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The Use of Remote Sensed Data and GIS to Produce a Digital Geomorphological Map of a Test Area in Central Italy

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1. Introduction

Thematic maps in the Earth Sciences are an essential tool for the representation, analysis and visualization of geological processes. Among the large variety of thematic maps, geomorphological maps are particularly useful in understanding natural phenomena associated with human activities (Dramis & Bisci, 1998 and references within).

Geomorphological maps report the erosion and depositional relief landforms, including submarine ones, highlighting the morphographic and morphometric characters and interpreting the endogenous and exogenous morphological processes, both past or present, that produce and shape the topographic relief. In this kind of maps, the chronological sequence is also reported, distinguishing between active and inactive landforms. The geomorphological mapping, in addition to its scientific value, is the necessary starting point of different studies such applied geology and environmental protection investigations for socio-economic improvement.

A major problem with geomorphological information is that it is extremely complex to be represented due to the huge amount of data.

In particular, the reproduced information can be summarized as follows:

- Topographic, hydrographical and morphometric data;
- Lithological and structural data;
- Morphogenetic processes:
- Structural and volcanic landforms,
- Mass wasting landforms,
- Karst landforms,
- Eolic landforms,
- Glacial and nival landforms,
- Marine (emerged and submerged), lagoon and lacustrine landforms,
- Large relict and flattened areas with minor forms of complex origin associated,
- Weathering landforms,
- Anthropic landforms.

- Morpho-chronologic data;
- Morpho-evolutive data.

Often the result is an analogical map that is not easily readable, both for the large amount of information, or for the great number of symbols associated with the different landforms.

In order to adapt this kind of data to a digital file, the original map must be converted in a vector format (points, poly-lines and polygons) using a Geographical Information System or GIS software (Bocco et al., 2001; Gustavsson et al., 2006; Vitek et al., 1996).

The use of the rich symbolism available in most GIS software, improve the graphic rendering, but does not solve the problem of readability of the map.

Images acquired by remote sensing and image analysis techniques can bring a significant contribution in improving the geomorphological mapping.

The main results of this approach are:

- a static and dynamic visualization (3D visualization) of Digital Elevation Models (DEMs) derived from satellite data. These techniques allow a better view of shapes and morphogenetic processes represented in the map.
- the calculation of primary and secondary topographic attributes (slope, aspect, planar and radial curvature, roughness) closely related to the presence of some morphogenetic processes and their level of activity. The selection of meaningful ranges of attribute values enable to identify the geometry of the landforms.
- an analysis of multispectral images, with various combinations of RGB bands to highlight some specific morphogenetic processes (such as landslide prone areas).

In this paper the geomorphological map of the Subasio Mountain Regional Park (Umbria region, central Italy) is presented. The map is the result of the interaction of different datasets, both traditional and innovative in geomorphology. Aerial photos and field survey are enhanced by DEMs and satellite images to achieve a digital final product that is not only a simple thematic map, but also an interactive and upgradable Geographical Database. The geomorphological processes producing the present landscape are therefore better visible and understandable through the use of new tools: hillshade layer in transparency under different thematic maps and 3D virtual flight on the area where the map is overlaid to satellite images in a new, prospective view.

2. GIS, DEMs and remotely sensed data in computer cartography: An overview

Automatic mapping techniques are currently supported by tools with a high potential in the field of graphic representation of data such as GIS and by the use of remotely sensed data. Thematic maps produced with these methods show clear advantages, although some limits in the restitution of certain themes, in particular the geomorphological symbology, are evident.

They represent a digital geo-referenced and updatable database, i.e. a cartographic document with hyperlinks to the obtained results by the manipulation of remotely sensed data. This document can be also exportable to different platforms (handhelds PC, WebGIS) for a wide spectrum of applications.

These types of data have significant advantages over traditional methods because they: i) overlay broad areas in relatively short acquisition times; ii) have a better accuracy and precision of the measured data relative to traditional techniques; iii) are in a digital format and, therefore, are simple to elaborate for both research and application purposes; iv) can be easily updated allowing to examine the same areas at different periods and to evaluate both the possible morphological evolution and the kinetics of investigated processes.

For these reasons, research in the Earth Sciences and in geomorphology is integrating, or in some cases completely replacing, traditional techniques of acquisition of spatial information with these new tools (Schmidt & Andrew, 2005; Yongxin, 2007).

It is worth noting that the use of images and digital data, in addition to the advantages described above, opens the possibility to apply new techniques of analysis of physical variables responsible for morphogenetic processes. This being so, the spatial analysis in GIS and the most common systems of image analysis, represent a new field of Earth Sciences and not only a simple application of the theoretical traditional knowledge (Burrough & McDonnell, 1998). The huge potential offered by modern systems, allowing the simultaneous integration and analysis of a large number of spatial data by a variety of mathematical functions, investigate the spatial connections between variables and reveal new relationships and landscape evolution models (sensu Evans, 1972; Hengl & Reuter, 2009; Pike, 2000).

Two new kinds of data are particular useful for the production of geomorphological maps: DEMs and remotely sensed images.

A Digital Elevation Model (DEM) is the modelling of the Earth's surface or part of it in a digital format. Two types of DEMs exist: Triangulated Irregular Network (TIN) and Grid DEM. A TIN is a complex vector data resulting from the interpolation of a set of irregularly spaced points (Braun and Sambridge, 1997; Peucker et al., 1977; Sambridge et al., 1995; Tucker et al., 2001). A square-grid DEM is a raster data where the topography assessment is modeled in a "*gridded set of points in Cartesian space attributed with elevation values that describe the Earth's ground surface*" (Wilson, in press). Although grid DEMs show several disadvantages due to the regular spatial resolution, occasionally causing the inability to detect some topographic variations, or the impossibility of modelling particular landforms features (such stream meandering), they are used in most studies focusing on terrain analysis in geomorphological, hydrogeological (flood analysis) and environmental applications (Moore et al., 1991). Moreover, the remote sensing techniques produce new data models increasing the quality and spreading of these data. Because of these reasons grid DEMs are nowadays the most widely used in geological models requiring topographic assessment.

DEMs can be produced by different procedures (Nelson et al., 2009; Taramelli et al., 2008; Wilson, in press):

1. Vectorization of existing hard-copy topographic maps. Contour lines and spot height can be digitalized and converted in a vector format to be stored like polylines and points with location and altitude value. This procedure allows to obtain a DEM for each part of the Earth represented on a topographic map, but show several disadvantages. In particular, they are time consuming and the quality of the final product strictly depends on the original map and on the acquisition methods.

2. Ground survey methods with a set of field data (points) collected with Global Position System (GPS) or Electronic Distance Measuring (EDM). Although this method allows to save a large number of input data in areas with a strong topographic complexity, it is time consuming and sometimes very expensive. Therefore, it can be a reasonable choice only for some restricted areas.
3. Remote sensing techniques with passive and active sensors. These procedures permit to obtain data with a very high horizontal resolution and vertical accuracy for large areas. Nowadays remote sensing DEMs are the improving resource in this field research and application.

