and their proximity to the coast, they contain a great variety of morphologic and topographic contexts including the coastal plain of Versilia, the western foothills, and the high peaks of the mountain massif (figs. 1 and 2).

The Apuan Alps have been renowned since the Roman Period for the extraction of valuable marble, which is exported and appreciated worldwide today. During the Renaissance, Michelangelo Buonarroti visited the Carrara Marble Basins (i.e. the Michelangelo Quarries) to select the raw blocks for sculpting some of his most famous and admired masterpieces. He also explored the Apuan Alps to find new sites for marble extraction. Less known but equally noteworthy are the wonders of the landscape of this mountain range, which are recognizable at a great distance from whichever direction a visitor approaches the Apuan Alps.

We herewith present our Geomorphological Map (Sheet 1), which was prepared at a scale of 1:50,000 and spans Apuan Alps Regional Park and its immediate surroundings. Sheet 2 consists of six thematic maps: the 'Neotectonic Map' and the 'Map of Selected Sites of Geomorphological Significance' at 1:100,000 scale, and the 'Elevation Map', 'Aspect Map', 'Drainage Network Map' and 'Map of Climatic Elements' at 1:200,000 scale. Sheets 1 and 2 are freely

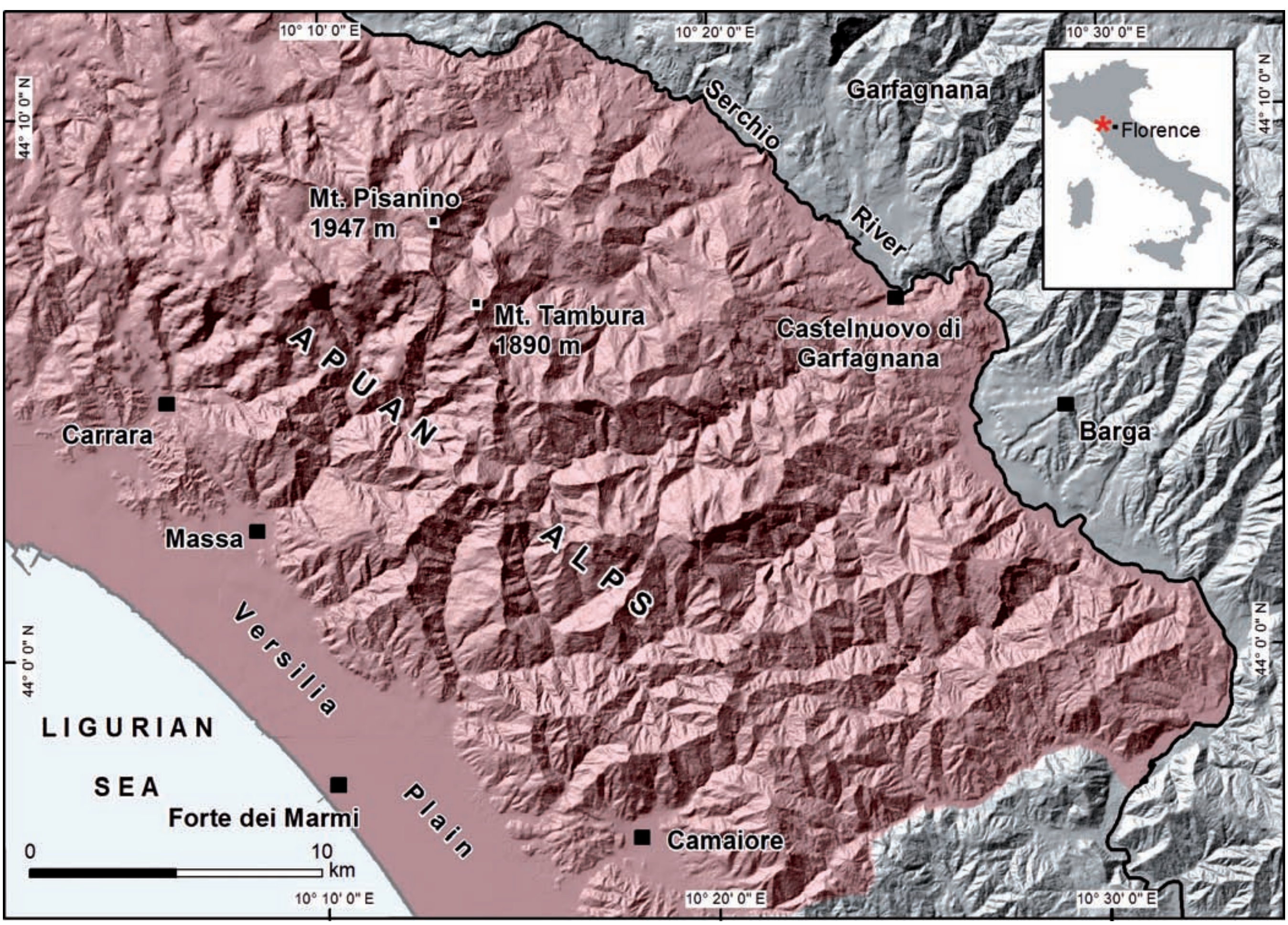

FIG. 1 - Location map of the investigated area. In pink the area represented in the Geomorphological and Neotectonic map (see Sheets 1 and 2 annexed to the paper).

FIG. 2 - The rough and harsh landscape of the Apuan Alps.
M. Fiocca and M. Sumbra are visible in the foreground. In distance the profile of M. Sagro (photo G. Ottria).

downloadable together with these explanatory notes from the website http://gfdq.glaciologia.it/issues/.

The Geomorphological Map is a valuable tool that allows for rapid understanding of the many landscape peculiarities of Apuan Alps Regional Park, including areas affected by landslides, river processes and faulting, which pose hazards in the area. The map also allows for easy recognition of areas affected by human activity.

The maps contain a synthesis of information accessible to both (i) a wider audience of hikers and (ii) a specialized audience seeking an overview of the main landscape features and interpretations of the geomorphic evolution of the Apuan Alps. Certain generalizations were necessary due to the map scale, and many small landforms were not mapped.

This work is the result of research in the region performed over many years by researchers from the University of Pisa and Siena. These experts shared published and unpublished data and integrated these with modern interpretations of the geologic and geomorphic evolution of the region to develop a comprehensive, and up-to-date product available to specialists, undergraduate students and visitors to Apuan Alps Geopark.

THE STUDY AREA

The Apuan Alps are regarded among the westernmost ridge in the Northern Apennines chain and are located a few kilometres east of the Ligurian Sea.

The Apuan Alps form a ridge parallel to the coast and extend approximately 50 km NW to SE with a width of approximately 30 km. The massif is bordered on the NE by the Garfagnana Basin (F. Serchio) and on the NW by the Lunigiana Basin (F. Magra). On the south-western side, the Versilia Plain, crossed by the Carrione, Frigido, and Versilia Rivers, lies between the massif and the Ligurian Sea. Located 10 km inland from the coast, M. Pisanino (1947 m) and M. Tambura (1890 m) are the two highest of the 15 peaks that exceed 1700 m a.s.l. in elevation.

Although located in Tuscany, far from the Alpine region, the Apuan Alps have earned the nickname "Alps", meaning region elevated above the neighbouring areas, because of their (i) jagged ridges and (ii) peculiar rocky peaks. Rugged profiles, steep slopes and high relief energy give the mountain range an impressive aspect that morphologically differentiates the Apuan Alps from the Northern Apennines representing an *unicum*, the Italian term "Alps" for mountains located outside the Alpine region. Known in ancient times as "Panie", these mountains were probably named "Apuan" eponymously for the Ligurian people (*Ligures Apuanes*) who lived there before the Roman conquest. Later, there were several other references to the mountains in the literature of the Middle Ages. In *De Montibus*, Boccaccio referred to the "*Petra Apuana Mons*", and in the *Divina Commedia*, Dante Alighieri referred to the mountain chain as "*Pietrapana*" (Inferno, XXXII, 29). In 1798, the term "Apuan Alps" appeared in official documents when the Cisalpine Republic established a Department of the Apuan Alps. The geographer Repetti (1833) used this place name in the first half of the 19th century, and since then, the toponym 'Apuan Alps' has been included in the scientific literature and on geographic maps (Federici, 2009).

A pronounced asymmetry characterizes the two sides of the Apuan Alps. The south-western, maritime side appears as a ridge backed by a steep wall rising abruptly from the coastal plain of recent origin. The steep slopes act as a stark barrier blocking the humid westerly winds laden with rain. This morphologic setting explains the average rainfall in excess of 3000 mm/yrs in the region, which is known as being among the rainiest regions in Europe (Rapetti & Vittorini, 1994). This high precipitation is due to the relief and the proximity to the Ligurian Sea, which combine to produce orographic cooling of air masses of Atlantic or Mediterranean origin and consequent intense rainfall.

The north-eastern side of the Apuan Alps (Garfagnana and Lunigiana) is characterized by flanks that slope gently from the watershed to the valley bottoms of the F. Serchio and F. Magra.

Despite the moderate elevation of the highest peaks of the Apuan Alps, the Apuan core has generally been inaccessible. The harshness of the mountain range, described since the 19th century, still characterizes the region, and communication is still difficult between the interior and the maritime areas to either side.

GEOLOGIC AND STRUCTURAL SETTING

The Northern Apennines is a collisional belt that originated from the closure of the Ligure-Piemontese basin, a narrow oceanic basin opened in the Middle-Late Jurassic between the European and Adria continental margins. This oceanic basin began to close since the Late Cretaceous as result of the convergence related to Europe-Africa motion. This geodynamic event produced an intraoceanic subduction followed by a continental collision in the Middle Eocene - Early Oligocene timespan. Continental collision was characterised by the eastward progressive migration of the deformation toward the internal domains of the Adria plate, resulting in the building of a thrust-and-fold belt made up of a stack of structural units detached from the Adria domains and deformed with an east to north-east vergence. Since Middle Miocene, the overthickened stack of the tectonic units of the inner Northern Apennines have been affected by extensional tectonics, coeval with the compression in the outer Northern Apennines. During the extensional tectonics the uppermost structural levels of the Northern Apennines were exhumed by low-angle normal faults in several tectonic windows, of which the most important is the Apuan Alps (Carmignani & Kligfield, 1990; Carmignani & *alii*, 2000, 2004).

