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SCIENCE

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Geomorphology and geoheritage in the Piana Crixia Natural Park (NW Italy)

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ABSTRACT

This research presents a set of geomorphological and geoheritage evidence from the Piana Crixia Natural Park, located in the northwest part of Italy. The Natural Park, which covers an area of just under 8 km2, was established for the conservation and enhancement of two geosites: the Piana Crixia mushroom, a 15 m high earth pyramid shaped in conglomerates representing an example of runoff erosion, and badlands landforms that crop out in the area, representing a regional uniqueness and characterize a landscape defined the 'Langhe of Liguria'. The methodology includes bibliographic research, aerial photographs, fieldwork and analysis of the data provided by the Park's archives. The main maps were realized by combining lithological and geomorphological data with geoheritage elements and information about hiking and tourism. The 1:10,000 map represents the main area of the Piana Crixia Natural Park, while the 1:3000 map was designed to characterize the Piana Crixia mushroom.

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Geosites; geomorphological mapping; geoheritage mapping; Piana Crixia; natural parks; geodiversity

1. Introduction

Geomorphological maps are recognized as one of the fundamental tools in order to identify landforms and show their spatial relations in the field. These maps may contain a wide set of information regarding, e.g. land management, planning strategies in urban areas, soil conservation strategies in rural areas, developing geotourism, and protecting the geodiversity of a territory (e.g. Bollati, Crosa Lenz, et al., 2017; Coratza et al., 2021; Dearman, 2013; Latocha, 2009; Lee, 2001; Smith & Pain, 2011; Verstappen, 2011).

A geomorphological map not only presents landforms and processes of a territory but can also show their state of activity and thus constitutes an essential source of information for the assessment of natural hazards and related risks. These maps may also contain basic geological, hydrogeological, and lithotechnical information (Bishop et al., 2012; Dramis et al., 2011).

In recent decades, particular attention has been paid to the identification and enhancement of geoheritage, which mainly includes geomorphological elements of the landscape worthy of conservation (Brocx & Semeniuk, 2007; Coratza & Hobléa, 2018; Reynard & Brilha, 2018). As a function of the intertwining of scientific, social and economic aspects, research on geoheritage has attracted increasing interest in the scientific community, evidenced by a rich scientific bibliography on geoheritage identification, assessment and management (e.g. Brilha, 2018; Fuertes-Gutiérrez & Fernández-Martínez, 2012; Herrera-Franco et al., 2022; Ibáñez et al., 2019 and references therein).

Many research groups have produced a wide variety of thematic maps dealing with the subject of geological heritage, with significant differences concerning the main purpose, the scale of the map and the type of user (e.g. Bollati, Crosa Lenz, et al., 2017; Castaldini et al., 2009; Comănescu et al., 2013; Erharti, 2010, Sacchini et al., 2018). Quite recently, attention has been paid to the methodological issues and procedures for geoheritage map implementation in different geological and geomorphological contexts and for different purposes (e.g. Coratza et al., 2021; Coratza & Regolini Bissig, 2009; Papadopoulou et al., 2022; Regolini-Bissig, 2010 and references therein).

Parks and protected areas have for decades represented open-air laboratories where the primary purpose was the conservation of biological and geological heritage, the latter with particular emphasis on geosites. In a Natural Park context, an illustrative map of geological heritage can be a useful tool both for local administrators and for users, hikers and tourists (e.g. Bissig, 2008; Bouzekraoui et al., 2018; Comănescu

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et al., 2013; Guerra & Lazzari, 2021; Serrano & González Trueba, 2011).

Based on this introduction, this research aims to investigate the geomorphological features as well as the geoheritage elements of Piana Crixia Regional Natural Park, located on the border between the Liguria and Piedmont regions in northwestern Italy. The Piana Crixia Natural Regional Park is a small protected area (7.9 km^2) established in 1985 to protect two striking geomorphological features: the 'stone mushroom', a 15 m-high earth pyramid shaped in conglomerates, and a badlands area north of Piana Crixia village, which is a unique area of erosion-associated landforms in the Liguria region. These two sites are included in the Italian National Inventory of Geosites. In addition, a third geosite, the palaeontological site of Bric Foresto, lies just outside of the natural park borders. Thus, despite small extent, the protected area hosts significant geoheritage, already recognized at the regional and national level.

The aim of this study is to present the first detailed geomorphological map of the Piana Crixia Natural Regional Park, including geoheritage elements and landscape and cultural features. The natural park is split into two areas (A and B in Figure 1), of which the larger one (A) comprises the badlands, while the other one (B) protects the 'stone mushroom'. Because of this, two maps have been produced, one at 1:10,000 scale for area A and a map at 1:3000 scale for area B.

Finally, the overview map shows geoheritage elements in the protected area, such as the three official geosites, other sites of geological and geomorphological interest and viewpoints; the hiking trail network, with the thematic routes identified by the park; visitors centers and other facilities, which are useful information for hikers.

2. Study area

The Piana Crixia Natural Park (Figure 1) is located in the Liguria region of Northern Italy. It is found in the Piana Crixia municipality, which is the northernmost municipality of the Ligurian stretch of the Bormida di Spigno valley, bordering with the Piedmont region. The municipality consists of four main villages, located along the Bormida di Spigno River: Borgo, Molino, Pontevecchio and Praie. The valley is surrounded by hills up to 600–700 m a.s.l., known as the *Langhe di Piana Crixia*.