When, by transparency tools, satellite images or digital orthophotos (geological, geomorphological, land-cover e.g.) are overlaid as several thematic maps to a shaded relief, a composite visualization is achieved. In geomorphology DEMs are commonly used to calculate topographic attributes (Franklin, 1991; Moore et al., 1991; Pike, 1988; Wiebel & Heller, 1991). Among them, primary attributes are morphometric parameters deriving from DEMs, i.e. slope, aspect, plan and profile curvature. The visualization of topographic attributes and their analysis can be a very useful tool to better understand the geomorphological processes acting on a study area.

Remotely sensed imageries have a large improvement in both areal coverage and technical characteristics. Moreover, the selection of the most fitting band combination in RGB (Red, Green, and Blue) allows highlighting the required morphological characteristics and processes and facilitates landforms recognition.

3. The study area: The Subasio Mountain regional park (Umbria, central Italy)

The study area is located in the Umbria region (central Italy). This region is well-known because of its natural heritage and exceptional geological value. Twenty-seven geosites or "*any place where you can define a geological and geomorphological interest for conservation*", (Gray, 2004) are already individuated and studied. Seven regional and one national natural park are present on the territory (Figure 1).

The entire region shows a strong correlation between geological attributes and the relief energy associated with topography assessment.

The Subasio Mountain regional park covers an area of 7,200 hectares. The area has a triangular shape, is bordered to the south by the Subasio massif, a rolled and asymmetric anticline. To the west the limit follows the Tescio River. Towards NE the central part and the apex are crossed by close river networks.

In the study area outcropping lithotypes can be clustered in three main complexes and in different types of superficial deposits (Figure 2).

The first and youngest is the Fluvial **L**acustrine Complex (Holocene – Pliocene) with pebbles, sand and clay sediments arranged in deposits that are heterogeneous for thickness, shape and areal extent. This complex is associated with the lowest slope values and plain areas.

The second complex is the Terrigenous one (Miocene), consisting of alternating layers of sandstone or limestone with clay or marl. According to the percentage of clay and the dip

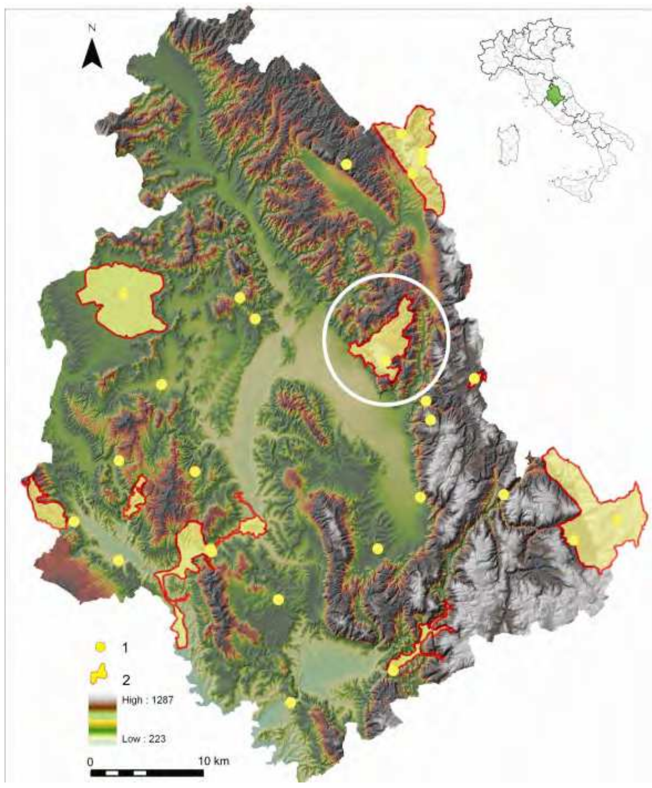


Fig. 1. Location map of the Umbria Region (central Italy). The white circle marks the Subasio Regional Park. (1) Geosites, (2) Regional Parks.

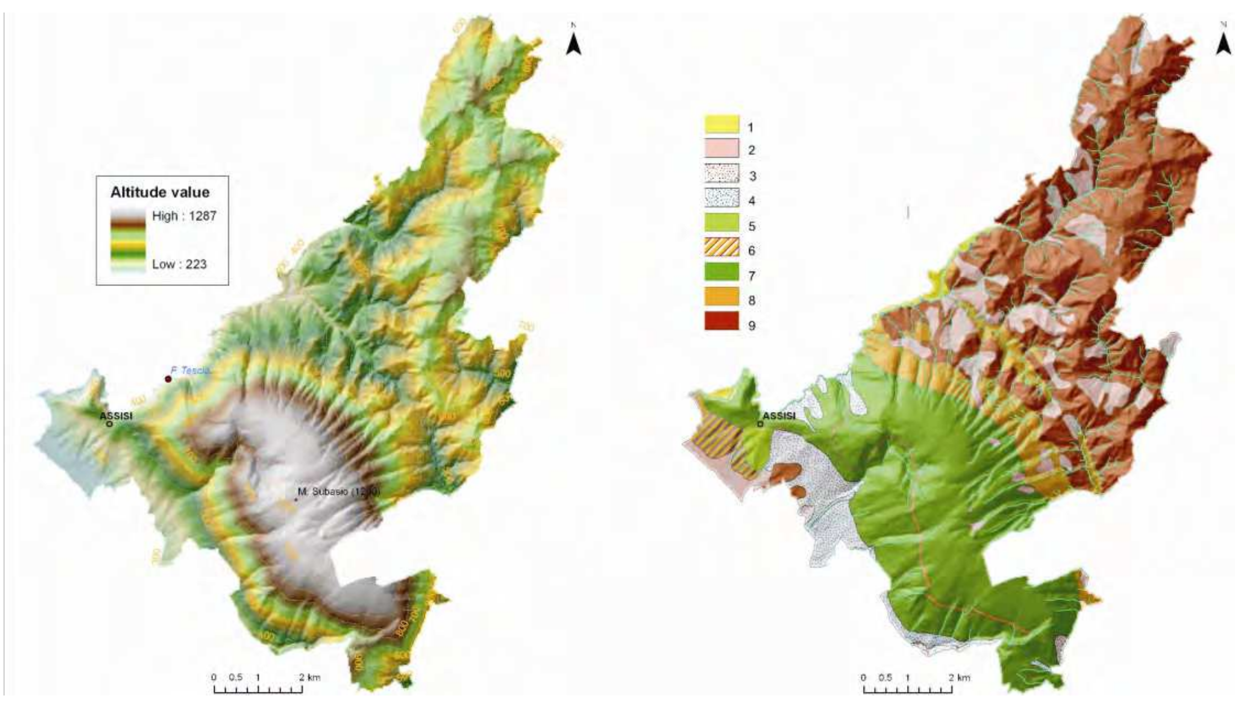


Fig. 2. Left: DEM of Subasio Mountain Regional Park with altitude values in meters a.s.l. Right: geological map. (1) Alluvial deposits, (2) Colluvial deposits; (3) Debris deposits (active); (4) Debris deposits (ancient); (5) Fluvial **L**acustrine complex; (6) Travertine; (7) Calcareous complex; (8) Terrigenous complex with prevalent clay percentage; (9) Terrigenous complex with prevalent arenaceous percentage.

direction of the layers, the energy relief shows medium values. Mass wasting processes prevail together with fluvial erosion landforms on a rolling hill landscape (Figure 3).