The geological setting of the Apuan Alps tectonic window (fig. 3) is thus characterized by several superimposed tectonic units, each characterized by successions representative of different paleogeographic domains.

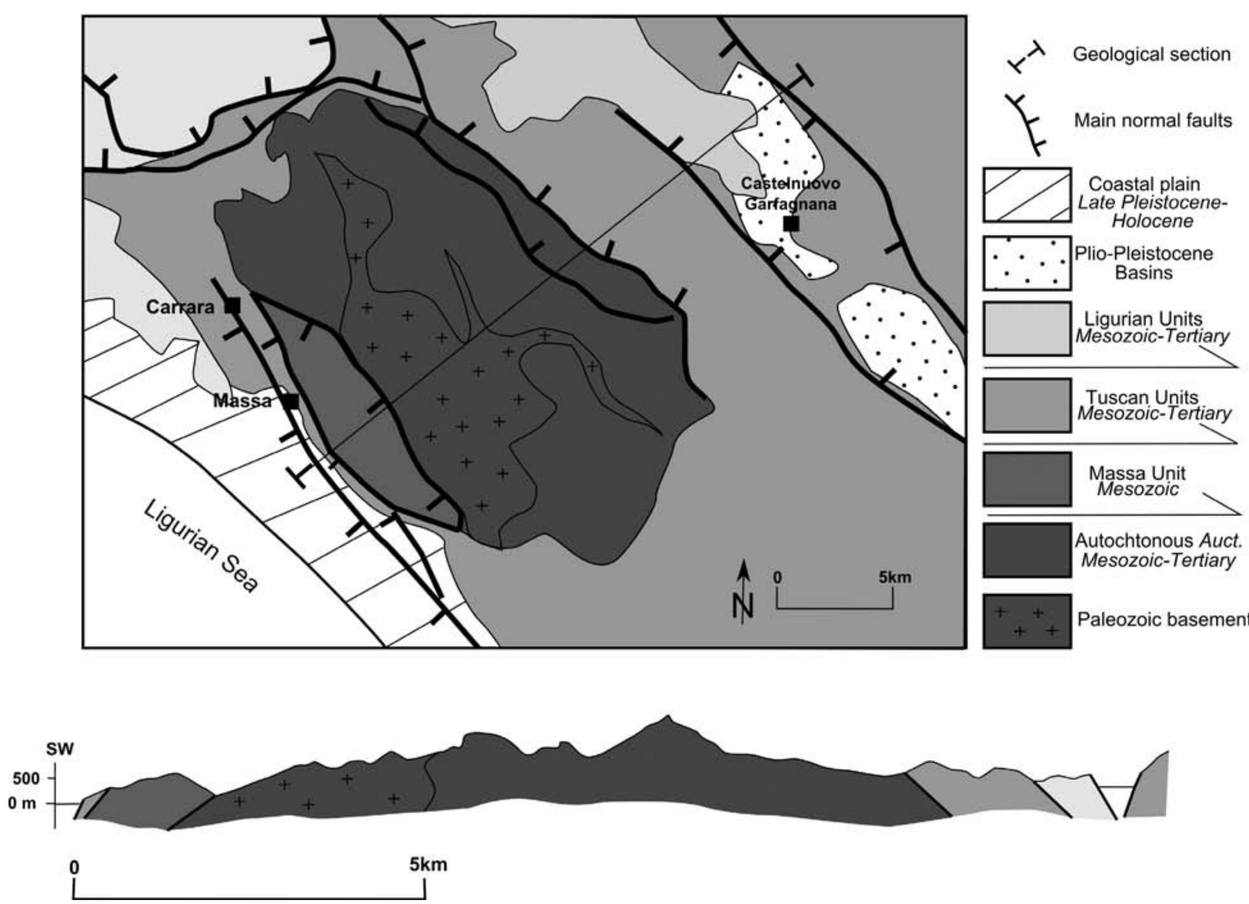

FIG. 3 - Geological and tectonic sketch map of the Apuan Alps (modified after Carmignani & alii, 2004, 2006). Low angle normal faults separate the tecnic units.

FIG. 4 - Marble quarries in the core of the Apuan Alps, along the south eastern slope of M. Sagro (photo L. Pandolfi).

At the core of the tectonic window, the Apuan Alps Unit is characterized by a Variscan basement, consisting of an Ordovician to Devonian succession deformed and metamorphosed at P/T conditions of greenschist facies during the Variscan orogeny. The Palaeozoic basement is unconformably overlain by the so-called Autochthonous *Auct.,* a Mesozoic-Tertiary sedimentary succession representative of the Adria continental margin. This succession consists, from bottom to top, of continental deposits ("Verrucano"), carbonatic platform (metadolostone, dolomitic marble and the "Carrara" marble; fig. 4) and pelagic metasediments (metalimestone, chert, calcschist and phyllite) showing a transition siliciclastic metaturbidites ("Pseudomacigno"). The Mesozoic-Tertiary sedimentary succession is affected by strong deformations and by medium- to low-grade metamorphism. The age of the metamorphism, leading to the formation of the famous "Carrara" marble of the Apuan Alps, is about 20 Ma, according to paleontological and radiometric data (Kligfield & *alii*, 1986).

In the western side, the Apuan Alps Unit is overlain by the Massa Unit, made up of a Triassic continental metasedimentary sequence ("Verrucano") consisting of metaconglomerate, metasandstone, metasiltstone and phyllite that pass upward to marine sediments consisting of marble, metabasalt, metarudite, quartzite and phyllite.

Both Apuan Alps and Massa Units are overthrusted by the Tuscan Nappe, showing a succession similar to that of Apuan Alps Unit but deformed at P and T conditions related to very low-grade metamorphism. The basal contact of the Tuscan Nappe is represented by a cataclasites ("Calcare Cavernoso") derived from the deformation of the Triassic evaporites.

At the top of the Tuscan Nappe, the Internal and External Ligurian, and Sub-Ligurian Units occur. These units, that are derived from the Ligure-Piemontese oceanic basin and its transition to the Adria continental margin, are characterized by Middle to Late Jurassic ophiolites and Late Jurassic to Middle Eocene pelagic and hemipelagic sediments (Bortolotti & *alii*, 2001; Marroni & *alii*, 2001).

The timing and mechanisms of the most recent deformation responsible for the uplift of the Apuan Alps will be discussed in the *Neotectonic* chapter.

MATERIALS AND METHODS

The Geomorphological and Neotectonic Maps of Apuan Alps Regional Park and its surroundings were created by integrating unpublished data from several geomorphological field campaigns by the authors and from published geomorphological (Baroni & *alii*, 2010) and geological maps (Carmignani & *alii*, 1985, 2000; LAMMA - Regione Toscana, 2012; Puccinelli & *alii*, in press).

Analysis of historical maps and stereoscopic aerial photographs (1995 black-and-white photographs of Regione Toscana at a scale of 1:33,000) allowed for the correlation and integration of the existing data.

The base for the Geomorphological Map (Sheet 1) consisted of topographic maps by the Italian Military Geographical Institute (IGMI), with a scale of 1:50,000 (series 50 and 50/L), specifically the Viareggio, Massa Carrara, Castelnuovo Garfagnana, and Lucca sheets. The base for the thematic maps of Sheet 2 was a hillshade topographic base obtained from the digital elevation model derived from the interpolation of 10-m contour lines of the 1:10,000-scale Technical Regional Topographic Maps of the Tuscany Region (CTR- Carta Tecnica Regionale, Edition 1995, http://www502.regione.toscana.it/geoscopio/cartoteca.html, last accessed in Nov. 2015).

The preparation of the Geomorphological Map followed the principles adopted by the National Group of Physical Geography and Geomorphology (Gruppo Nazionale Geografia Fisica e Geomorfologia, 1993) and by the National Geological Survey, Working Group for the Geomorphological Cartography and was updated using the guidelines for the fieldwork and preparation of the Geomorphological Map of Italy at a scale of 1:50,000 (Gruppo di Lavoro per la Cartografia Geomorfologica, 1994; Cosci & *alii*, 2007).

Due to the geomorphic peculiarities of the Apuan Alps, we used specific symbols implementing those of the commonly used dataset. Particular attention was paid to anthropic activity such as those that strongly modified the landscape in and around the large marble quarries.

The landforms and associated deposits are depicted in various colours depending on the geomorphologic processes responsible for their development. Various symbols denote the geometry and nature of the features, whereas their morphodynamic character or levels of activity or inactivity are denoted by, respectively, darker or stronger and lighter tones. A landform was considered active if its development is the result of a morphogenetic process driven by present-day morphoclimatic conditions; whereas features resulting from processes not acting anymore in the current morphoclimatic framework are considered inactive. In a few cases, morphometric (dimensional) data are also represented using various symbols.

According to the legend developed by Gruppo di Lavoro per la Cartografia Geomorfologica (Working Group on Geomorphological Mapping) (1994), the bedrock is divided into lithotypes based on their resistance to erosion and degradation. An exception was made for the marble, due to its being the peculiar geologic feature of the region and its strong association with anthropic activity, principally quarrying. Structural features such as thrusts, other faults and bedding orientations were mapped. These features were extracted from the LAMMA-Regione Toscana (2012) geological database and were selected based on their importance and distribution relative to the map scale.

Quaternary deposits are delineated on the Geomorphological Map (Sheet 1) based on their morphogenetic agent, and on the Neotectonic Map (Sheet 2), they are delineated based on the presence of unconformities bounding the various generations of deposits and their related ages (UBSU, see *Neotectonic* chapter). The dominant texture of each deposit is depicted symbolically.

The geomorphologic data obtained from direct and indirect surveys and from existing data were stored in a spatial database and managed in a GIS environment (ArcGis™). The topographic data were generalized from the topographic map of Tuscany (Cartografia Tecnica Regionale, CTR) at a scale of 1:10,000. For the final layout and printing, we used the Official Topographic Sheet at a scale of 1:50,000, "Serie 50", published by the Istituto Geografico Militare (IGM).