The Bormida di Spigno valley has a warm and temperate climate with dry and warm summer (Csb in the Köppen-Geiger classification: Geiger, 1954; Köppen, 1936). Mean annual rainfall is about 1000 mm, with most precipitation occurring in autumn and spring. Mean annual temperature is about 11.5°C. July represents the warmest month, with a mean temperature of 21°C, while January is the coldest, with a mean temperature of 1.5°C.

The Natural Park lies on the western side of the Bormida di Spigno valley, and it consists of two separate areas. The principal area (area 'A' in Figure 1) is located northwest of the Pontevecchio hamlet, and it comprises part of the catchment of the Rio della Madonna, a tributary of the Bormida di Spigno which flows in a W-E direction.

The highest peaks (Bric del Castello, 653 m a.s.l.; Col Bertorè, 626 m a.s.l.) are found in the western part of the area, near the watershed with the adjacent Uzzone valley. On the northern side of the Rio della Madonna valley, lower hills rise (Bric Rossani, 456 m a.s.l.; Mt. Bergone, 418 m a.s.l.). Going eastward, the elevation gradually decreases until the Bormida valley floor, at about 250 m a.s.l, which represents the eastern border of the park.

The second area is located in the immediate surroundings of the Borgo hamlet (area 'B' in Figure 1) and extends for about 8 ^{ha}. This second area protects the rocky scarp due to denudation between Borgo and the underlying Bormida di Spigno River, where the Piana Crixia 'stone mushroom' is located (see Section 5 for further details).

The bedrock of the study area is characterized by sedimentary rocks belonging to the Tertiary Piedmont Basin (Figure 2; Gelati, 1968; Lorenz, 1969; Gelati et al., 2010). In particular two Tertiary Piedmont Basin formations can be distinguished: the Molare Formation (Lower Oligocene) and the Rocchetta Monesiglio Formation (Lower-Upper Oligocene). The Molare Formation outcrops near the Bormida di Spigno valley floor. It is made of polygenic and heterometric conglomerates, with clasts mainly composed by various ophiolitic rocks (serpentinites, metagabbros, metabasalts etc.) and up to several meters in diameter. In the upper part of the formation, the conglomerates are fine grained, and interbedded with fossiliferous sandstones (Mutti et al., 1995).

The Molare Formation lies uncomfortably on an Alpine metamorphic substratum. Small outcrops of the metamorphic rock masses are found in the Piana Crixia municipality (Figure 2), outside of the park area. They are represented by Jurassic serpentinites belonging to the Voltri Unit.

The Rocchetta-Monesiglio Formation is a 1200 m thick sequence of hemipelagites, containing various members characterized by different lithologies. The Rocchetta-Monesiglio Formation has a 'muddy framework' composed of gray marls interbedded with thin fine-grained sandstone layers (Gelati et al., 2010). In the study area, three distinct members of the Rocchetta-Monesiglio have been detected: (i) the Piana Crixia Conglomerates, (ii) the Noceto Sandstones, and (iii) the Case Poggi member. The Piana Crixia Conglomerates member crops out along the