The oldest complex is the Calcareous one (upper Trias – Oligocene) corresponding to the mountain areas of the region and to the highest values of energy relief and altitude. The Calcareous Complex consists of a thick multilayer sequence where limestone prevails and karstic features and debris deposition at the base of the slopes are the most frequent geomorphological morphotypes (Figure 4).

Fig. 3. The Terrigenous Complex view, photographed from the top of Subasio Mountain, northwards (photo by L. Mancinelli).

Fig. 4. The Calcareous Complex on the top of the Subasio Mountain with a macro-doline in the foreground (photo by L. Mancinelli).

The geologic history of the area is tightly related with geological evolution of central Italy. From a tectonic point of view the area is the result of two different tectonic periods. In the Miocene a compressive phase originated anticlines and synclines (like the Subasio Mountain) followed, since Pliocene, by uplift with an extensional tectonic phase affecting the entire area. Because of this, a sharp increase of energy relief has forced the entrenchment of the stream network resulting in headward and stream erosion and with the simultaneous triggering of landslides along the slopes (Malinverno & Ryan, 1986, Mayer et al., 2003).

The strong heterogeneity of the substrate is responsible for the great variety of relief and geomorphological processes acting on the area. Hence, the Subasio M. Park is a perfect test-area to assess a method focusing the geomorphologic map editing.

4. The interactive geomorphologic map: A qualitative and quantitative approach in a GIS environment

The essential steps required to elaborate the final digital geomorphological map are summarized in Figure 5.

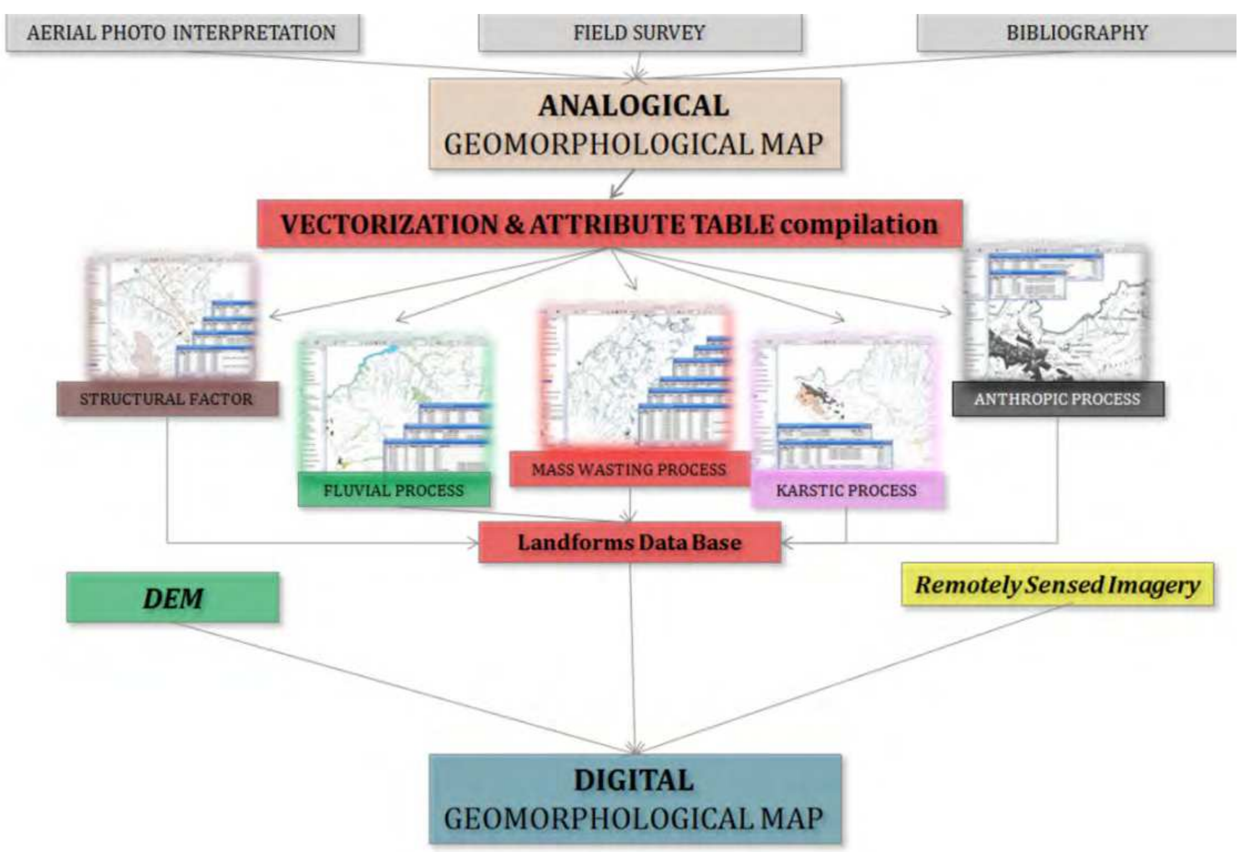


Fig. 5. Flow chart showing the steps required to produce the final digital geomorphological map starting from the analogical data.

The geomorphological map was produced to a medium scale 1:25000, with ESRI's ArcGIS 9.3 (© ESRI) with an equivalent project scale. The Spatial Reference is ED50 (European Datum) UTM (Universal Transverse Mercator) Zone 33N. The project extent is set on the mask corresponding to the polygon shape of the park boundaries. In the GIS project the background is prepared with a topographic raster image in the TIFF format (Sheet N. 123 of the Topographic Map of Italy) and the river network in a vector format (DWG). The drainage pattern is separated from the other topographic data to highlight the relationships with fluvial landforms.

The traditional working techniques are the first step. Therefore, field survey, aerial photo interpretation and collection of scientific papers focused on the study area are required. An analogical geomorphological map is the intermediate result. The map, scanned and rasterized with a high accuracy, is imported in the GIS project and then georeferenced.

The following stage, the vectorization of each single group of landforms, is particularly important. The symbology associated with a geomorphological map is complex. Thus, it is not always possible to draw symbols identical to those proposed in the traditional and official legends. The "Legend for the Geomorphogical Map of Italy" at a scale of 1:50000 is used as a reference (GLCG, 1994).

Thirty-eight vector layers are compiled. Each layer includes a variable number of landforms. Table 1 summarizes the layers and the relative information.

