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# The Mt. Catria–Mt. Nerone Ridge in the North-Marchean Apennines (Central Italy): A Potential Geopark?

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**Abstract:** The inventory and evaluation of geosites are fundamental steps of any geoconservation strategies and in setting priorities for the management of protected areas. The North-Marchean Apennines (central Italy) host an extraordinary geoheritage, making its use by society worthwhile and meaningful (e.g., teaching/learning, tourism, and recreation). An area of 600 square kilometres embracing 18 municipalities, mainly distributed along the Mt. Catria–Mt. Nerone ridge, is home to numerous spectacular geosites. The purpose of this study is to analyze the environmental heritage of the North-Marchean Apennines through the recognition, selection, and description of an extensive list of geosites, with a view to providing useful data for the establishment of a possible geopark discussed in the context of a region that is rich in protected areas. Among these, seven geosites were chosen as representative of the area and were processed through a quantitative evaluation method. The calculated Q-values are indicative of geosites of high significance and well represent the great variety and strong potential of this area. The seven geosites, witnesses of sites with a high aesthetic value, are framed from a geological and geomorphological point of view, without neglecting the additional values that make these localities particularly attractive for geotouristic and educational purposes. The study area is finally framed in the context of the region's protected areas, with a view to the conservation and enhancement of its environmental heritage.

**Keywords:** geoheritage; geosites; North-Marchean Apennines; geoconservation; geopark

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## 1. Introduction

In the last few decades, interest in the geo-environment has steadily increased. Recent challenges facing the planet in relation to global changes have highlighted the need for an in-depth understanding of our natural heritage. Terms such as 'geosite' (an area or locality that bears exemplary witness to the geological and geomorphological events that have characterized the history of a region and helped to define its landscapes and, as such, should be valued and preserved [1]), 'geopark' (a region with relevant geosites, favouring economic and local development through sustainable tourism, achieving preservation and educational objectives [2,3]), and 'geodiversity' (the variety of geological phenomena and related processes that shape the landscape [4,5]) have become increasingly common. These concepts are intrinsically linked to the desire to protect and preserve the geological heritage, also with a view to the renewed economic and cultural growth of different areas [6]. The article by Dowling (2010) addresses geo-tourism and its nature, development, growth, and trends, and considers it a sustainable way for tourists to learn about geosciences and the multiple ways of viewing natural landscapes and their processes [7]. The research associated with the definition and establishment of geological heritage, in addition, has proven to be fundamental to the development of a sense of human responsibility towards geo-preservation, the development of sustainable use of natural resources, and the dissemination of knowledge about various geological hazards [8–10].

Geo-education can play a fundamental role in promoting geosites as ideal places for educational activities linked to the comprehension of the landscape and the territory [11–20]. Furthermore, geotourism is growing very rapidly and represents a potential path for offering alternative types of tourism, such as 'slow tourism' [10,21–25].

The North-Marchean Apennines, in central Italy, are home to a unique geological and geomorphological heritage, enriched by spectacular views in the contexts of great natural and cultural significance. It is an area of 600 square kilometres, which includes a heritage of numerous geosites. An open-air museum characterized by a continuous stratigraphic succession of 200 million years, hosting unique geosites, a network of karstic caves [26], superb scientific and cultural landscapes; and a Holocene palaeolake, named Montelago [27,28]. In this area, the Jurassic-Cretaceous sedimentary sequences are extensively represented; the important K-Pg boundary, indicating the end of the dinosaur era, is exposed (at Petriccio di Acqualagna site); probable fossil footprints of an ancient marine reptile (called 'Ugo') were found (site still under research) at the Cantiano Village (Mt. Catria) [29]; there are important fossiliferous localities (e.g., the ammonites of Mt. Catria), the natural amphitheater of Mt. Tenetra and the natural arch of Fondarca (in Mt. Nerone). In short, the area represents a unique geoenvironment that meets all of the requirements to become a geopark.

Of note is the relatively recent and rapid growth of the global geopark movement, which started in Europe and then spread internationally. The first international initiative was carried out in the Netherlands in 1988, establishing the European Working Group, which in 1993 became ProGEO (The European Association for the Conservation of the Geological Heritage [30]. In the 1990s, two new global initiatives were proposed by the scientific community: the Global Geosites Project [31,32] and the UNESCO Geoparks program [33]. The European Geoparks Network was created in 2000, followed by the Global Geopark Network, born in 2004, but the "UNESCO Global Geoparks" (UGG) was finally established in 2015, within the "International Geoscience and Geoparks Program (IGGP) [34–36].