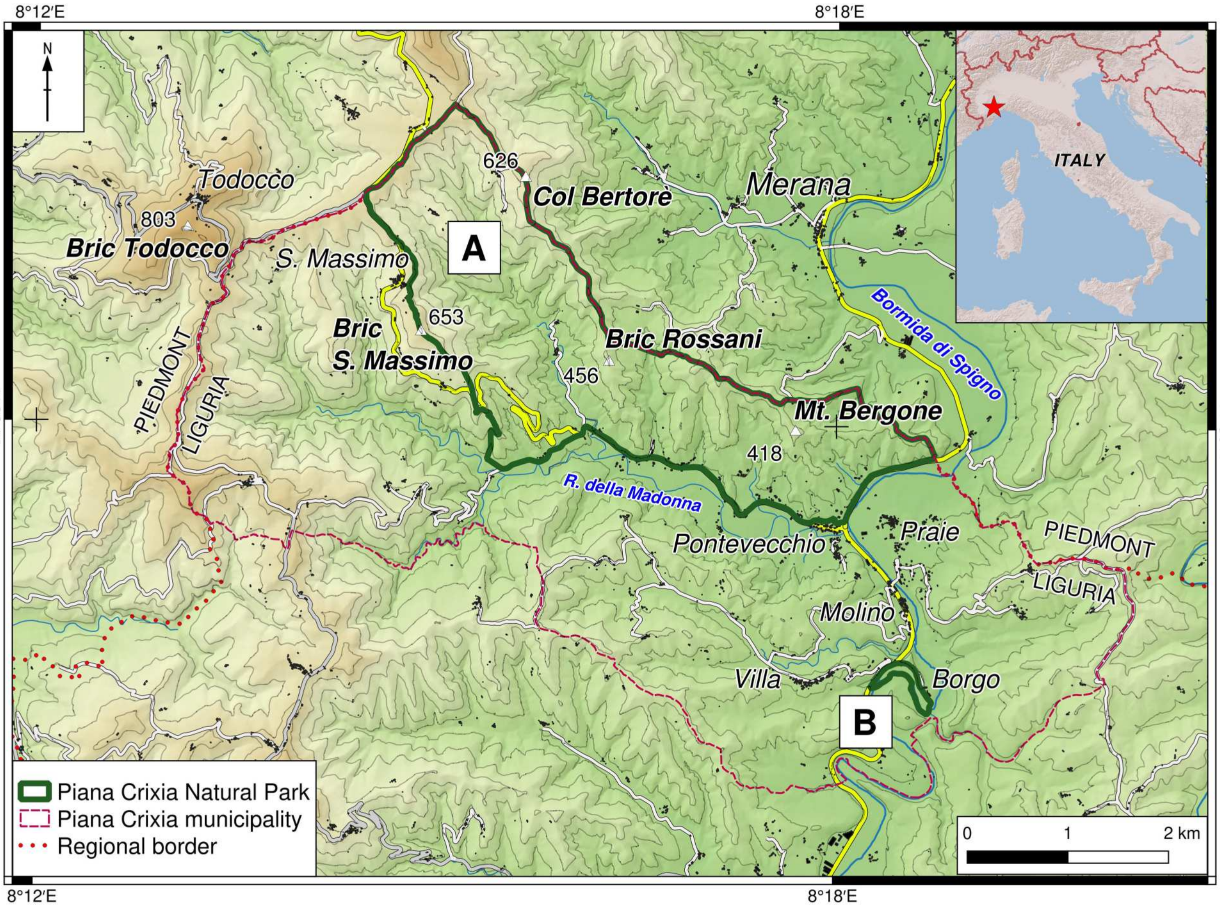

Figure 1. Map of the Piana Crixia Natural Park and the surrounding Piana Crixia municipality.

Bormida di Spigno River north of the Pontevecchio village. It is a layer of conglomeratic sandstones interbedded with conglomerates, up to 35 m in thickness (Cazzola et al., 1981). The Noceto Sandstones member, up to 350 m thick, is made of medium to coarse sandstones with microconglomeratic lenses (Cazzola & Fornaciari, 1990). The Case Poggi member is a 100 m-thick layer composed of thin-bedded pelites with chert nodules and lenses. The two latter members outcrop in the western part of the protected area.

The sedimentary strata form a monocline with NW dip direction and dip between 10° and 20° (Gelati et al., 2010), which greatly influenced the Quaternary evolution and the morphogenesis and the morphodynamics in the area and consequently the landforms.

Among gravitational landforms, translational landslide bodies are frequent, influenced by the bedding of the sedimentary strata. The main fluvial and runoff erosional landforms are represented by earth pyramids, rill-interrill and badlands. Moreover, deposition landforms associated with both fluvial deposition (e.g. fluvial terraces and floodplains) and runoff (e.g. colluvial talus evidence) can be recognized in the area. Runoff landforms are present both in the hilly part of the area as well as on the valley floors. In the hills, badlands represent the most frequent and imposing landforms. An inventory of the badlands as well as of the rill-interrill landforms in the Piana Crixia area was carried out by Maerker et al. (2020).

3. Materials and methods

The two geomorphological maps, respectively 1:10,000 and 1:3000 in scale, were executed in QGIS environment by integrating both field survey data and other data collected from local and national archives and geoportals (Figure 3).

Geomorphological information has been collected by means of extensive field surveys conducted between February and December 2022. Field survey was carried out at 1:5000 scale for the main protected area, and at 1:2000 for the Piana Crixia 'stone mushroom' area. The surveys were carried out using the application 'QField' on tablet, with Google satellite images and the Regional Technical Map as the cartographical basis.

Field data have been integrated with: (i) interpretation of orthophotos at 1:5000 scale, produced in 2019 and available in the Regional Cartographical Database of Liguria (https://geoportal.regione.liguria.it/); (ii) interpretation of the DTM of the Liguria region; and iii) comparison with existing geomorphological data (e.g. Gelati et al., 2010; Maerker et al., 2020 for rill-interrill and badlands areas).