N.	Layer Landforms	Geomorphologic process	Shape feature	N.	Layer Landforms	Geomorphologic process	Shape feature
1	Park boundary	Topographic	Polygon	20	Fluvial lacustrine deposit	Fluvial	Polygon
2	Eluvial Colluvial deposits	Superficial deposit	Polygon	21	Fluvial scarp	Fluvial	Polyline
3	Terrigenous Complex 1	Bedrock	Polygon	22	Sheet erosion	Fluvial	Polygon
4	Terrigenous Complex 2	Bedrock	Polygon	23	Gully erosion	Fluvial	Polygon
5	Calcareous Complex	Bedrock	Polyline	24	Gully erosion	Fluvial	Polyline
6	Fault	Structural Factors	Polyline	25	Badlands	Fluvial	Polygon
7	Fractures and joints line	Structural Factors	Polyline	26	Elbow river capture	Fluvial	Polyline
8	Ridge	Structural Factors	Polyline	27	Gorge	Fluvial	Polyline
9	Peaks	Structural Factors	Point	28	Debris deposit (actual)	Mass wasting	Polygon
10	Sadde	Structural Factors	Point	29	Debris deposit (ancient)	Mass wasting	Polygon
11	Slope asymmetry	Structural Factors	Point	30	Gravitational scarp	Mass wasting	Polyline
12	Structural Scarp	Structural Factors	Polyline	31	Landslide, fall	Mass wasting	Polygon
13	Flatiron	Structural Factors	Polyline	32	Landslide, slide	Mass wasting	Polygon
14	Esplanade area	Structural Factors	Polygon	33	Landslide, slump	Mass wasting	Polygon
15	Triangular facet	Structural Factors	Polygon	34	Landslide, flow	Mass wasting	Polygon
16	River	Fluvial	Polyline	35	Travertine	Karstic	Polygon
17	Valley	Fluvial	Point	36	Doline	Karstic	Polygon
18	Alluvial deposit	Fluvial	Polygon	37	Anthropic scarp	Anthropic	Polyline
19	Alluvial fan	Fluvial	Polygon	38	Quarry	Anthropic	Point

Table 1. Layers of shapefile corresponding to geologic bedrock complexes, superficial deposits and geomorphologic features vectorized in the project.

For each landform a unique code for the graphic properties of the layer is individuated.

As an example, Table 2 reports some of the used codes.

Layer - landforms	Type	FONT	UNICODE
Layers dip direction	Character Marker Symbol	ESRI Geology AGSO 1	162
Peaks	Character Marker Symbol	ESRI Transportation & Civic	114
Slope asymmetry	Character Marker Symbol	ESRI Geology	196
Saddle	Character Marker Symbol	ESERI Cartography	164
Valley	Character Marker Symbol	ESRI Geology USGS	56
“V” shaped valley	Character Marker Symbol	Lucida Sans	86
Valley with a flat bottom	Character Marker Symbol	ESRI Geology USGS	200
Quarry (active)	Character Marker Symbol	ESRI Geometric Symbols	199
Quarry (inactive)	Character Marker Symbol	ESRI Geometric Symbols	198
Gully erosion	Character Marker Symbol	ESRI Geology AGSO 1	193
Sheet erosion	Character Marker Symbol	ESRI Geology AGSO 1	114

Table 2. Some examples of codes used for drawing the symbols in the final map, according to the features proposed in the official Italian Geomorphological Legend.

In the Attribute Tables several information are stored for each layer. In particular, for the different lithotypes and superficial deposits the following fields are included: i) a brief description of the lithology, ii) its age and iii) thickness, and iv) a link to a photo of a significant outcrop. For each landform the data included in the attribute table are: i) the main geomorphologic process responsible for landform creation, ii) the state of activity, and iii) the area and the perimeter. A link to a photo, together with a description of the most significant characteristics of the landform, are included.

5. Remotely sensed data as a support for the map creation

Several digital and analogical sources of data can be used to produce thematic maps both in the stage before the preparation of the map and in the successive stages.

Aerial photo interpretation is a well-established working tool in Earth Science research; DEMs and satellite images, on the contrary, are considered as new tools with an enormous potential, not yet fully explored. In the following paragraphs the different data are described according to their use in this work.

5.1 The aerial photo interpretation: A traditional technique for landform detection

The main goal in reading an aerial photo in the Earth Science applications is to identify and understand the physical landforms on the terrestrial surface and, in some cases, underground morphologies. Aerial photos can be in an analogical or in a digital format. Both of them are acquired by an aerial platform using a camera slipped into a mount located at the bottom of the aircraft. Analogical and digital cameras are quite similar. Analogical images, taken on a photographic film, can be in natural or black and white colours and show the topographic surface as a series of overlapping photos for a large percentage of the detected area. Digital images are taken on a strip with a linear scanner in black and white, colour (RGB format) or infrared. The most important difference is the storage device where the digital camera system uses a charge-coupled device (CCD) that can strongly vary in capacity and resolution, affecting the quality of the images. Both data sets have advantages. Digital images can have a better resolution and filter only few bands of the electromagnetic spectrum allowing the use on specific research fields. In addition they are subjected to editing and post-processing, for example to sharpen the edges of the objects represented on the image. On the contrary analogical films are more nuanced and show a better colour rendering. Moreover, in the analogical data, the images show a much more natural aspect giving the opportunity to better visualize and identify natural features on the surface.

In both cases aerial photos show a "bird's – eye" view of the Earth surface and, unlike the topographic maps that are a selective representation of reality, omitting a large number of natural features, aerial photos provide an objective idea of the arrangement of the spatial pattern.

The limits of this technique are related to the presence of clouds or haze in the atmosphere and snow on the Earth surface covering the topographic pattern. Moreover, distortion effects have to be corrected for an optimal use of the data sets.

Aerial photos are used in a wide group of applications: engineering, logistic and planning, mineral exploration, geoarchaeology, mining and resource extraction, land use and landcover analysis and so on.

In geomorphology air photos interpretation is an irreplaceable tool to detect landforms allowing to identify the type of bedrock and the main morphological processes acting in the study area and the palaeogeographic reconstruction of particular morphological situations (past river captures or the infilling of ancient lacustrine depressions). Some large landforms are more evident on the aerial photos than on the field due to the landform location or the topography arrangement.

Therefore, the aerial photo interpretation is a fundamental method in every geomorphological mapping process.

Moreover, the possibility to observe images taken in different periods of time, and with diverse scales, permits to monitor the landscape evolution (multitemporal and multi-scalar observation). Examples include the evolution of a landslide, the health status of vegetation, the rate of retreat of a cliff, the changes affecting a river drainage network.