A geopark is a protected area that promotes sustainable development and contains a number of geological heritage sites of particular importance, rarity, or aesthetic appeal. A geopark is established with the intention of increasing the interest of researchers in Earth Heritage Sites (including geosites) and of contributing to develop the economy of the involved areas through geotourism. These Earth Heritage Sites are part of an integrated concept in a view of protection, education, and sustainable development. A geopark therefore achieves its objectives through a three-pronged approach, focused on conservation, education, and geotourism [23,37–39].

Over the past few years, the 'Catria and Nerone Mountain Union', in agreement with 18 municipalities in the North-Marchean area, has expressed its intention to submit the 'North-Marchean Apennines Aspiring Geopark' candidature to the UNESCO Global Geopark Network.

This territory is characterized by a geological heritage of considerable importance (e.g., Mt. Cagnero GSSP Chattian golden spike, Petriccio K/Pg boundary, and other important fossiliferous sites), associated with equally high natural and cultural values. This assumption, together with the territorial development strategies implemented by the Catria and Nerone Mountain Union, makes the area a privileged laboratory for the activation of geo-conservation policies, the promotion of geotourism, and educational activities related to the respect of heritage and eco-sustainability policies. The establishment of a geopark in the North-Marchean Apennines, as a promoter of geotourism, could have a strong and positive impact on the economic activities of this area, possibly contributing to the improvement of the living conditions.

Despite the widespread use of the concept of geodiversity in the scientific literature, it is only in the last few decades that geoscientists have addressed issues relating to its assessment [40,41].

Among assessment procedures, one can distinguish qualitative and quantitative assessment methods. Qualitative methods have a descriptive character and are suitable for nominal and ordinal data [42–45]; these methods are based on the assessment by an expert and are therefore characterized by a high degree of subjectivity. Quantitative methods are based on a set of parameters and indicators to determine a geodiversity index [46–51]; the repeatability of the results and the relatively high objectivity make these methods highly preferable. Quantitative methods, however, also have their limitations: scoring, in fact, is subjective, conditioning the entire calculation. Finally, some authors propose hybrid qualitative–quantitative methods offering more reliable results [52–57].

This work aims to define the geographical limits of what could represent a potential geopark and highlight the geological and geomorphological peculiarities of the area through the description of both the scientific and additional naturalistic and cultural values of some of its most interesting geosites. The objective is to propose an inventory of the area's geosites and provide a quantitative assessment of some of them, selected for their particularly significant characteristics, able to represent the study area.

## 2. Geological Setting and Distribution of Geoheritage

The area covered in this work is in the northern sector of the Marchean Apennines and includes 18 municipalities in the provinces of Pesaro-Urbino and Ancona, listed as follows: Sassoferrato, Arcevia, Serra Sant'Abbondio, Frontone, Cantiano, Cagli, Acqualagna, Piobbico, Apecchio, Isola del Piano, Fossombrone, Fermignano, Urbino, Urbania, Peglio, Sant'Angelo in Vado, Mercatello sul Metauro, and Borgo Pace (Figure 1).