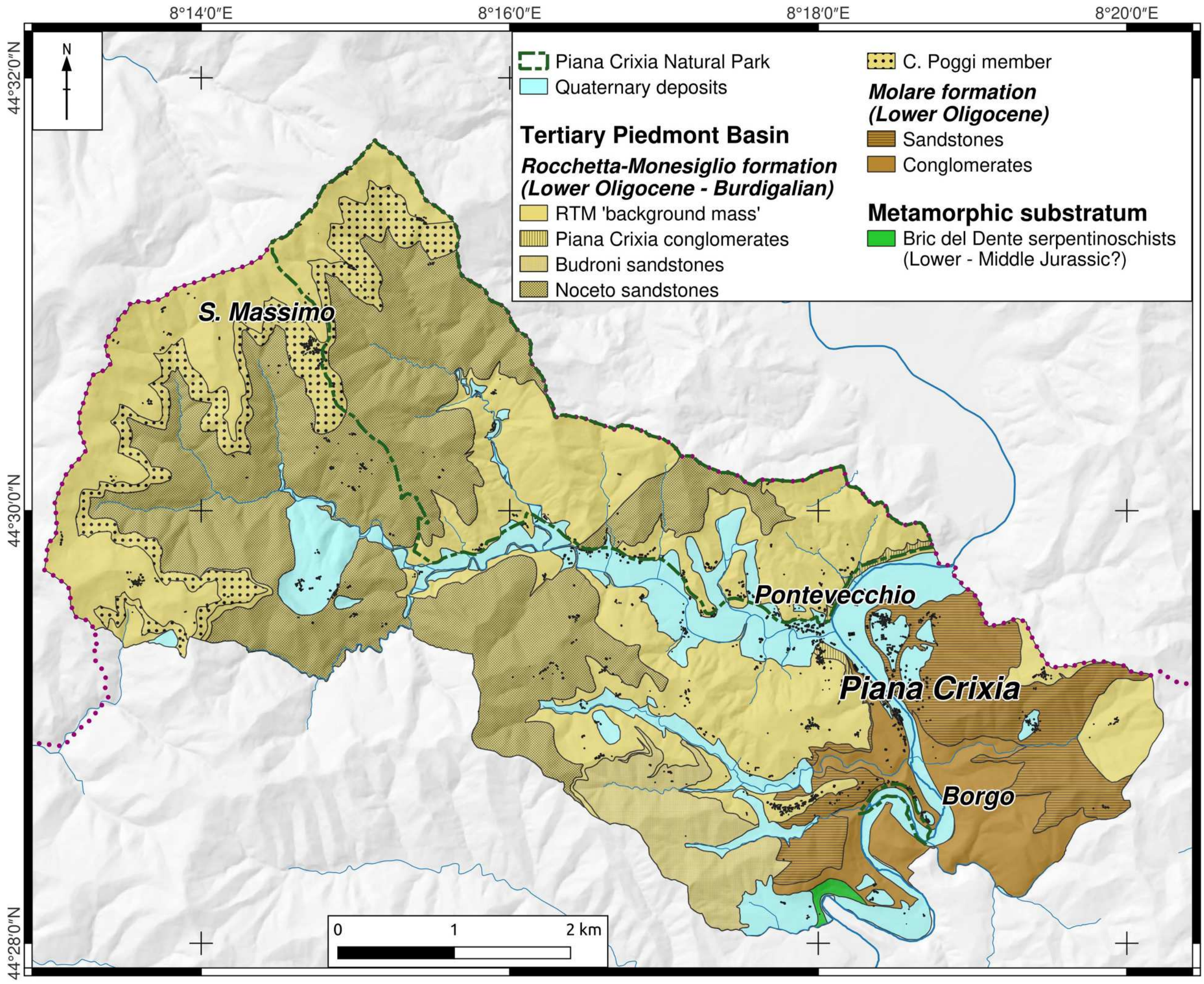

Figure 2. Geological sketch map of the Piana Crixia municipality, modified after Gelati et al. (2010); vector data from the lithological map of the Liguria region (https://geoportal.regione.liguria.it/).

Geomorphological data have been organized in three separate vector layers, including respectively: point features, linear features and areal features. Geomorphological mapping mainly followed the guidelines for geomorphological surveying and mapping (Campobasso et al., 2021) proposed by ISPRA (Italian National Institute for Environmental Protection and Research, formerly the National Geological Survey). Some symbols were slightly adapted or modified to be drawn in the QGIS environment, or to better highlight some particular landforms.

In parallel with the geomorphological surveys, during field activity all the hiking trails of the Natural Park have been surveyed. Tracks in .gpx format of the hiking trails have been recorded using a Garmin GPSMap 64sx, and then converted to shapefiles to be implemented in QGIS.

Other than the vector layers containing geomorphological data and the hiking trails, in the map the following cartographical layers, freely available in the Regional Cartographical Database of Liguria (https://geoportal.regione.liguria.it/), were used.

The shaded relief on the background of the map is provided by the DTM of the Liguria region, with 5 m × 5 m cell size. The topography is highlighted with contour lines with an interval of 10 m in vector format, taken from the topographic database of the 1:5000 Ligurian Regional Technical Map.

Base geographical features in vector format, such as buildings, infrastructure (roads and railways), pathways and administrative boundaries are taken from the same topographic database. The boundaries of the park area are derived from the vector layer of the protected areas of the Liguria region, scale 1:10,000.

The lithological information is provided by the lithological map of the Liguria Region in vector format (https://geoportal.regione.liguria.it/). It is derived from the 1:50,000 geological maps of Italy, made by the ISPRA as part of the CARG project.

4. Processes and landforms

The study area is characterized by diversity of landforms, among which the most frequent are those related to fluvial and runoff processes (Figure 4). Among erosional landforms, the most significant are earth pyramids, surfaces affected by badlands and gullies, V-shaped valleys and entrenched meanders.