The spatial database was organized in terms of several featural classes in accordance with the system of Gruppo di Lavoro per la Cartografia Geomorfologica (1994) and using the guidelines suggested by Cosci & *alii* (2007). The features were assigned to various layers based on their geometry (areal, linear and point-like features). A feature attribute table was developed to organize a set of attributes corresponding to the individual morphotypes and characterizing the morphogenesis, morphodynamics, morphometry and, when available, the chronology of the erosional and depositional landforms. Spatial analysis was used to resolve cartographic conflicts and improve the detailed depiction of the field data and their spatial relationships with the topographic data.

The morphogenetic agents and their map colours and states of activity are as follows.

- Structurally controlled landforms: brown, state of activity uncertain.
- Gravity-controlled slope landforms (slope landforms due to gravity): red denotes active, orange denotes inactive.
- Fluvial landforms and deposits (landforms and deposits due to running waters): dark green denotes active, light green denotes inactive.
- Karst landforms: bright orange, active.
- Glacial and cryonival landforms and deposits: purple, inactive.
- Marine, lagoonal and lacustrine landforms and deposits: dark blue denotes active, light blue denotes inactive.
- Anthropogenic landforms (Man-made landforms): black.

SHEET 1 - THE GEOMORPHOLOGICAL MAP

Apuan Alps Regional Park and its surroundings were modelled and are presently affected by a great variety of geomorphic processes.

The plain between the coast and the foot of the mountains is characterized by landforms and deposits generated by marine, aeolian and fluvial processes (Bini & *alii*, 2009, 2012, 2013). Extensive alluvial fans and fluvial landforms (i.e., palaeomeanders; Bisson & Bini, 2012) dominate the eastern side of the plain at the foot of the massif. The slopes, particularly the interior of the Apuan Alps, are affected primarily by fluvial and gravitational processes including giant landslides and deep-seated gravitational slope deformations (Coltorti & *alii*, 2008; Federici & *alii*, 2007). Structural lineaments and related zones of weakness play an important role in favouring these processes, and rapid tectonic uplift is responsible for fluvial downcutting (Putzolu, 1995).

The carbonatic rocks of the massif's core host one of the most impressive karst systems on the Italian peninsula. The epigeous landforms constitute the main geomorphic features in places (e.g., Vetricia plateau and Carcaraia; fig. 5), and the hypogeous systems include more than 1500 caves (Fallani & Piccini, 2003). Some of the caves are extensive and are of scientific interest, as exemplified by the several studies of the Corchia system, Grotta del Vento cave and Abisso Revel (Zanchetta & *alii*, 2007; Piccini & *alii*, 2003a, 2008; Regattieri & *alii*, 2012, 2014a, b).

At the highest elevations of the massif, there are well-preserved glacial and cryonival landforms and deposits, which are mostly Late Pleistocene in age (fig. 6). These relicts of past glaciations represent the lowest glacial traces in the Apennine chain.

Finally, when describing the Apuan Alps, is important to include human impacts, which, particularly in the renowned marble extraction areas of Carrara, generated large-scale landforms and deposits related to past and present marble quarrying activity. This activity is extraordinarily evident from a long distance (Baroni & *alii*, 2000).

Geologic and structural elements

The various rock types respond differently to erosion, and their stratigraphic overlapping highlights the importance of differential erosion in shaping the landscape (fig. 7).

On a scale of the entire massif, the most prominent structurally controlled landforms are those associated with the contacts between the main structural units. On the western side of the Apuan Alps (Carrara, Massa), hogback-like landforms mark the presence of the west-dipping Ligurian Units where they overlap the Tuscan Units, which in turn cover the Massa Unit and the "Autochthonous". Similar features are also present on the NNW side of the region (Tenerano, Ugliancaldo, Minucciano). On the NE and SSE sides, the presence of several important high-angle normal faults and folding of the structural units make it difficult to precisely map these contacts.

The interior of the massif, where the metamorphic Palaeozoic and autochthonous rocks are exposed, is characterized by high energy relief. Many huge scarps, hundreds of metres tall, are developed on the marble outcrops, such as those on the left slopes of V. Serenaia and V. di Lucido, on the NE slope of M. Sagro and on the southern and northern slopes of M. Sumbra. These great escarpments were formed by differential erosion between the harder dolostone, dolomitic marble and marble and the softer limestone and dolomite of the Tuscan Units or the Palaeozoic Pseudomacigno metasandstone. This is the case of the huge escarpments of the M. Matanna - M. Nona - M. Procinto, on the eastern side of the massif. Sharp ridge crests are common where the metamorphic units dip vertically dip. Similar features are also common where the Inner Tuscan Domain and the Ligurian units have high-angle dips.

Scarps produced by differential erosion are also commonly associated with contrasts between lithotypes with differential resistance to erosion. Phyllite, marl and argillite are the main weak layers responsible for the formation of these scarps together with the several faults and associated cataclastites. In some places, folds are marked by the presence of structural scarps, such as along the M. Penna anticline in the NE Apuan Alps.

Triangular facets associated with high-angle normal faults are present along the main fault escarpments that border the SW side of the Garfagnana-Barga-Serchio basin system and the NE side of the Camaiore basin, which are elongated NNW to SSE. ENE-WSW-trending fault systems border the NE margin of the Lunigiana basin and the northern slope of V. Pedogna. Other aligned triangular and trapezoidal facets can be observed along the main escarpment bordering the Apuan Alps on the SW, abruptly separating the mountains from the coastal plain. This fault system is probably the main one in the region and is associated with opening and deepening of the Ligurian basin. However, its trace is difficult to map precisely due to its burial under Late Pleistocene marine and continental deposits of the coastal plain.

Landforms and deposits due to running water

Erosional processes due to running water have been dominant in shaping the core of the Apuan Alps. The landscape and the steep slopes that face northeast towards the Garfagnana and Lunigiana basins are dissected by Turrite Secca, T. Lucido and the proximal reach of the F. Serchio di Gramolazzo, which have formed gorges hundreds of metres deep. There are also several gorges carved into the southern slopes of the ridge formed by M. Cavallo, M. Tambura, Alto di Sella and M. Sumbra. Impressive potholes have also developed along the thalwegs of these gorges (fig. 8).

The south-western side of Serchio valley contains several strath terraces positioned at various heights above the valley floor. These are unpaired terraces formed during progressive downcutting of the valley. Elevational and geomorphic correlations between the terrace surfaces on opposite-facing slopes allow for reconstruction of the transverse profile of the ancient valley during its progressive incision. Such terraces are present in Turrite di Gallicano Valley between the villages of Vergemoli and Verni and along the left side tributary of Turrite Cava valley (Canale dei Finocchini) in the area of the village of Fabbriche di Vallico.

Past drainage directions are indicated by alluvial deposits that are unrelated to the present-day drainage based on their elevations and locations. In some cases, these features are associated with fluvial elbows. A good example is found south of Castelnuovo di Garfagnana, where extensive terraced fluvial deposits covering the slopes on both sides of the M. Perpoli - Torrione ridge (Puccinelli, 1987) have been assigned to the Monteperpoli Supersynthem (Coltorti & *alii*, 2008). Evidence of ancient fluvial directions can also be found in the area between M. Pedone and M. Vallimona (east of Camaiore), where the Rio Luccese and the T. Pedogna abruptly change direction in response to important tectonic features marked by an alignment of facets along a tectonic scarp.

FIG. 5 - Characteristic Apuan karst landscape in the Carcaraia, M. Tambura area (photo I. Isola).

FIG. 6 - Alpine morphology in the norther western sector of the Apuan Alps (M.Pisanino, on the left, and Pizzo d'Uccello, on the right, photo L. Pandolfi).

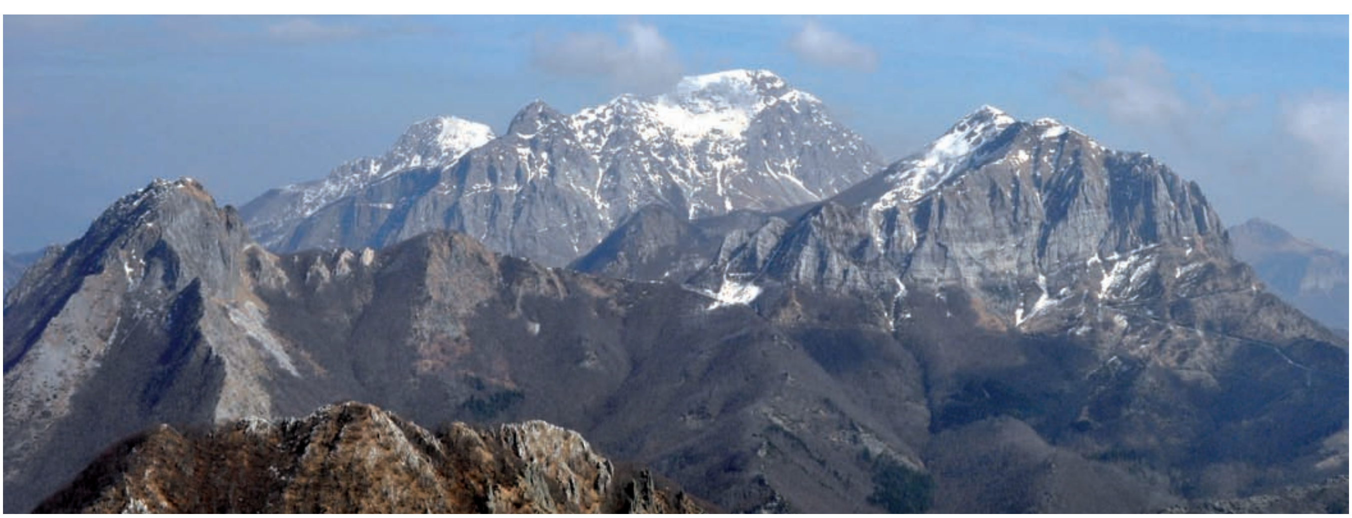

FIG. 7 - Selective erosion underlines lithological contact of Mesozoic carbonatic rocks on the Palaeozoic basament on M. Corchia (M. Freddone on the left and the "Panie" in the background).