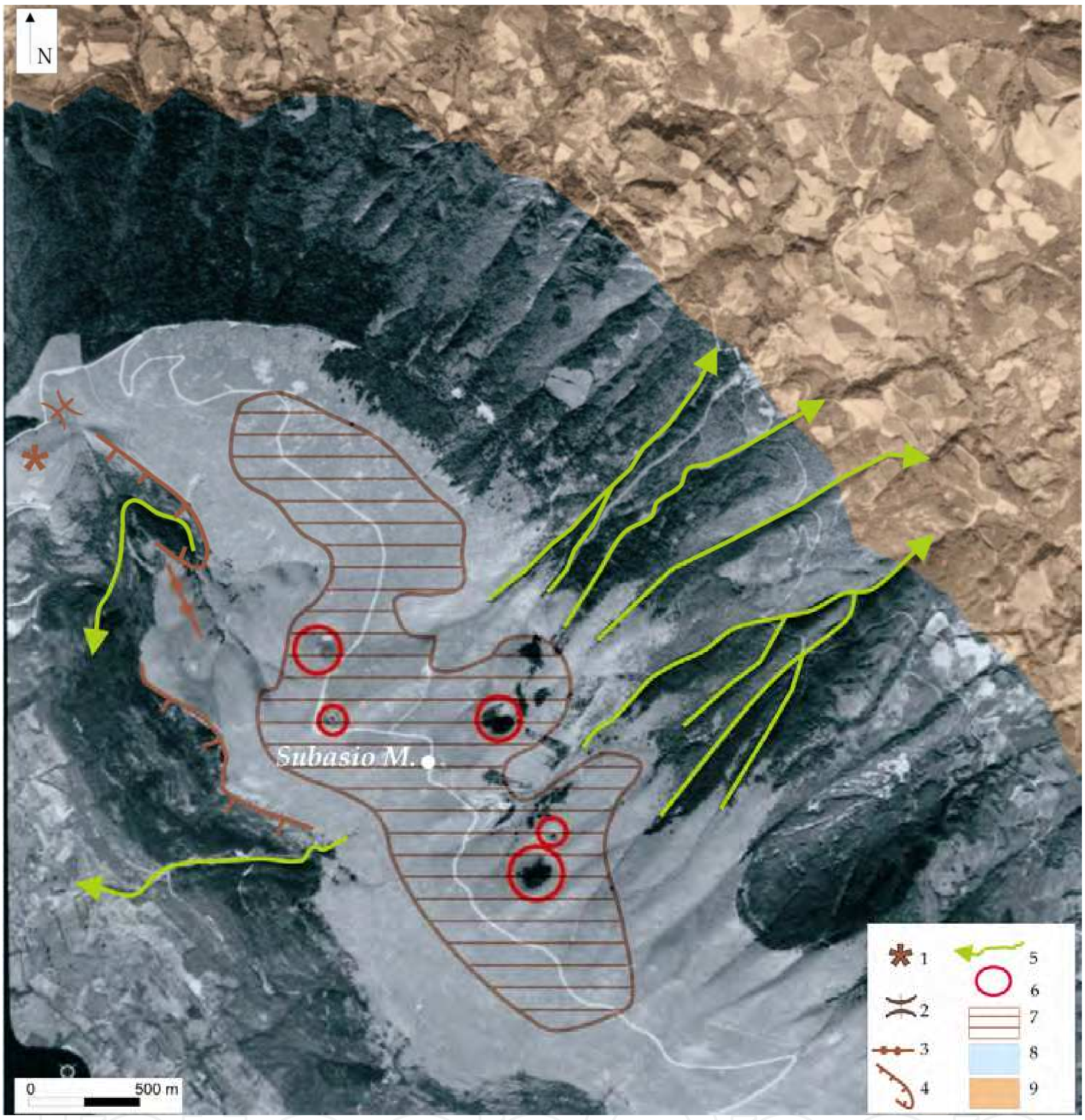
The first elements of interpretation in geomorphology are the *size* of the objects identified and their *shape*. Also the spatial arrangement is very important, so site, situation and association are characteristics to be taken into account. *Site* is the relationship of a feature to the environment (elevation, slope, surface cover). *Situation* observes the mutual spatial relationship of the features. *Association* refers to the possibility that, when particular geomorphological processes or landforms are recorded is quite obvious to find associated features. Other important characteristics are diagnostic for geomorphogical interpretation: *tone* or colour is the brightness or the shade of gray or the colour of the detected element and depends on the amount of light that it reflects, constituting a sort of spectral signature of anthropogenic and natural objects in the area. Also, a transition between two different tones is relevant to detect a variation in some physical processes and useful to locate landform limits. *Texture* can be defined as the arrangement of tone or colour structured in a well recognizable pattern and depends strongly on the scale of the photos. When features are too small on an image to be identified, their repetition can be a clear evidence of a specific feature. So, the smoothness (uniform and homogeneous texture) or the roughness (coarse and heterogeneous texture) of an image can identify a particular vegetation cover (e.g. tree as rough, grass as smooth). *Pattern*, or the spatial arrangement of a landform, is the last characteristic used in geomorphology, particularly useful in drainage network recognition (dendritic, rectangular, parallel and so on).

In the study area aerial photo interpretation was one of the first activity carried out, joined with field survey and bibliographical research. In this project analogical photos in black and white were used at a scale of 1:33000 (year 1977) and 1:10000 (year 2004).

The use of black and white in this case is preferred because it allows to better highlight tones and textural variations on the images. At first it is useful to observe photos on a small scale (1:33000) for an overview of the area. Features due to tectonic and structural control like faults, ridge alignments, structural scarps, discontinuity along slopes are best identified in this scale. Also the river drainage pattern, any anomaly along river tracks and large landslide phenomena are well evident at this scale. In the study area these photos highlight the morphological units linked with the different bedrocks. The calcareous anticline of the Subasio Mountain shows distinctive characteristics (high slope values, low rates of drainage density), significantly different from the rest of the area, where the presence of rock types with an high clay abundance, strongly influences the morphological arrangement (i.e. high value of drainage density and medium and low slope values, high index of landslides, fluvial erosion with badlands and fluvial scarps). Photos analysed at a larger scale (1:10000) are more useful for identifying and drawing landforms. The accuracy is detailed enough for mapping the different morphological elements of a landslide (e.g. crown, main and minor scarps, the displaced material, the accumulation and so on). The choice to use two distinct years of acquisition of the images (1997 and 2004) ensure the multitemporal analysis of the area assigning a relative age to some deposits and landforms (active, inactive). The work is divided into a first phase of identification and drawing of landforms directly on aerial photo (Figure 6) and subsequent transposition of vector data in a GIS environment.

5.2 DEMs and satellite images: A new perspective to view the landscape

The resulting geomorphologic map has several advantages. The final document is upgradable and easily editable. The organization of data into layers lets the user to select, for viewing and printing operations, one or more layers simultaneously. The attribute tables associated with the themes contain alphanumeric data in unlimited quantities.



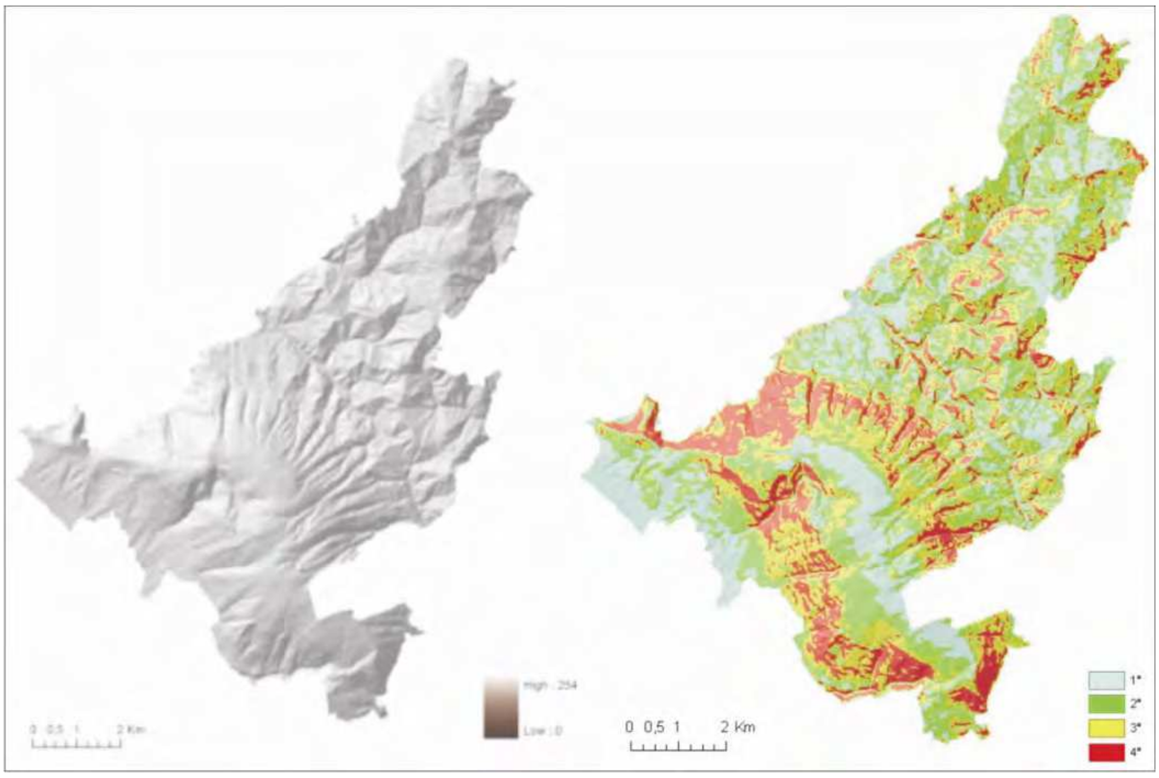
1) Peak, 2) Saddle, 3) Ridge, 4) Scarp, 5) River valley with a "V" shape, 6) Doline, 7) Structural surface, 8) Calcareous Morphological Unit, 9) Marly Morphological Unit.