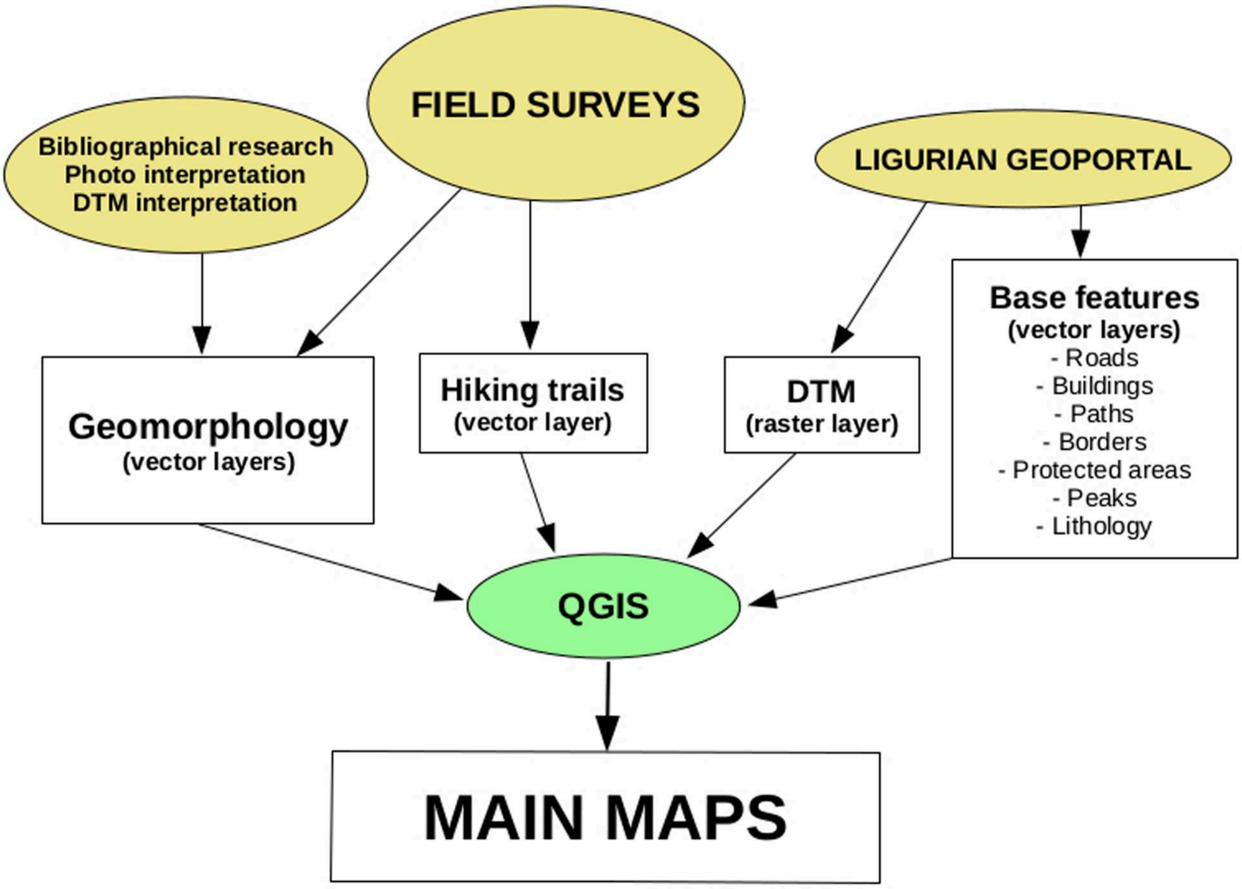

Figure 3. Flow chart of the methodological approach for the production of the map.

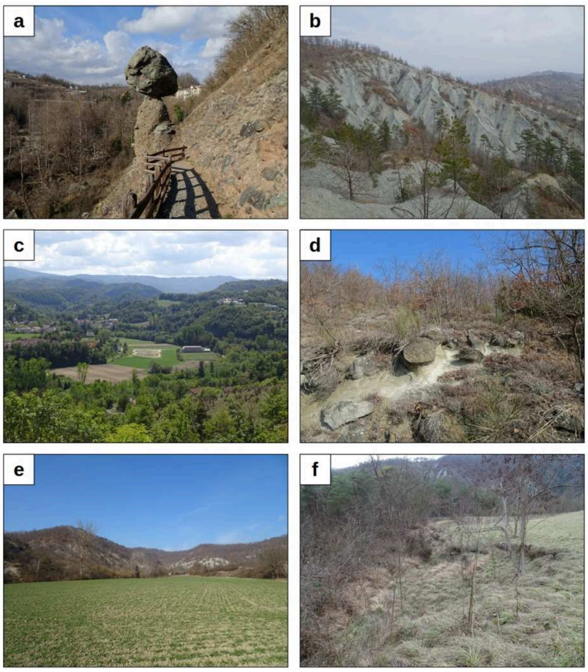

Figure 4. Landscape features of the Piana Crixia Natural Park. (a) The 'stone mushroom'; (b) Badlands on the eastern slopes of Mt. Bergone; (c) View of the Bormida di Spigno alluvial plain near Piana Crixia; (d) *Murion* along the hiking trail no. 2 of the Natural Park; (e) Colluvial talus deposit remodeled for agriculture along hiking trail no. 2; (f) Rotational landslide scarp and body on colluvial deposits along hiking trail no. 4.

The earth pyramids of the Piana Crixia Natural Park are unique evidence of runoff. Usually, earth pyramids are associated with heterometric glacial deposits, or in some cases with slope deposits (Bollati, Pellegrini, et al., 2017). In Piana Crixia, the pyramids occur in the conglomerates of the Molare Formation and the Noceto Sandstones member of the Rocchetta-Monesiglio Formation.

Two isolated earth pyramids are found in the very coarse conglomerates of the Molare Formation: the Piana Crixia 'stone mushroom' (Figure 4(a)) and the *Funghetto* (i.e. 'little stone mushroom') which is just beyond the park borders. The Piana Crixia 'stone mushroom' is 15 m high, while the *Funghetto* is 3 m high. The 'mushroom caps' are ophiolitic blocks up to several meters in diameter, which protect the underlying 'mushroom stipe' from erosion.