Thick fluvial terrace deposits are observable at Agliano (near Lake Gramolazzo) and Roggio (near Lake Vagli) and near the villages of Bergiola, Bedizzano and Miseglia (near Carrara).

Fluvial deposits are thicker and widespread along the piedmont areas, whereas in the inner narrow valleys, they are reduced to small patches that cannot be mapped due to the small map scale. These deposits are differentiated based on their dominant grain size (sand, gravel) and on their state of activity. Fluvial terraces suspended (> 10 m) above the valley bottoms and not reached by extraordinary floods are considered inactive, whereas the deposits of alluvial plains that are slightly incised (a few metres) by present-day streams are classified as active because they may be reached by ordinary or exceptional floods.

The piedmont area on the Ligurian Sea side of the Apuan Alps is dominated by many locally coalescing alluvial fans that extend into the principal river basins (i.e., those of T. Carrione, T. Frigido, T. Vezza. and T. Camaiore). These landforms typically display gentle topography crossed by abandoned fluvial channels, indicating a history characterized by changes in stream flow directions during the Late Holocene (Federici & Mazzanti, 1995).

Many of the major alluvial fans coalesce with minor fans formed by deposits from secondary or tributary streams.

The states of activity of some of the alluvial fans bordering the coastal plain are uncertain. These landforms have been modified extensively by urbanization and agriculture, and their surface hydrology has been extensively modified by artificial channels and levees. However, during exceptional meteorologic events, some of the streams overflow their banks and cause damage (e.g., in the Carrara area).

Case-by-case analysis is needed to determine whether these events are limited to a single stream overflowing onto the active fan surface or represent sporadic reactivation of the fan itself. For this reason, on the map, the alluvial fans are assigned an intermediate status between active and inactive.

Slope landforms due to gravity

The great steepness of many slopes in the Apuan Alps and the dense network of fractures locally affecting the rock masses are factors controlling the development of a great variety of gravitational processes (APAT, 2007; Federici & *alii*, 2007). Moreover, the widespread dip-slope conditions in certain areas coupled with the presence of high-angle faults favour the mobilization of great amounts of debris. High rainfall amounts, particularly when concentrated in a short time span, are the main factor triggering the gravitational processes (D'Amato Avanzi, 1999). A correspondence between large landslides and important seismic events cannot be ruled out, particularly along the borders of the tectonic basins and in association with faults (CNR-Regione Toscana, 1986).

Fig. 8 - Giant's pot-holes along Fatonero stream, in the Turrite valley (photo E. Lotti).

Slope degradation generates great amounts of debris that accumulate at the bases of the scarps in the form of debris cones or talus slopes. Most of these deposits can be attributed to the cold climatic condition of the Last Glaciation based on their morphostratigraphic positions, cementation and thicknesses, but there were important contributions during historical time following vegetation clearance for pasture and farming, based on an observed increase in fluvial sediment transport (Bini & *alii*, 2013).

Landslides of most types have been documented in the region (Cosci & *alii*, 2007). The rocks most involved in the landsliding are the chaotic members of the Ligurian units and the schist and phyllite of the metamorphic units.

Currently, rock falls and topples affect the densely fractured steep escarpments, and their rock fall deposits locally accumulate at the bases of cliffs and are reworked by erosional processes (i.e. stream erosion).

Intense rainfall is the main factor triggering the frequent and widespread debris flows and mudflows affecting many portions of the region, often causing widespread damage and casualties (e.g., the 1996 Cardoso-Serravezza event that took 14 lives, Rapetti & Rapetti, 1996). Due to the steep slopes and the saturation of soil overlying impermeable rocks, these flows activate rapidly and affect entire slopes (D'Amato Avanzi & *alii*, 2000, 2009; Falaschi & *alii*, 2009; Giannecchini & *alii*, 2012). These events are also very frequent along slopes underlain by quarry waste from the marble extraction (*ravaneti*), in the Carrara marble basins (Baroni & *alii*, 2000, 2001, 2010).

Rotational and translational slides are also widespread, as are complex landslides, which are typically characterized by a rotational sliding mechanism in the source area that evolves downslope into a flow. These landslides, which may be several kilometres wide, are widespread on the chaotic terrains of the Ligurian units exposed in the northern and north-eastern portions of the massif. Complex landslides are also present ~~in~~ associated with normal fault systems, in particular along the borders of the Garfagnana and Lunigiana basins. Many of these landslides are at least partly active (Federici & *alii*, 2007, 2011).

Giant complex landslides are located at the highest elevations of the massif. However, many of the landslide masses are deeply incised by stream channels and do not show traces of recent activity. Many villages are located on the counter scarps or the flat surfaces of the landslide masses, including Terrinca, Levigliani and Stazzema in the south-eastern area and Antona, Casette, Vinca and Azzano in the north-western area of the Apuan Alps.

Deep-seated gravitational slope deformations (DSGSDs) have also been mapped in the region and can be classified as sags in accordance with Hutchinson's classification scheme (Hutchinson, 1988). They primarily involve the Ligurian units and densely fractured rock masses (D'Amato Avanzi & Puccinelli, 1996). In many places, the clearest evidence of movement such as secondary scarps and trenches are present in the crown area, whereas the distal part may display relatively little movement. This difference can be attributed to a basal sliding surface that does not yet connect the proximal and the distal sections.

Marine, lagoonal, and lacustrine landforms and deposits

Landforms and deposits of marine origin are widespread between the present coast and the toes of the alluvial fans in the piedmont area (Bini & *alii*, 2009, 2012, 2013).

Some of these fans locally show evidence of an inactive cliff generated by marine erosion during the Versilian transgression (Sestini, 1957; Federici, 1993). This cliff, which marks the line of maximum marine transgression during the Holocene, is parallel to the coast and approximately two kilometres inland. In the Frigido River area in particular, the Versilian cliff is clearly evident, exceeds 5 m in height, and connects with the erosional stream banks carved by the Frigido palaeo-river (Sestini, 1957; Cozzani, 1971; Bisson & Bini, 2012). To the north, the corresponding cliff of the F. Carrione is poorly evident, whereas to the south, on the fan generated by the Versilia River, its morphologic evidence disappears, and only the contact between fluvial and marine deposits is observable.

According to Federici (1993) and Antonioli & *alii* (2000), the deposits at the base of the cliff yielded ages of approximately 6000 yr BP. From then on, there was progressive progradation of the coast along the Versilia Plain, as indicated by the deposition of a series of beach ridges subparallel to the present-day coast. These beach ridges are composed primarily of homogeneous sand of medium grain size with remnants of marine molluscs (Bini & *alii*, 2013). North of F. Frigido, the beach ridges merge into a single large one, although it is possible to recognize the individual ridges standing 2–2.5 m above current sea level. Although human activity and settlements have largely obliterated the beach ridges, in a few areas it is still possible to recognize as many as five ridges between the alluvial fans and the present-day coast.

In the southern portion of the coastal plain, depressions between the beach ridges contain marshes and/or swamps locally filled with silt and peat. Locally, the marshes and swamps were once coastal lagoons that were isolated from the sea by the growth of new beach ridges. This development explains Lake Porta (Lago di Porta) and Lake Giardo (Lago del Giardo; Bini & *alii*, 2013). A few relicts of these ancient water bodies are still preserved today.

The present-day beach, which is characterized primarily by sandy deposits, has a width that increases southward up to 150 m. Currently, extensive erosion affects a large portion of the northern coastal area, where the erosion is fought using extensive anthropogenic defence features such as groynes, jetties, and seawalls.

The littoral drift is generally south-eastward across the area except near the mouth of F. Motrone, on the southern end of the coast, where the drift is opposite.

Karst landforms

Karst processes play a major role in driving the geomorphologic evolution of the Apuan Alps, both by shaping the surface landforms and by favouring the evolution of an astonishing hypogean karst landscape. Underground drainage plays a major role in the karst development and strongly controls the distribution of the main springs on the Versilian maritime side and the western and northern sides of the Apuan Alps. Several well-developed karst systems, some epigean but generally hypogean, characterize the region. There are many dolines and doline fields, limestone pavements and karren, and hundreds of caves and shafts in the Apuan Alps. The development of karst features in terms of growth and density is mainly associated with marble bedrock belonging to the "Autocthonous" or Massa units. Nevertheless, dolomitic and limestone rocks belonging to the Tuscan units are also affected by karstification, as is the "Calcare Cavernoso" (Carmignani & *alii*, 2004).

The Apuane Alps host cave systems with potential vertical development exceeding 1600 m and contain some of the longest karst complexes in Italy.

The glaciers that modified the landscape of the Apuan Alps during the Late Pleistocene (see the following paragraph) favoured the development of glacio-karst landforms and contributed to scouring by glacial erosion. Furthermore, the glaciers modified the formerly gentle topography, which predisposed the ground for the development of karst surface landforms after the glacial retreat. Many nival niches sculpted in karstifiable rocks are of nival-karstic origin. Chemical dissolution played a role in sculpting fluvial landforms such as canyons (gorges in Sheet 1) and small V-shaped and trough-shaped valleys; in many cases, these are landforms of complex origin.

Karst processes have been active in the Apuan Alps since at least the Early Pleistocene, when denudation of the metamorphic carbonate rocks of the Apuan core occurred (Abbate & *alii*, 1994: Balestrieri & *alii*, 2003, Coltorti & *alii*, 2008), as indicated by the presence of metamorphic pebbles of Apuan origin in fluvial conglomerates in Garfagnana (Perilli & *alii*, 2004; Coltorti & *alii*, 2008).

According to Piccini (1996, 1998, 2011) and Piccini & *alii* (2003b), there were three main morphogenetic phases of Pliocene (?)-Pleistocene speleogenesis in the Apuan Alps, and these are particularly recognizable in the M. Corchia karst system. These authors recognized relict phreatic caves at various elevations, the highest being preserved at approximately 1400 m a.s.l., only a few hundreds of metres below the highest peaks of the massif. Fluvial sediments in this phreatic system are evidence of allogenic rivers that reached the Apuan Alps. This first phase of karst evolution and the development of epi-phreatic conduits is tentatively assigned to the Early Pleistocene. Two other relict phreatic cave systems are present at 750-900 m and at 500-650 m a.s.l.. The first of these systems is assigned to an Early Pleistocene phase of tectonic standstill and the latter one to the Middle and Late Pleistocene uplift of the Apuan Alps.