Fig. 6. Aerial photo of the Subasio Mountain and the surrounding area with some examples of features identified and drawn on the photo (b/w, scale 1:33000, year 1977).

However, at this point of the project, the paper is simply a digital geomorphological map. The subsequent implementation of satellite data is an added value and offers the possibility to obtain additional useful spatial information for different types of applications.

The topographic model used in this project is the Shuttle Radar Topography Mission DEM elaborated for Italy with an horizontal resolution of about 90mx90m (Taramelli & Barbour, 2006).

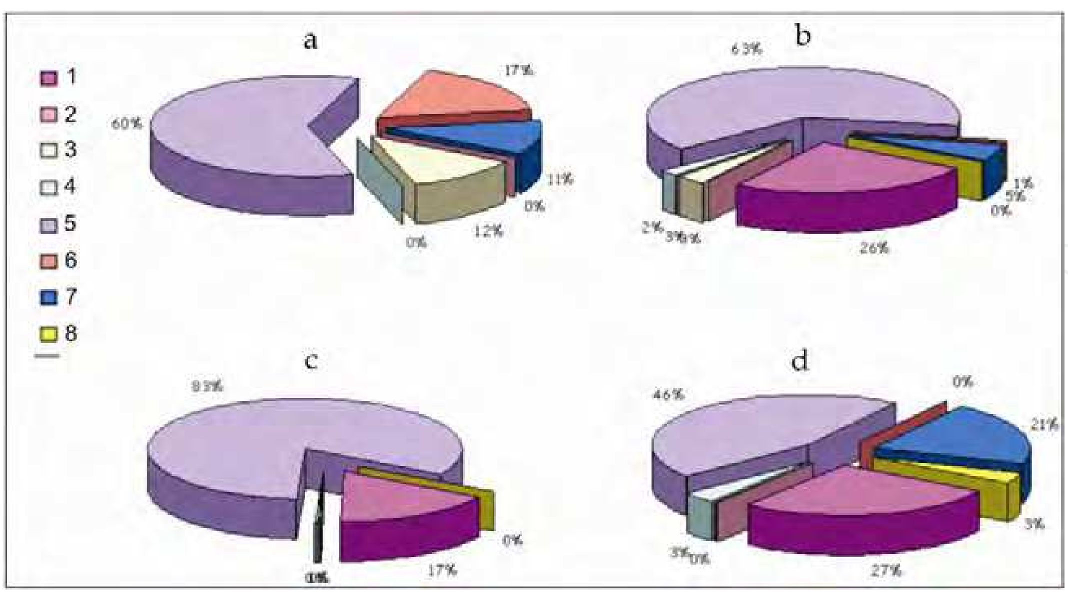
Several topographic attributes including an hillshade, to better visualize the topographic surface and slope and aspect grids are derived (Figure 7).



The four slope classes are: 1) 0°-13°, 2) 13°-20°, 3) 20°-27°, 4) 27°-48°.

Fig. 7. Hillshade (on the left) and slope (on the right) grids derived from SRTM DEM.

Geomorphological processes are strictly related to topographic trends and the spatial distribution of the phenomena is always significant.



a) Falls, b) Slides, c) Flows, d) Complex landslides. 1) Eluvial and colluvial deposits, 2) Alluvial deposits, 3) Calcareous Complex, 4) Terrigenous Complex (1), 5) Terrigenous Complex (2), 6) Debris (active), 7) Debris (inactive), 8) Fluvial lacustrine deposits.

Fig. 8. Diagrams showing the spatial distribution of landslides on several lithotypes.

Spatial analysis tools can calculate the statistical distribution of the landforms, starting from the topographic grids (Melelli & Taramelli, 2010; Taramelli & Melelli, 2009). In Figure 8 a statistical distribution of the different types of landslide is shown.

To better understand to what extent the topographic parameter influences the spatial distribution of a geomorphological process a quantitative analysis is required. Therefore, the digital map, with the addition of a DEM, becomes an interactive document for further applications.

Remotely sensed data also offer further enhancements to geomorphological mapping and landscape comprehension. A different perspective view of the area, together with the overlapping of different types of data in a 3D view, is an appealing idea for a different use of geomorphological mapping, in particular for a non-specialized audience. Due to the aforementioned difficulties in interpreting the geomorphological symbolism, a backdrop layer resulting from remotely sensed images can aid in the comprehension of the landforms. The perspective view, joined with virtual flights through the area, increase even more the visualization of the landscape. The user can observe any landform in a perspective view and, with a virtual cloche, can fly near and above the feature. So it is possible to intuitively distinguish the main scarp or the convexity on a slope corresponding to the accumulation of a landslide. The transparency tool can make simultaneously visible the alignment of a fault system on the geomorphological map and the corresponding geomorphological features (scarps or triangular facets) on the underlying DEM or satellite image. In the same way a badland drawn on a map is better evident with an image overlaid, where the dense network of valleys engravings on a slope with the absence of vegetation and the grey light colours of the clay bedrock are shown.

The use of remotely sensed images can improve this kind of perception. It is well known that particular RGB arrangements can highlight different natural aspects on the ground: 432 for vegetation, 741 for the moisture content in the soil coverage and so on. So the manipulation of a remotely sensed image under the digital geomorphological map with a 3D perspective view due to the DEM addition, is the best possible analysis of a geomorphological map.

In this example, the Arcscene ESRI Tool was used to obtain a 3D view of the park and a virtual flight on the area. In order to achieve a more realistic view an ASTER image (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is overlapped (Abrams, 1999; Yamaguchi et al., 1998). ASTER is an imaging instrument flying on the Terra satellite (http://asterweb.jpl.nasa.gov/index.asp). The satellite was launched in December 1999 as part of NASA's Earth Observing System (EOS). The data are in 14 bands (from the visible to the thermal infrared wavelengths) and offer high-resolution characteristics. Thanks to the swath width of the sensor, each ASTER image takes an area of 60 x 60 km (Figure 9).