In the Noceto sandstones, the formation of earth pyramids is due to the alternation of microconglomeratic lenses, which form the 'caps', and more erodible sandstone layers, which form the 'stipes'. The earth pyramids of the Noceto sandstones are small (0.5 to 1 m in height) but occur in high density, and often have very irregular shapes. These pyramids are popularly known as *Murion* (Figure 4(d)).

Badlands (Figure 4(b)) are typically associated with the gray marls of the Rocchetta-Monesiglio

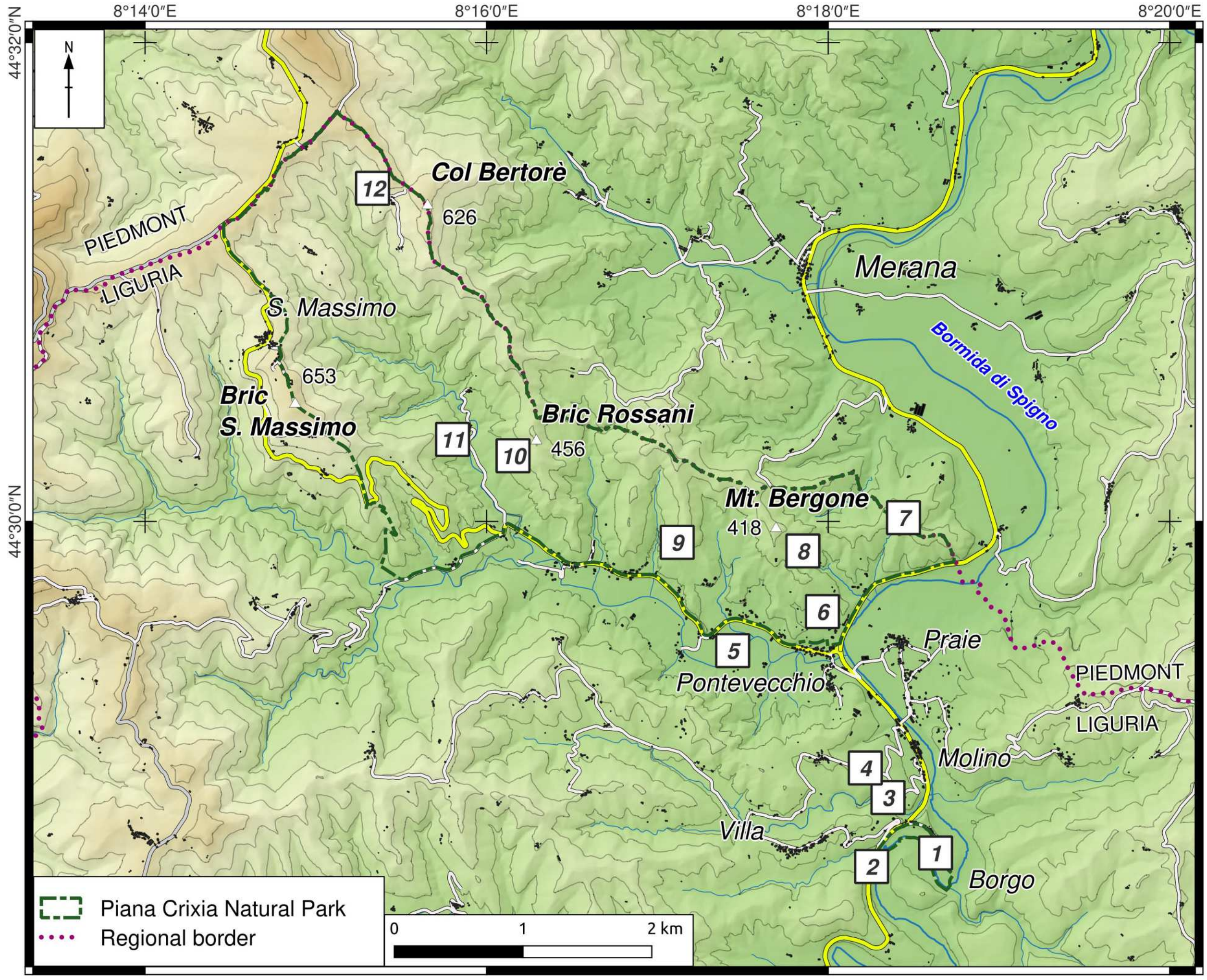

Figure 5. Main geoheritage elements of the Piana Crixia Natural Park. (1) Stone Mushroom; (2) Entrenched meanders of the Bormida di Spigno River; (3) *Funghetto*; (4) Fluvial terrace surface of Case Buscarini; (5) Fluvial terraces of the Rio della Madonna; (6) Fluvial terrace surface of Mt. Bergone; (7) Viewpoint on the alluvial plains of the Bormida di Spigno River; (8) Badlands area of Mt. Bergone; (9) *Murion* of Ferrieto; (10) Deep-seated gravitational slope deformation of Bric Rossani; (11) Badlands area of Erche Sottane; (12) Translational landslides near Bertorelli.

Formation, sometimes extending on the overlying Noceto Sandstones member. Most of them present a typical A-type morphology described by Moretti and Rodolfi (2000). These badlands are characterized by knife-shape ridges, with steep slopes where the vegetation is sparse or absent and slope processes can be observed. In the surfaces affected by badlands many gully landforms can be mapped, demonstrating that the runoff processes are still active.