Piccini & Pranzini (1989), investigating the hydrogeologic setting of the F. Frigido basin, the largest karst drainage basin in the region, attributed the predominantly south-westward underground water flow to differences in the base level, which is lower in elevation in the valleys of Versilia (200-300 m) than in the Garfagnana (500 m). Therefore, the western, maritime side of the Apuan Alps is dominated by horizontal caves, which provide mostly a drainage function in these phreatic conditions.

Epigean karst landforms. In the highest areas of the Apuan Alps, epigean karst landforms are the dominant element in the landscape. *Karren* or *lapiéz* (e.g., solution pits, grooves, runnels, and grikes) are widespread where karstifiable rocks are exposed (fig. 9). These features were

FIG. 9 - Well developed surficial karst morphology in the Vetricia, Pania della Croce area (photo A. Giuntoli).

FIG. 10 - Doline field in the Carcaraia, M. Tambura area (photo I. Isola).

not mapped due to the scale of the geomorphological map. Large-scale features such as polje did not develop in the study area. The most representative karst landforms are medium-scale features such as dolines, which are distributed as isolated features (a few metres to tens of metres wide) and in small groups, but extensive doline fields are also well represented (fig. 10). Piccini (1998) indicates an average distrubution of 0.5 doline/km^2 where soluble rocks are exposed. The highest concentration of dolines is between elevations of 1400 m and 1700 m (Piccini, 1998), in association with slopes underlain by marble and other carbonatic rocks.

The most spectacular example of epigean karst in the Apuan Alps is located on the Carcaraia slope, on the northern side of M. Tambura (fig. 10). This doline field, with a density of 320 elements/km^2, is associated with several cave entrances. Several small to medium surficial karst dissolution features such as solution channels and runnels are widespread in the area (*karren* of various shapes and sizes such as *rillenkarren* and *rinnenkarren*) and solution pits (*kamenitza*). Note that there is a very high rate of rainwater absorption on the Carcaraia slope.

The highest elevations in the Carcaraia area, where snow cover persists long into the spring, are characterized by extensive *karrenfields* and grikes with limestone blocks often isolated by deep fractures (*kluftkarren*) and by distinct *karren* with sawtooth edges (fig. 11).

Equally rich in epigean karst features is the Vetricia plateau, on the northern slope of the Panie Group (Marcaccini, 1964; Federici & *alii*, 1981), where there are scattered extensive solution channels supported by a network of fractures that favoured the development of deep grooves and grikes. The bedrock surfaces also display etching and

FIG. 11 - The very particular Karren with sawtooth edges on the marble of the Carcaraia, M. Tambura area (photo I. Isola).

FIG. 12 - Entrance of the abyss Revel in the Vetricia, Pania della Croce area (photo A. Russino, GSPI).

FIG. 13 - Entrance of the abyss 5 Luglio, M. Pisanino (photo G. Dellavalle, GSAL).

carving in a wide variety of microforms such as rectilinear and meandering grooves and solution runnels, solution pits and pans. They are less abundant there than on the Carcaraia slope, and mostly rounded and bowl-shaped dolines are present on the Vetricia Plateau; Federici & *alii* (1981) report peculiar dolines at Campocecina developed on "calcare cavernoso".

The "Catino del Sagro" is a large valley on the northwestern slope of M. Sagro at approximately 1260 m (Federici & *alii*, 1981). This valley is elongated NW-SE and is bounded by walls approximately fifty metres high. The underlying rocks and the valley's elliptical shape suggest a karstic origin of the basin, which is also supported by several microforms. However, we cannot rule out an important glacial contribution to the formation of this landform.

Hypogean karst landforms. There are several cave entrances that are the surface expressions of complex underground karst systems (figs. 12 and 13). Vertical caves dominate the highest areas of the Apuan Alps, whereas horizontal conduits leading to past or present-day springs are the expression of these systems in the low-lying areas (Piccini, 1996).

An inventory of the caves of Tuscany by Fallani & Piccini (2003) includes more than 1,500 cave entrances in the Apuan Alps (http://www.speleotoscana.it), including some of the deepest and most extensive caves on the entire Italian peninsula. The greatest concentration of cave entrances, approximately one hundred, is present on the Carcaraia slope and Vetricia plateau.

Piccini (1996, 1998), who analysed the elevation of several entrances to the Corchia cave system, recognized three main phases of preferential development of karst phenomena and related these to multiple phases of uplift of the Apuan massif. New dates provided by speleothems in the karst system of M. Corchia (Piccini & *alii*, 2003a; Zanchetta & *alii*, 2007) support the hypothesis that uplift of the massif was not significant during the Late Pleistocene.

The approximately 200 caves in the Apuan metamorphic complex and exceeding 100 m in length total approximately 210 km in length. Among these, the network of interconnected caves of the M. Corchia system (figs. 14 and 15) contains a total length of approximately 60 km and spans a total elevation difference of 1187 m (http://www.speleotoscana.it).

The Abisso Paolo Roversi (T / LU 705), developed in the dolomitic marbles of the Carcaraia slope, holds the record of the deepest cavity in the Apuan Alps, reaching 1350 m of total elevation difference. Next to the Abisso Roversi is the 35-km-long Saragato (T / LU 350)–Aria Ghiaccia (T / LU 1027)-Squisio (T / LU 1628) cave system, which is also referred to as the Carcaraia Complex.

Among the horizontal caves, the "Tana che Urla" cave at Fornovolasco (T/LU 26) is a noteworthy example of a spring cave. This opening is at 620 m a.s.l. south of Pania Secca and follows the contact between schistose metamorphic rocks at the base and dolomitic rocks ("Grezzoni"). The "Tana che Urla" cave contains interesting flowstones dated at 159-121 ka that indicate hydrologic changes on a regional scale spanning the glacial/interglacial transition and periodic switches

Fig. 14 - Stalactites of different generation in the Antro del Corchia cave (photo C. Baroni).

Fig. 15 - Prelovsek gallery with aragonitic concrections, Antro del Corchia (photo G. Dellavalle, GSAL).

between wetter and drier climatic conditions on a multi-centennial scale (Regattieri & *alii*, 2014b).

Several karst caves in the Apuan Alps have attracted great scientific interest over the centuries since the beginning of the 18th century, when Antonio Vallinseri (1726), in 1704, visited the "Tana che Urla" at Fornovolasco (T/LU 26) and Lazzaro Spallanzani (1783) described the Tanone di Torano (T/MS 179) and other caves in the Apuan Alps. Since then, the caves of the Apuan region have attracted numerous scientists interested in (1) understanding geodynamic processes that occurred since the first karstification phases (Piccini, 1996, 1998, 2011; Piccini & *alii,* 2003b) and (2) characterizing and constraining palaeoclimatic events recorded in speleothems (Drysdale & *alii*, 2004, 2007; Regattieri & *alii*, 2014a; Zanchetta & *alii*, 2007, 2014; Zhornyak & *alii*, 2011).

Glacial and crionival landforms and deposits

The highest peaks and the heads of several valleys of the Apuan Alps, particularly on the NE side of the chain, preserve remarkable traces of the Pleistocene glaciation (fig. 16), as noted since the second half of the 19th century (e.g., Stoppani, 1872; Cocchi, 1872; De Stefani, 1874, 1890; Zaccagna 1896, 1937; Sestini, 1935, 1937).

The important position of this mountain range on the Italian Peninsula, specifically, between the Mediterranean basin and the Alpine region, underlines the relevance of the glaciation of the Apuan Alps. The glaciers of the Apennines reached their lowest elevations on the inland side of this range.

Erosional landforms – Along the main watershed to the heads of the valleys, there are several cirques of glacial origin and many others of cryogenic origin. Although most of these features display no typical shape and are not well defined along their lower margins, Jaurand (1996, 1998) counted 84 glacial cirques in the interior of the massif, 23% of which face south. Along the main watershed, the ridge crests are clearly modified by cirques down to elevations of 1300-1350 m. The preglacial morphology, strongly affected by the morphostructural setting of the Apuan chain, most probably favoured the development of glaciers on steep slopes.

Among the largest and probably one of the best examples in the Apuan Alps is the cirque at the head of the valley on the north-eastern side of Pania Secca, described by Suter (1936) and Valduga (1946). The cirque is characterized by a typical profile with an arcuate, vertical headwall and a gently sloping floor filled with debris.

Federici (1981) reported other examples of cirques on the seaward side of the Apuan Alps: small cirques are present on the slopes of M. Altissimo and M. Macina and at the heads of the valleys below M. Spallone, M. Borla and M. Sagro.

Fig. 16 - Northern slope of Pizzo d'Uccello sculpted by glacial erosion during the Late Pleistocene (photo G. Ottria).

Other erosional landforms of glacial origin are not common. However, roches mountounnèe directly crop out above Gramolazzo, around Serenaia and Tecchiarella (1031 m).

Arnetola Valley and the terminus of Orto di Donna Valley present rare cases of characteristic glacially shaped valleys. The Arnetola Valley has a U shape along approximately 1 km of its length above Vagli di Sopra and also displays traces of glacial shoulders. The presence of glacial shoulders has also been suggested in Orto di Donna Valley (Putzolu, 1995).

Glacial deposits – The Apuan Alps preserve the lowest glacial deposits of the entire Apennines chain. Well-preserved moraine deposits and ridges are present within many glacial valleys. Most authors agree that the terminal moraines below 1000 m can be attributed to the Last Glacial Maximum (Tongiorgi & Trevisan, 1940; Braschi & *alii* 1987; Federici, 2005a, 2005b).

In the north, vast moraine complexes enable the reconstruction of the ancient positions of the glaciers during the Last Glacial Maximum and, in some cases, during Late Glacial phases.