All the data described above can be represented in the final double-sided printing layout of the map showing how interactive this kind of document can be (Figures 10 and 11). Figure 10 represents the first side of the map with the Figure 11 on the back.

In the final layout, the part dedicated to the geomorphogical data and the section for the grids and satellite images have the same importance. So the remote sensing information is added to make the final product in keeping with the rest of the maps, becoming a source of information for the knowledge of the territory.

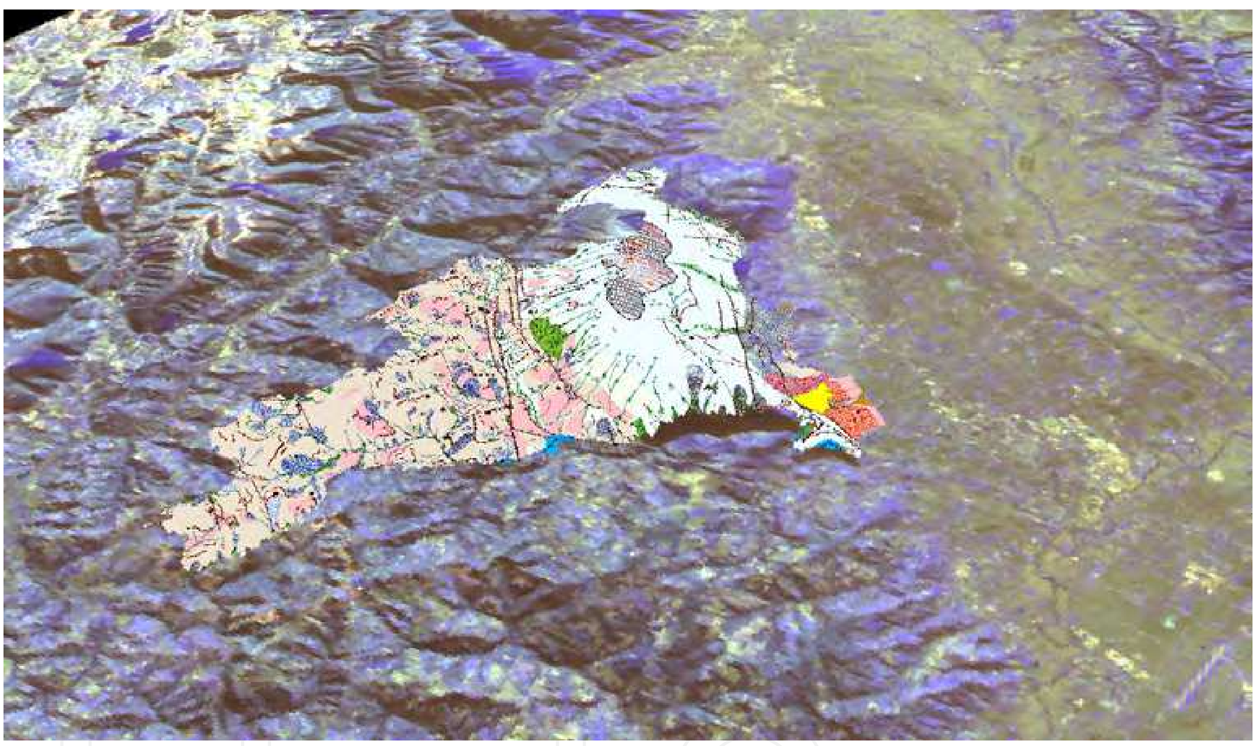


Fig. 9. A still image of the virtual flight on the park with the geomorphogical map overlapping an ASTER image (view from SW). The RGB combination is the 742. The 3D view is assured by the SRTM DEM height values.

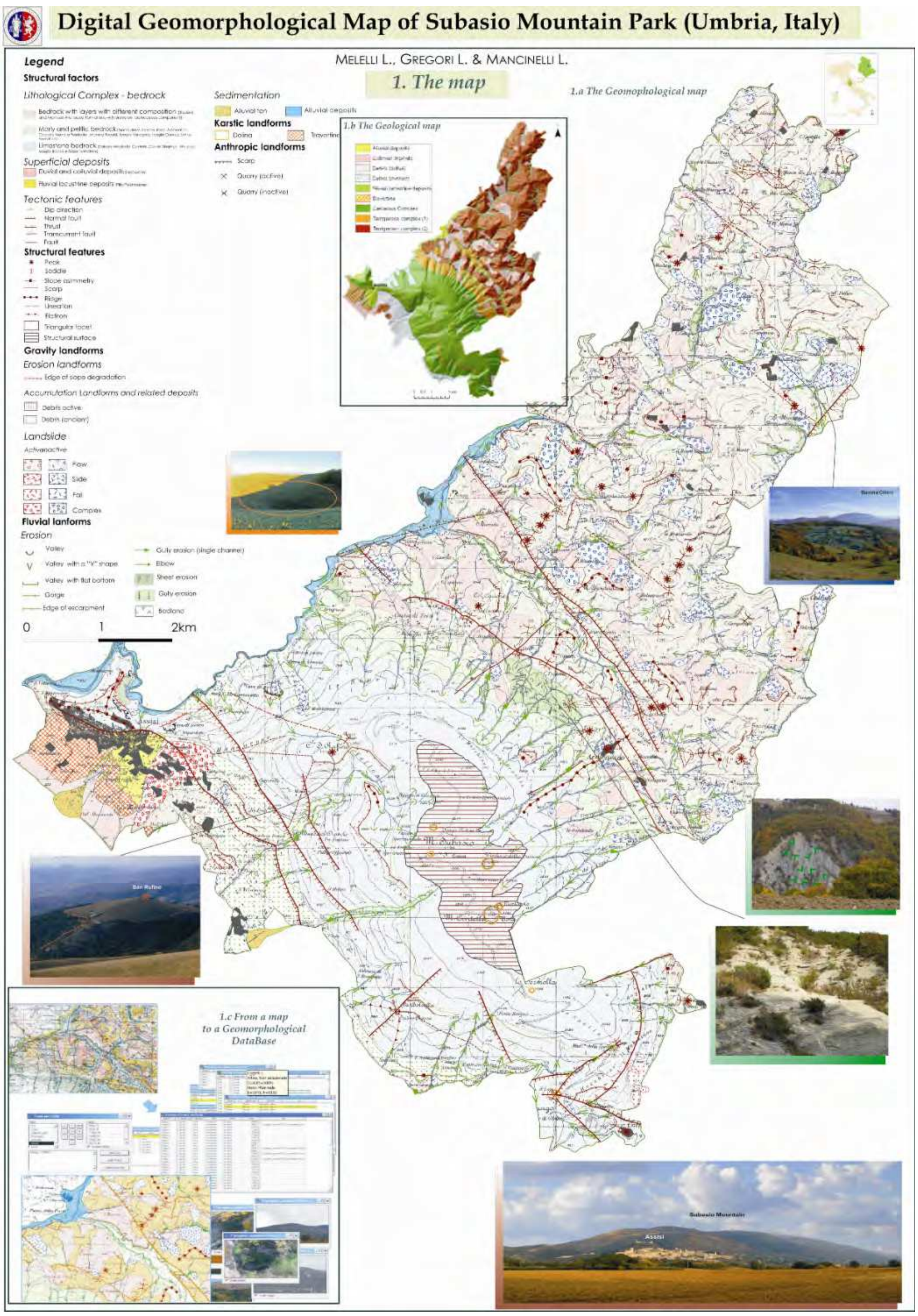


Fig. 10. The final layout of the geomorphological map (front side) with the geomorphological map, a geological sketch, some significant photos and the scheme of the transition from the analogical product to the digital one.