The northern side of the Natural Park is characterized by the occurrence of small valleys associated with several tributaries of the Rio della Madonna. These valleys tend to be V-shaped, narrow and incised on the western sector of the park, where the hills are higher. They are wider and gentler in the eastern sector, where the valley floors are often filled with colluvial deposits. The Bormida di Spigno River is characterized by entrenched meanders with well-developed point bars close to Borgo.

Among depositional landforms, there is wide evidence of colluvial deposits, alluvial plains and fluvial terrace surfaces (Figure 4(c)). Colluvial talus is widespread on the lower hill slopes, at the bottom of most of the surfaces affected by badlands and on the floor of several small valleys in the eastern sector of the Natural Park. Near Molino and Pontevecchio, the Bormida di Spigno River flows through a wide alluvial plain. Ancient fluvial terrace surfaces are found on the sides of the alluvial plain, at about 275–285 m a.s.l., while recent terrace surfaces extend all along the valley floor of the Rio della Madonna. Gently sloping colluvial surfaces connect the hill slopes to the underlying terrace surfaces. Two more levels of relict fluvial terrace surfaces have been recognized. One is located at about 300–310 m a.s.l., and is found in the Borgo village, and north of Pontevecchio near Case di Monte Bergone (see main map). The other is at about 340–350 m a.s.l., and is found west of the Molino village, on the wide and almost flat surface on which Case Buscarini are built.

The most significant gravitational landforms have been detected in the western part of the protected

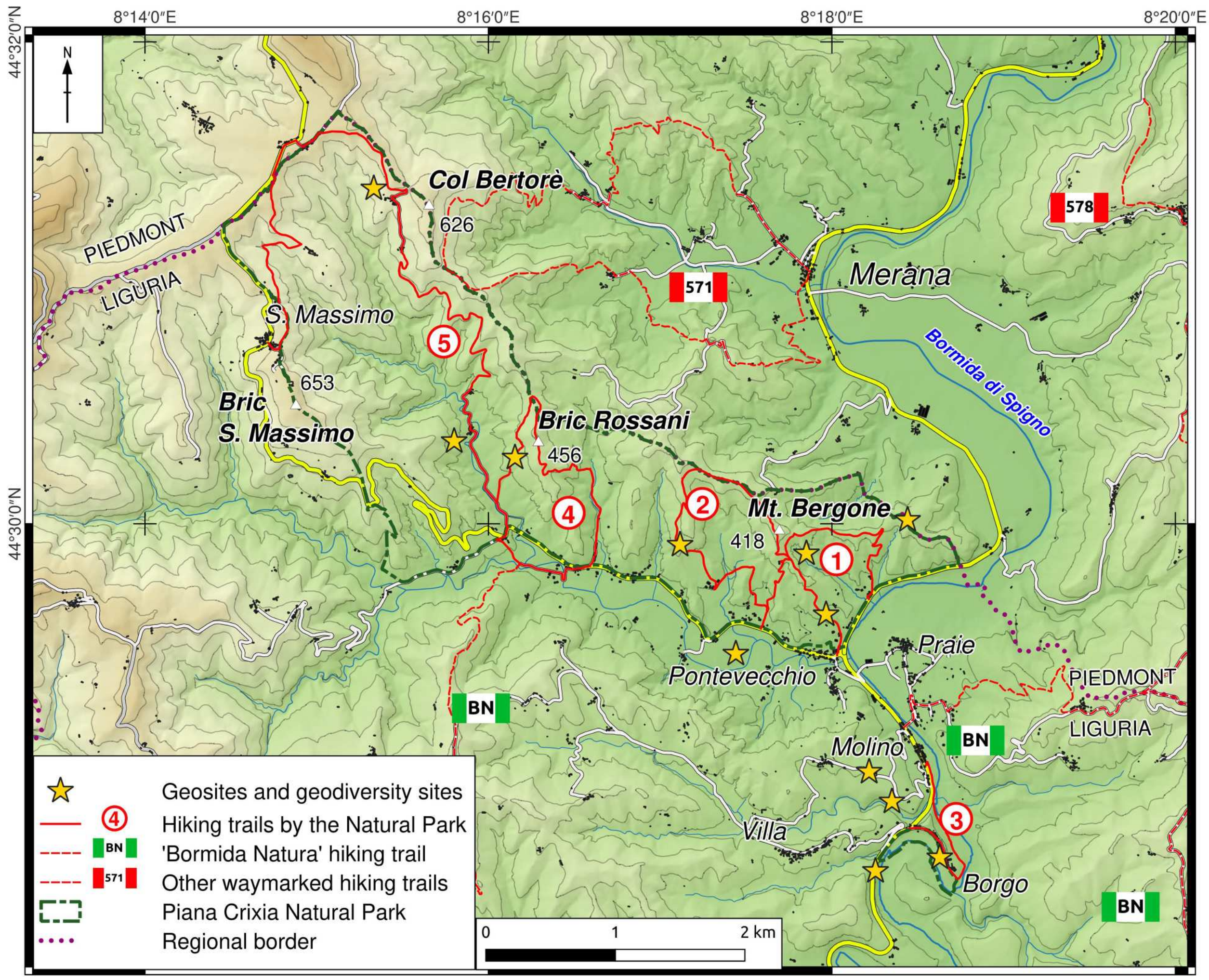

Figure 6. Hiking trails of the Piana Crixia Natural Park and its surroundings. Geoheritage elements are also shown (see Figure 5 for further details).

area. Inactive translational landslide bodies are present near the villages of Case Tappe and Bertorelli. Translational landslides are influenced by the monoclinal disposition of the sedimentary strata and are found on slopes with west aspect.