However, locally, many glacial deposits have been strongly reworked by gravity and fluvial processes during the postglacial period and by human activity, including the quarrying of marble erratics (e.g., in the vicinity of Vagli).

The Campocatino moraine complex (fig. 17), the moraine ridges in the valley NE of Pania Secca, and the glacial deposits in the valley of Serchio di Gramolazzo are the greatest examples of the Apuan glaciation, and some of these features merit inclusion in the list of Italian geosites.

Locally, such as in the Gorfigliano glacial deposits, the great petrologic variety of the ancient accumulation basins and the strong morphostructural setting are reflected in the petrologic heterogeneity of many Apuan moraines (Federici, 1978, 2010).

In the southern portion of the Apuan massif, there are the remarkable Arni and Campagrina glacial deposits. In particular, the Arni terminal moraine was the first glacial deposit discovered by Stoppani (1872) and Cocchi (1872) in the Apuan Alps. This moraine lies a few metres above 900 m, which is interesting considering that it was deposited by a glacier on a south-facing slope.

According to Braschi & *alii* (1987), the perennial snow line elevation (at this latitude corresponding to the equilibrium line altitude, ELA) for the north-facing glaciers is at approximately 1100 m a.s.l. and that of the south-facing basins is approximately 1250 m a.s.l.. The mean ELA, calculated using the accumulation-area ratio (AAR) method, ranges between 1150 and 1350 m a.s.l. based on the reconstructed glacial extension we developed for the Apuan Alps.

Landforms and deposits of complex origin – Some of the Apuan valley heads have been shaped by interactions between glacial and karstic processes. Their original glacial cirque profiles inherited from glacial erosion are presently affected by karstic processes.

Good examples of glaciokarstic depressions are present in the bottoms of the M. Sagro and M. Spallone glacial cirques and on the spectacular Carcaraia slope.

FIG. 17 - Campocatino complex morenic system with M. Roccandagia cirque in background (photo A. Bartelletti).

FIG. 18 - Overview of Ravaccione area in the Torano basin, Carrara: active (ligh grey) and ancient (dark grey) quarries and quarry dump deposits (ravaneti, photo C. Baroni).

Certain glaciolacustrine and glaciofluvial deposits are also remarkable. Near Gorfigliano, there is a terrace underlain by glaciofluvial and lacustrine deposits that were dammed by glacial deposits. One noteworthy example is the Ripiano della Mandria in V. Gramolazzo, which was studied by Suter (1936): this deposit was dammed on the south by a lateral moraine deposited by the Orto di Donna glacier during the maximum glacial expansion and displays a complex internal structure consisting of glaciofluvial and lacustrine deposits interbedded with a coarse till facies. However, this deposit is not shown on the map due to the small scale.

MAN-MADE LANDFORMS

The Apuan landscape shows the effects that thousands of years of human activity had in modifying the landforms, particularly where marble and other economically valuable rocks are exposed (D'Amato Avanzi & Verani, 1998; Baroni & *alii*, 2000, 2010; Gentili & *alii*, 2011).

The most prominent anthropogenic landforms in the Apuan Alps are the huge marble quarries and their waste deposits (fig. 18). There are traces of quarrying activity dating to the Iron Age in the 1st Millennium BC, when the Apuan people first exploited the Carrara Marble (Bruschi & *alii*, 2004; Baroni & *alii*, 2010). Quarrying expanding during the Roman Age, and their archaeological remains are still identifiable in the area (fig. 19). The world's largest preserved Roman quarry is located in the vicinity of Colonnata (Mannoni & Mannoni, 1984; Dolci, 1985, 2003; Paribeni, 2003; Baroni & *alii*, 2013).

Quarries are widespread across the Apuan region and attain their highest concentration northeast of Carrara, in the Boccanaglia, Torano, Miseglia and Colonnata marble basins.

Baroni & *alii* (2010) reported 78 active quarries in the Carrara Marble basins alone; we have counted 62 active quarries and 142 abandoned quarries across the Apuan region.

There are different types of quarries, and there may be working faces at various elevations within a given quarry. In the Carrara marble basins, these faces reflect the increasing density of the quarries, which forced the extraction to expand upslope or downward to greater depths. As a consequence, sequences of quarry faces are superimposed along the same slope or on the opposite walls of quarries extending to great depths.

Also common are quarries with overhanging walls (fig. 20), which were carved to extract the most valuable marble. Recently, to maximize security and economic performance and to minimize impacts on the landscape, underground quarries have been started. There are also quarry prospects of various ages and sizes across the marble outcrops.

Quarry waste dumps, referred to as *ravaneti*, have also had a great impact on the landscape. This rejected material represents approximately 70% of the total material extracted. The waste was dumped on the slopes since a very long

FIG. 19 - Relict of Roman quarry cuts in the area of Fossacava (photo C. Baroni, note the hammer to the left for scale).)

time ago, thereby generating debris layers of different generations. The debris texture is correlated with the quarrying techniques and provides a record of the historical development of the extraction (Fossen, 1886-1887; Baroni & *alii*, 2003, 2010), and the debris also retains other information of archaeological interest (Mannoni & Mannoni, 1984; Dolci, 1985, 2003; Paribeni, 2003). The grain sizes, clast shapes, nature of the fine matrix, degree of weathering, and vegetation cover allow for classification of the *ravaneti*. In several locations, the stratification of the *ravaneti* allows for recognition of pre-Roman, Roman, Medieval, Renaissance, 19th century and modern wastes, which are separated by buried soil horizons that indicate interruptions in quarrying activity (at least locally) (Baroni & *alii*, 2010).

On the Geomorphological Map, the quarries are subdivided into those that are active and those that are abandoned. However, due to the map scale and the high density of information, it was not possible to differentiate the various types of quarries and/or *ravaneti*.

Mines are also widespread across the Apuan region, particularly in the upper elevations of the Versilia area (Stazzema and Levigliani). However, none of the mines is still active.

Most of the streams in the coastal plain have been artificially diverted and rectified, some since Roman times. Many of them are currently controlled by artificial levees to prevent flooding during extraordinary rainy events. The intense human activity is evident also on the wetlands located between the coastal plain and the foothills. An example is the Lake Porta (Lago di Porta) wetland where the long-lasting reclaiming activity is well documented (Federici, 1998).

Finally, normal and transversal groynes have been constructed along the coast, particularly in the Marina di Massa and Marina di Carrara areas, to minimize or stop the marine erosion.

SHEET 2 – NEOTECTONIC AND OTHER THEMATIC MAPS

Sheet 2 includes a group of six thematic maps, two at a scale of 1:100,000 and four at a scale of 1:200,000. The first two sketch maps are the *Neotectonic map* and the *Map of selected sites of geomorphological significance*. The four sketch maps at a scale of 1:200,000 are the *Elevation Map*, the *Aspect Map*, the *Drainage network Map*, and the *Map of Climatic Elements*.

NEOTECTONIC MAP (1:100,000)

Neotectonics is the study of tectonic movements that generated features during recent geologic time. It includes the occurrence of fragile and ductile deformations, areas affected by absolute or relative uplift or downdropping, and faulting. Certain authors confine the chronologic interval of neotectonics to the Late Pleistocene and Holocene, although others who study the geomorphology of the Apennine chain include the Late Miocene and Early Pliocene. According to Mörner (1978), neotectonics includes "every movement or deformation of the earth surface, mechanisms, their geological causes and their implication for practical purposes and future predictions". This definition was accepted by the Tectonic Commission of the International Union of Quaternary Science (INQUA) and was used during the production of the Neotectonic Map of Italy as part of the Finalized Geodynamic Project of the National Centre for Research (CNR, 1987), which included the Apuan Alps. In our analysis, we regarded neotectonics as encompassing those geologic and related geomorphologic processes and features that were active during the Quaternary.

The events that led to the shaping of the present-day landscape can be identified by analysing the patches of planation surfaces preserved at the top of the mountain chain and the sedimentary records preserved in the tectonic basins east and west of the chain (Coltorti & *alii*, 2008 and references therein) and by comparing these with a thermochronological analysis of the rocks (Balestrieri & *alii*, 2003; Fellin & *alii*, 2007 and references therein).

The higher patches of the planation surfaces, which correlate in age with the maximum uplift, are found at elevations above 2000 m on the Apennine ridge, east of the Apuan Alps (Coltorti & *alii*, 2008). This evidence of planation has been observed in other areas of the Apennines (Calamita & *alii*, 1999; Coltorti & Pieruccini, 2002) and interpreted as a plain of marine erosion, a ravinement, formed during the Middle Pliocene. South of the F. Arno, coastal sediments of this period are found at the top of the Outer and Inner Tuscany Ridges, the latter being the southward continuation of the Apuan Alps (Coltorti & *alii*, 2011). The planation surface is not preserved in the central part of the Apuan Alps due to the high degree of dissection, but it is preserved to the north and south at progressively lower elevations away from the core (Bartolini, 1980). Compared with the Apennines, the Apuan ridge is therefore clearly lower, possibly due to activity along the fault system bounding the eastern sides of the Serchio and Lunigiana tectonic basins. This tectonic line, known in the literature as M. Orsaro - M. Giovo fault system, is characterized by west-dipping high-angle master faults oriented N30-40°W. It is one of the most active tectonic zones in Tuscany and is well known for its numerous recent earthquakes. The fact that the Apuan ridge is lower than the Apennine ridge suggests that this fault system offsets the low-angle faults that offset the various structural Apuan units rather than being an anastamosing member of this set of faults as suggested by Eva & *alii* (2014). This fault system is parallel and secondary to the main fault system of the Versilian coast that delimits the west side of the Apuan ridge and displaces the terrains to depths of several thousands of metres below the Ligurian Sea.