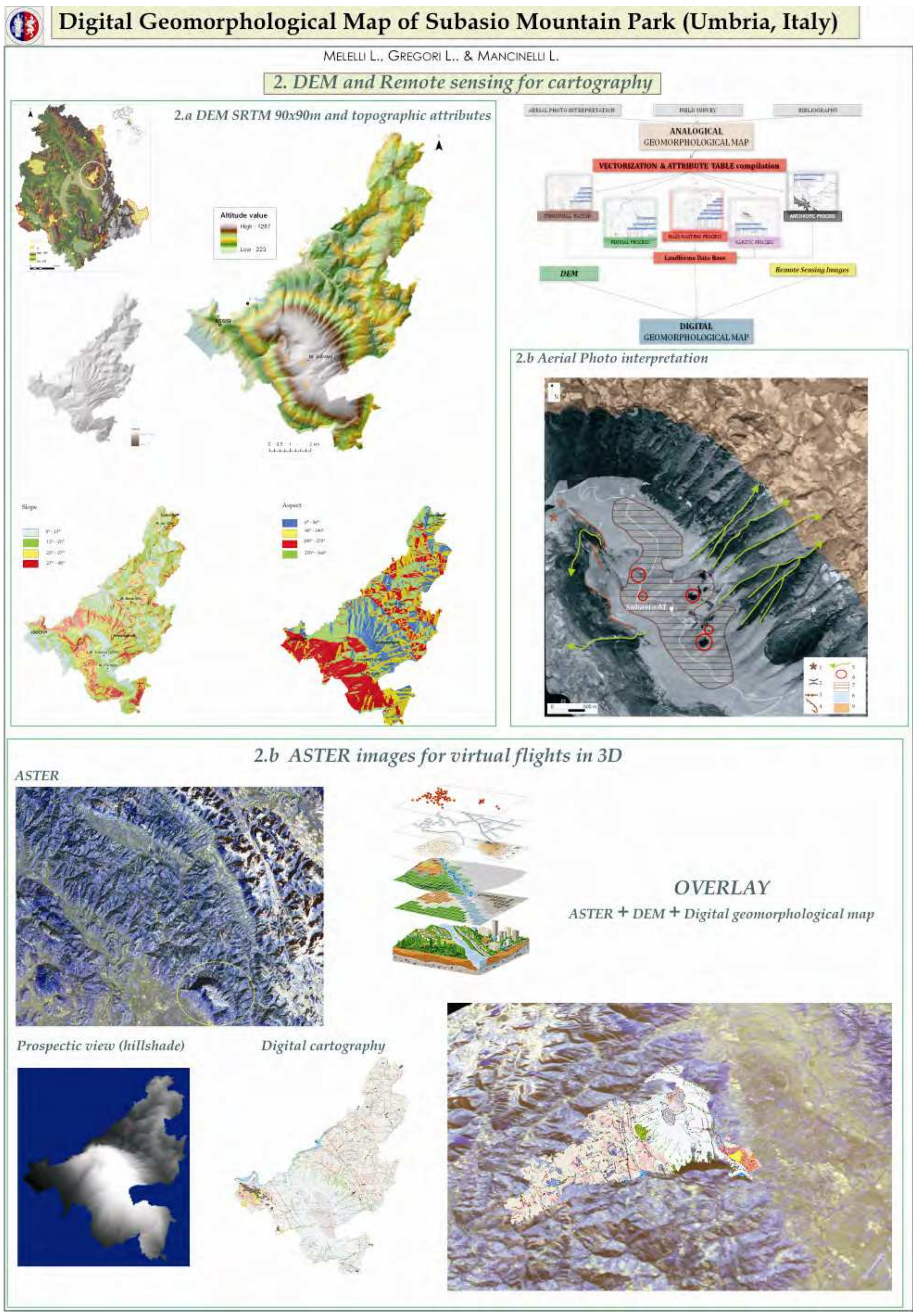


Fig. 11. The final layout of the geomorphological map (back side) including the remotely sensed data.

6. Conclusions

Cartography is experiencing an important change with the introduction of computer systems and digital images (GIS, satellite images). In particular in the Earth Sciences, geomorphological mapping begins to benefit from the digitalization of information.

From a graphical point of view, given the complexity of symbology, geomorphological maps interpretation is often difficult, especially for non-experts.

The potential offered by GIS can solve this problem. In addition, the input of satellite data allows integrating additional information to better understand the mechanisms that regulate the morphogenetic processes.

The remote spatial data acquisition techniques are also moving important steps. Therefore, the availability of data with high accuracy allows having a progressively more accurate information on the topographic attributes evaluation and for 3D observations of landforms.

Statistical distribution of landforms, morphogenetic processes and numerical calculation of quantitative indices (Melelli & Floris, 2011; Serrano & Ruiz-Flaño 2007a,b) benefit significantly from these new techniques. Today is possible to merge the information collected by traditional techniques (aerial photo-interpretation or field survey) with numerical data, obtaining final documents completely different from traditional cartography. The data can be updated, queried and displayed in various ways. They can also, with the help of statistical analysis, offer new research methods to build advanced models for morphogenetic processes of landscape evolution.

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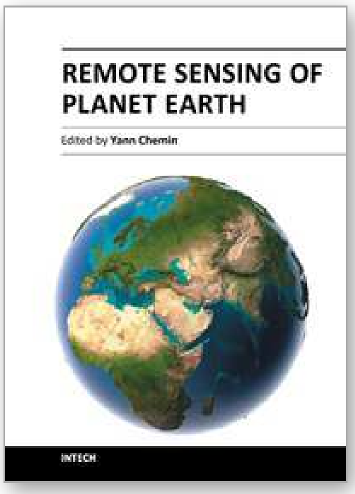

Remote Sensing of Planet Earth
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Monitoring of water and land objects enters a revolutionary age with the rise of ubiquitous remote sensing and public access. Earth monitoring satellites permit detailed, descriptive, quantitative, holistic, standardized, global evaluation of the state of the Earth skin in a manner that our actual Earthen civilization has never been able to before. The water monitoring topics covered in this book include the remote sensing of open water bodies, wetlands and small lakes, snow depth and underwater seagrass, along with a variety of remote sensing techniques, platforms, and sensors. The Earth monitoring topics include geomorphology, land cover in arid climate, and disaster assessment after a tsunami. Finally, advanced topics of remote sensing covers atmosphere analysis with GNSS signals, earthquake visual monitoring, and fundamental analyses of laser reflectometry in the atmosphere medium.