An active complex landslide has been recognized north of the hamlet of Villarello. On the western slopes of Bric Rossani, a deep-seated gravitational slope deformation (DSGSD) has been surveyed, crowned by a trench with a length of several tens of meters. Finally, some of the steeper colluvial surfaces are remobilised by active mud flows (e.g. near Erche Soprane) or by minor rotational landslides (Figure 4(f)).

Anthropogenic action is recognizable in most of the protected area. Many areas have been remodeled for agriculture (Figure 4(e)), especially where fluvial terraces, colluvial deposits, or inactive landslide deposits occur. Fluvial terrace surfaces are often flattened, while on steeper slopes dry stone wall terraces can be found. In the Pontevecchio village, the Rio della Madonna has been constrained between artificial levees. Embankments and excavation surfaces are also found along the main roads and the railway, and near villages and hamlets.

5. Geoheritage elements and geotourism

The Piana Crixia Natural Park encompasses a striking geoheritage, notwithstanding its area of only 8 km^2. In the park one can find two geosites included in the Ligurian Regional Inventory of Geosites (Ferrando et al., 2021) and thus in the Italian National Inventory of Geosites (http://sgi.isprambiente.it/GeositiWeb/default.aspx?ReturnUrl=%2fgeositiweb%2f) and several other geomorphological features of local interest (Figure 5). Local driveways, as well as the hiking trail network, give easy access to most of these sites.

The 'stone mushroom' is the better known of the two geosites, due to its scenic beauty and impressive size. The other geosite includes a sector of the badlands which characterize most of the protected area. The badlands area of Piana Crixia is the largest in the Liguria region, and thus it is recognized as a site of regional relevance. The geosite includes the badlands between the villages of Taglio and Erche Sottane. Many other badlands areas with very high scenic interest are present in other sectors of the park.

Apart from the two geosites, a number of other sites of local geological interest have been recognized in the park area and its immediate surroundings (geodiversity sites *sensu* Brilha, 2016). In particular, several levels of relict fluvial terrace surfaces can be found, up to about 80 m above the current floodplain. Together with the entrenched meanders near the Borgo hamlet they testify to recent uplift of the region. Other significant geodiversity elements are the *Murion*, which are present in the area where the Noceto sandstones crop out. The most scenic sites are located north of Ferrieto and in the surroundings of Passo Tappe. The *Murion* can be also observed in the adjacent municipality of Merana, in the Piedmont region. Finally, among geodiversity sites, there is the *Funghetto* earth pyramid, which occurs just beyond the park borders north-west of Borgo.

Most of these sites are accessible on foot, some of them even by bike, thanks to the dense network of paths and dirt roads which cross the Piana Crixia Natural Park (Figure 6). Five waymarked trails are present in the park, numbered from 1 to 5 and marked with red and white stripes. Trails no. 1, 2 and 3, are the ones with the greatest geotouristic interest. Trail no. 1 is known as the 'Route of the Crests' (*Sentiero delle Creste* in Italian), as it goes through the crests of the badlands in the northeastern sector of the park. Along this hiking trail one can observe the most scenic surfaces affected by badlands in the park, and visit scenic viewpoints on the Bormida di Spigno valley, with its alluvial plains and several levels of fluvial terrace surfaces. Trail no. 2 passes the same badlands area, then touches the Bric Roncaste top and one of the *murion* outcrops. Trail no. 3 connects the hamlets of Molino and Borgo, following the Bormida di Spigno River; on the way, one can observe the alluvial plain, an entrenched meander and the notorious Piana Crixia 'stone mushroom'.

6. Final remarks

The paper presents the first detailed geomorphological map of the Piana Crixia Natural Park, a small protected area located in northwestern Liguria (Italy), known for its outstanding geomorphological features. The geomorphological map has been built starting from extensive field surveys, coupled with interpretation of aerial photos and digital terrain models. The map combines in a single cartographic document geomorphological data, geoheritage and main hiking and trail networks of the study area and can be a useful tool for geoconservation and sustainable environmental management. Moreover, the map is useful to evaluate geomorphological processes and dynamics which have affected and are still active in the park, as well as their interaction with the sites of touristic interest and the hiking trail network. It can be a functional tool to optimize decisional processes within protection actions of the Natural Park. The geosites with primary geomorphological interest (e.g. geomorphosites) of the Piana Crixia Natural Park are active, and thus subject to rapid evolution. A detailed geomorphological map is essential to local administrators in order to evaluate the state of conservation, the vulnerability and the degradation risk of geomorphosites, particularly in the cases when their evolution poses a threat to the visitors (Bollati et al., 2020). In addition, the geomorphological map is useful to pinpoint critical issues along the hiking trail network, other infrastructure and inhabited areas. The resolution or mitigation of these issues is important for the safe and long-lasting fruition of the park itself.

Finally, the map can represent the basis on which simpler, user-friendly geothematic maps of the park can be built, to be distributed to the general public.

Software

All data processing and the designing of the map layout was carried out with the free and open source software QGIS.

Disclosure statement

No potential conflict of interest was reported by the author (s).

Data availability statement

Data available within the article or its supplementary materials.

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