The Plio-Pleistocene evolution of the Apuan region has been studied by analysing the compositional and architectural characteristics of the sediments preserved in the Barga basin (Coltorti & *alii*, 2008). The Early-Middle Pliocene sediments in this basin include a high percentage of metamorphic rocks, indicating stream transport of source rocks originating from the slope exposures located on the west side of the Apuan massif. Thermochronological analyses (Balestrieri & *alii*, 2003; Fellin & *alii*, 2007) indicate that until 4-5 Ma, the metamorphic core of the Apuan Alps was buried to a depth of approximately 2 km. Beginning in the Quaternary, the percentage of metamorphic rocks increased in the fluvial sediments of the Serchio basin and includes sediments derived from the erosion of the Apennine ridge to the east (Coltorti & *alii*, 2008). This deep and fast erosion is associated with tectonic inversion and delamination along the low-angle normal faults that offset the various tectonic units. Beginning in the Quaternary, the high-angle normal faults became active and formed the grabens and half-grabens of Lunigiana, Garfagnana and the Ligurian Sea.

The recent tectonic activity is responsible for the historic seismicity, which includes the earthquakes of 7 May 1481 (I_{max} VIII MCS, $M_w \sim 5.6$), 14 February 1834 (I_{max} IX MCS, $M_w \sim 5.8$), 11 April 1837 (I_{max} X MCS, $M_w \sim 5.8$), and 7 September 1920 (I_{max} X MCS, $M_w \sim 6.5$). More recently,

FIG. 20 - Overhanging cliff in a quarry of Carrara marble (photo E. Lotti).

there were the earthquakes of 21 June 2013, (M_w = 5.2, depth of approximately 5 km) and 25 January 2013 (M_w = 4,8, depth of 15 km (Rovida & *alii*, 2011). The Neotectonic Map shows the main high- and low-angle faults that delimitated the uplifted and lowered areas. The central part of the massif, underlain by the exposed metamorphic core, including the Massa Unit, contains a record of the highest uplift rates, which have been estimated at approximately 0,5 mm/yr based on the fact that the rocks of the peaks were at sea level 3.5 my ago (Coltorti & *alii*, 2008). Lesser uplift rates affected the peripheral areas, producing lesser relief energy. The high-angle normal faults bound the areas with the lowest uplift rates (Lunigiana and Garfagnana), i.e., the basins bordered by triangular and trapezoidal faceted slopes. A major E-W-trending lineament has also been reported to the north, in the higher areas of the massif, between Equi Terme and Marpiaco. In the literature, this lineament is regarded as a right-lateral strike-slip zone that transfer tectonic activity from the Serchio to the NW-trending, west-dipping master fault delimiting the east side of the Serchio Valley and to the NW-trending east-dipping master fault of the Lunigiana basin. Recent seismicity (Eva & *alii*, 2014) and recent displacement have been attributed to this lineament (Stramondo & *alii*, 2014).

Pliocene and Early Pleistocene fluvial deposits are preserved within these basins. Middle and Late Pleistocene fluvial terraces are also present along the valleys at various elevations above the valley floor. These are climatically controlled terraces that formed during the cold phases and were dissected during the interglacial periods, indicating the interactions of uplift and climatic oscillations. No evidence of displacement has been observed in the Late Pleistocene deposits, although a few knickpoints in the longitudinal profiles of the rivers prompted Di Naccio & *alii* (2013) to suggest that tectonic activity extended to the Late Pleistocene.

The coastal area is affected by lowering. An abrupt change marks the boundary between the plain, and the relief being characterized by rectilinear slopes with triangular and trapezoidal facets associated with the faults that offset the various tectonic units. Seismic profiles and boreholes reveal that marine, coastal and alluvial fan deposits, which are probably Late Pleistocene to Holocene in age, overlie a flat surface scoured into the bedrock to a depth of approximately -100 m. This surface, which might correspond to the ravinement surface of the Last Interglacial, is continuous and not displaced by faults, although its depth suggests tectonic movements after the beginning of the Late Pleistocene. However, the main faults of the Versilian coast are located west of the continental escarpment. The fault trace crossing the coastal plain has been shown on the map to indicate its presence rather than its exact location. The absolute downdropping of this area is indicated by the abrupt transition to marine deposition and the presence of a large space for accommodating coastal sediment.

Synthems

The continental Quaternary deposits have been grouped into unconformity-bounded stratigraphic units (UBSUs) following the recommendations of the ISPRA-APAT (1992) for preparing the 1:50,000-scale geological map of Italy. These UBSUs are characterized by lower and upper surfaces consisting of regional unconformities or para-conformities that are laterally traceable using litho-, morpho-, pedo- and chrono-stratigraphic criteria.

Agliano Supersynthem

The Agliano Supersynthem contains the oldest continental deposits presented on the map. These deposits crop out along the watershed separating the Serchio basin from the Aulella-Magra basin north of the village of Agliano. They are composed of polygenetic conglomerates many tens of metres thick that correlate with the deposits at the top of the Barga Basin succession (Conglomerati di Barga Formation, Perilli & *alii*, 2004; Coltorti & *alii*, 2008) and in the Lunigiana Basin (Olivola Conglomerates; Azzaroli & *alii*, 1988; Gliozzi & *alii*, 1997). Their lower boundary is an erosional surface scoured into various bedrock units. This surface is assigned an Early Pleistocene age based on a Late Villafranchian faunal assemblage.

Monteperpoli Supersynthem

The Monteperpoli Supersynthem consists of alluvial deposits underlying a fluvial terrace at approximately 340 m a.s.l. in the Monteperpoli area in a saddle formed in the bedrock between the Castelnuovo Garfagnana and Barga, along the F. Serchio (Landi & *alii*, 2003; Coltorti & *alii*, 2008). These are the oldest deposits associated with a present-day river basin. They are composed of polygenetic gravels and sands with horizontal and trough cross-bedded gravels as much as 100 m thick. They indicate that in the Middle Pleistocene, the F. Serchio was located west of the present-day thalweg but that strong river downcutting also occurred after the deposition (Coltorti & *alii*, 2008). In the northern part of the map, there are similar deposits along the watershed between the Aulella and the Bardine Rivers. Along the left side of the F. Edron, they are present near the village of Roggio and indicate the former direction of the Rio Cavo, which was later captured and redirected to the NNE. Small patches of this supersynthem are scattered across the area. It has been tentatively assigned a Middle Pleistocene age (Coltorti & *alii*, 2008).

Campocatino Synthem

The Campocatino Synthem consists of glacial and fluvial sediments deposited on alluvial fans or alluvial plains. This synthem has been attributed to depositional dynamics of the Last Glacial cycle. Glacial deposits are found in the inner parts of the massif at high elevations within glacial cirques or at lower elevations within glacial valleys. The largest alluvial fan deposits are located along the inner edge of the coastal plain at the mouths of the major water courses. One of the best examples is the alluvial fan of the Frigido River, on which the town of Massa is located. The end of the deposition most likely occurred as the climate warmed during the Late Glacial and Early Holocene. These deposits are composed of polygenetic, heterometric gravels as much as 100 m thick that are strongly cemented locally and extended laterally downslope to a sea level lower than the present one. The alluvial plain deposits are composed primarily of gravelly deposits with thin sandy interbeds underlying terrace surfaces at elevations as high as 40 m above the present-day river bed.

The Holocene deposits

The Holocene deposits are associated with the present-day dynamics and include facies that correspond to various depositional environments and geomorphic processes. The coastal plain is a long belt that includes the present-day sand-dominated beach deposits and relict beach ridges formed by progradation during historic time. The inner edge of the plain is locally marked by an inactive sea cliff eroded into the alluvial fan deposits. Locally, the transition from the fans to the plain is gradual because some deposition also occurred during major floods, primarily during the Early Holocene. A few alluvial fans are also present at the confluences of the secondary streams and the main rivers that dissect the ridge. In the Barga area, pottery fragments allowed for assigning a Holocene age to the fluvial terrace deposits now suspended at elevations many metres above the river bed. The channel bottoms of the main rivers are floored by gravelly and minor sandy deposits. Colluvial and debris deposits generated by fans and debris flows are present at the toe of the main escarpments. The former predominate along the bases of slopes underlain by marl and marly limestone, and the latter are developed at the bases of limestone cliffs.

MAP OF SELECTED SITES OF GEOMORPHOLOGICAL SIGNIFICANCE (1:100,000)

The sites shown on the Map of Selected Sites of Geomorphological Significance are only a selection of few of the most-relevant sites of geologic heritage in Apuan Alps Regional Park. This map focuses on sites of geomorphologic significance for their scientific, historic or educational value. The park displays high geomorphologic variability, primarily due to the powerful action of exogenous agents and to the great diversity of the bedrock on which they act. The selected sites are also representative of the natural and cultural history of the region.

As a result, 283 sites were classified and mapped in accordance with criteria of the Gruppo di Lavoro per la Cartografia Geomorfologica (1994), who developed a classification scheme based on the dominant geomorphic processes. Six sites were mapped as polygons, 125 sites as polylines, and 152 as points. Glacial-related sites are the most heavily represented class, followed by those sites attributed to karst and anthropogenic processes. In addition, structural, fluvial and marine sites were included, testifying to the great variety in the region's geomorphologic heritage.

What follows are descriptions of significant geomorphic features attributed to the three geomorphic processes responsible for most of the sites in the Apuan Alps.

Glacial sites. The glacial landforms mapped on Sheet 1 were selected primarily for their importance to understanding the glacial landscape of the Apuan Alps and secondarily for their palaeoclimatic relevance in a Mediterranean regional context. Due to their geographic position in the middle of the Mediterranean, they represent a link between the southern latitudes of the European Alps and Pyrenees and the Balkan Ranges (Finsinger & Ribolini, 2001; Ribolini & *alii*, 2011; Federici & *alii*, 2015). They also potentially provide valuable data for comparing and contrasting models of glacial behaviour under local climatic conditions.

Among the most important features, the Arni and Campagnina moraines were selected after taking into account their historic value: they provided the first evidence of glaciation recognized in Italy outside of the Alps (Stoppani, 1872; Cocchi, 1872). Other features, such as the Campocatino moraines on the eastern side of the Apuan Alps at the base of Roccandagia rock wall, were selected for their educational value. This moraine complex is the best-preserved concentric system of lateral and terminal moraines, although it was slightly dissected in its terminus by fluvial erosion during the glacial retreat. Upvalley, minor moraine ridges provide evidence of minor advances that interrupted the retreat phases.

Karst sites. Intense karst development in the Apuan Alps has produced more than 1500 caves (Fallani & Piccini, 2003). Some of these caves were selected for their size and their geomorphologic significance (e.g., the Corchia system, Saragato-Aria Ghiaccia-Squisio complex, Abisso Revel and Abisso Roversi). Several epigeous features that represent typical surface karst landforms were selected as sites of geomorphologic significance, such as the Carcaraia area on the northern slope of M. Tambura. Among the hypogeous karst features, the Corchia cave, which was opened to the public in 2001, is the most important site, not only for its more than 50 km of galleries and depth of 1210 m (one of the largest in the world) but also because it is one of the most studied caves for palaeoclimatic and palaeotopographic reconstructions (Piccini, 1996; Zanchetta & *alii*, 2007).

The arrangement of galleries at three well-defined levels at 1,400, 1,200 and 850 m a.s.l. reflects three tectonic standstills during the uplift of the Apuan chain. These standstills occurred since at least Early Pleistocene (Piccini, 1996, 1998). Moreover, study of the Corchia speleothems has enabled researchers to reconstruct the regional Quaternary palaeoclimatic history (Zanchetta & *alii*, 2007).

Small caves, for example the Buca della Neve on Pania della Croce and Cantoni di Neve Vecchia, located on the northern slope of Pizzo d'Uccello, that were commercially exploited for snow until the first half of the 20^{th} century are sites of historical interest.

A characteristic and very attractive geosite is the natural arch of M. Forato (Stazzema), whose 32-m span and 25-m height make it one of the largest in Italy (fig. 21).

Anthropic sites. The region's cultural and natural heritage includes the landforms related to past and ongoing marble quarrying in the Carrara basins, which extends back to the Pre-Roman and Roman periods. The study of anthropogenic landforms allows for reconstruction of local technological development and its links to cultural events, such as the introduction of gun powder and compressed air devices, the advent of new materials (e.g., synthetic diamonds for cutting with helicoidal wires or chain cutters), and new methods of material recycling based on modern industrial processes. In addition, the overlapping of natural and anthropogenic landforms clearly demonstrates how certain recent technological developments in quarrying techniques and material recovery have favoured the occurrence of geomorphological process (e.g., debris flows, landslides). Among the quarries of historic interest, an outstanding example is Fossacava, located in the Colonnata basin (fig. 19), whose working dates back to the 1st century B.C. This quarry has a typical amphitheatre shape and may be one of the largest Roman marble quarries in Italy. Here, in addition to clear geomorphic evidence of extraction (e.g., banks, excavation faces, traces of manual cuts), there are several archaeological findings in the form of rock inscriptions, blocks, altars, and tools for marble quarrying (e.g., hammers, picks and wedges). Another site of significant anthropogenic landforms in the marble extraction areas is the site of tracks built in the 19th and 20th centuries for the manual transport of marble blocks down to the valley. These dangerous tracks, known as *vie di lizza*, are clearly visible on the slopes as extremely steep ramps that locally are supported by retaining walls.

The *via di lizza di Padulello* overlooking the village of Resceto and descending the slopes of M. Cavallo is one of the most spectacular tracks. With a length of 1,920 m and a drop of 907 m, it is not the longest, but it is one of the most charming and well-preserved ancient marble tracks in the Apuan Alps (Bradley & Medda, 1989).

OTHER THEMATIC SKETCH MAPS

Using a digital terrain model generated from the interpolation of contour lines and points from the Technical Regional Maps (CTR) at a scale of 1:10,000, we prepared two thematic sketch maps. The first is the Elevation Map, on which the elevations in metres (a.s.l.) are represented using hypsometric colours and a hillshade overlay of the region. The contour interval is 200 m, and the elevations range from 0 m near the coast to almost 2000 m on M. Pisanino. The second sketch map is the Aspect Map: its categories are intervals of azimuthal degrees.

Fig. 21 - M. Forato natural arch, Stazzema (photo M.C. Salvatore).

The Drainage Network Map was prepared by overlaying streams derived from the CTR maps at a scale of 1:10,000 onto the hillshade map of the region. This map also shows the watersheds separating the three major river basins of the region: the F. Magra basin, which extends across the northernmost part of the region; the North Tuscany basin, which drains to the Ligurian Sea; and the F. Serchio basin, whose stream network directly feeds the F. Serchio.

The Map of Climatic Elements is modified after Rapetti & Vittorini (1994, 2012) and Potenti & Vittorini (1995). The various colours on this map represent the spatial distribution of the mean annual air temperatures in degrees Celsius, which were obtained from measured temperatures and from temperature estimated based on thermal gradients derived from linear regressions between elevation and air temperature (°C/100 m, Rapetti & Vittorini, 2012). Values of mean annual precipitation are represented by isohyets that were reconstructed for the period of 1956-1985 by Rapetti & Vittorini (2012) and were drawn onto the climatic map.

The impressive Apuan ridge, which extends NW-SE almost parallel to the coast, is a natural barrier to the passage of northerly cold, dry winds and the wetter westerly winds from the sea. The main watershed separates two principal zones: the slope on the maritime side, facing southwest, is characterized by a temperate climate with cool summers and mild winters, whereas the inland slope, facing northeast, has a climate that tends to be more continental, with cold winters, relatively short summers and a higher rainfall rate.

The average annual temperature in the coastal area is controlled by the thermal regime of the sea surface, whose effect tends to decrease inland and with increasing elevation.

The complex topography and relief of the region create a significant variety of microclimates controlled by local factors such as the presence of the sunny and windy slopes alternating with cold valley bottoms and sunny and wind-protected areas that contrast with densely shaded wooded slopes. The north-east-facing slopes occasionally host permanent or semi-permanent snow fields in addition to the widespread karst dolines and depressions (Rapetti & Vittorini, 1994). Evocative toponyms, such as Passo degli Uomini della Neve (Pass of the Snow Men) between Canale dell'Inferno and Costa Pulita, represent evidence of commercial exploitation of the snowfields. The trade in ice taken from the snowfields on the east side of Pania della Croce and Vetricia was an alternative livelihood to sheep farming and agriculture. The importance of this activity during the 19th century is indicated by a law enacted in 1855 by the governments of Modena and Tuscany that called for a census of karst caves and regulated the divisions of cave ownership. Many caves were used to store snow and ice for later use during the summer.

The Apuan Alps is one of the most rainy regions in Italy. The rainfall is concentrated in the autumn and winter, and the annual rainfall is second only to that in the pre-Alps, the Carnic Alps and Julian (6000 mm/year).

The peculiar geographic location and topography control the distribution of precipitation, which is a maximum in the summit areas and much less on the surrounding plains (Baldacci & *alii*, 1993; Rapetti & Vittorini, 1994).

The rainiest station is Campagrina, where the annual average rainfall is 3111 mm and where maximum values of 4731 mm and 2109 mm were recorded in 1960 and 1956, respectively (Rapetti & Vittorini, 2012).

The vicinity of the watershed separating the eastern (F. Serchio basin) from the western slopes (northern Tuscany basin) is a zone of high rainfall, i.e., more than 3200 mm / year (Baldacci & *alii*, 1993). The isohyet pattern indicates an asymmetry between the Versilian and Garfagnana sides; rainfall gradients result in higher rainfall on the Garfagnana side, in accordance with the model predicting maximum rainfall on the leeward side.

CONCLUSIONS

The Geomorphological Map of Apuan Alps Regional Park at the scale of 1:50,000 (Sheet 1) is a unique tool depicting the landforms that characterize the landscape of this region, which bear an invaluable geomorphological heritage. The Apuan Alps are a mountain range in the middle of the Mediterranean Sea and contain a record of surface processes related to Quaternary climatic events (i.e., glacial, fluvial, and marine). In addition to climate-driven processes, the analysis of tectonic landforms allows for a reconstruction of the most relevant phases of the tectonic history of the mountain building. The proximity to the coast, smooth landscape of the foothills, deeply incised valleys, and slopes rising steeply to approximately 2000 m a.s.l. all contribute to favouring one or more among a wide variety of morphogenetic agents. Peculiar marine and fluvial landforms along the coastal plain transition to beautiful peaks rising from steep rocky slopes in the interior within the span of a few kilometres. These peaks, like giant natural sentinels, today overlook the Ligurian Sea; during the periods of Quaternary glaciation, their highest elevations were carved by cirque and valley glaciers.

Rapid tectonic uplift created steep slopes and deeply eroded valleys that have been affected by gravitational processes and running water. The mostly carbonatic nature of the bedrock of the massif core, including marble, provided conditions for the development of some of the most beautiful and extensive karst terrain on the Italian peninsula. Distinctive landforms and deep, complex cave systems stand out for their beauty among the panorama of Italian karst landforms and represent a natural heritage of great value, notwithstanding the importance of the caves in storing clean water in the Apuan region. Finally, the present-day landscape was also shaped locally as a result of a long history of anthropic activities, which have included agriculture, timber production and intense marble quarrying in the interior and widespread urban and agricultural settlements on the coastal plain.

The selected scale has allowed us to represent a synthesis of the morphologies related to the geomorphic agents that led to the shaping of the present-day landscape, including the anthropic agent, which has been one of the main morphogenetic factors since pre-historic time. The map can be used for promoting and disseminating scientific knowledge.

Moreover, the map is also of high cartographic and scientific value due to its preparation using widely accepted methods of landform classification and its synthesis of available published and unpublished scientific data using field and remote checks. The map also depicts the elements related to the main geologic and geomorphologic hazards in the region, including phenomena induced by gravity, running water and tectonism. The attached thematic maps (Sheet 2) at a scale of 1:100,000 provide additional information regarding (a) the neotectonics and related seismic hazards in the areas affected by earthquakes during historic time and the long- to mid-term landscape evolution following the emergence and tectonic uplift of the Apuan Alps; and (b) the important sites of geomorphologic heritage of the region. The mapping of these sites is valuable for tourism in that it aids in understanding the origins of landforms that can be observed along roads and hiking trails. The other thematic maps at a scale of 1:200,000 are useful in terms of providing additional data about the environmental setting of Apuan Alps Regional Park.

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