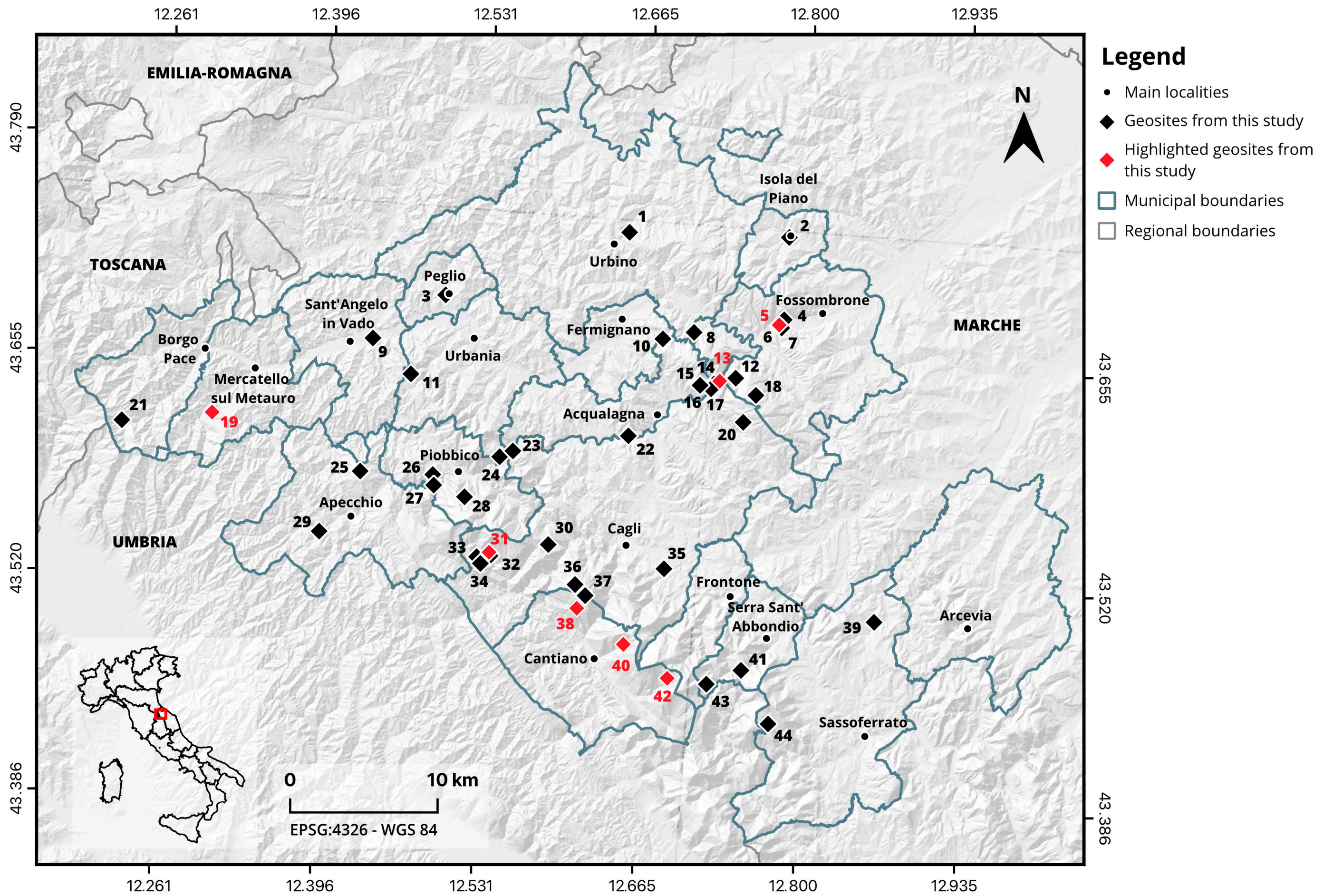


**Figure 1.** Geographical framework of the study area and location of 44 geosites. DEM (digital elevation model) from [58].

The municipalities are distributed along the Mt. Catria–Mt. Nerone ridge, which embraces the peaks of Mt. Strega (1278 m), Mt. Catria (1701 m), Mt. Acuto (1669 m), Mt.

Petrano (1162 m), Mt. Tenetra (1240 m), and Mt. Nerone (1525 m); towards the Adriatic Sea, it also includes the ridge of Mt. Paganuccio (976 m)–Mt. Pietralata (889 m) and the spectacular Furlo Gorge.

The Umbro-Marchean Apennines, an arc-shaped fold and thrust belt with eastward convexity and vergence, form the external part of the Central-Northern Apennines.

Several authors demonstrate the complexity of the evolution of the Northern Apennines, with adjacent zones showing abrupt variations in their history and style of deformation [59–61].

Alvarez (2019) presents an overview of the Earth's history record in the Cretaceous, Palaeogene, and Neogene of the pelagic carbonates of the Umbro-Marchean Apennines, which can be considered a reference work also for the comprehensive bibliography cited therein. This extensive paper briefly reviews the highlights of the lithologic, biostratigraphic, sedimentologic, magnetostratigraphic, impact-stratigraphic, geochemical, geochronological, time-scale, and cyclo-stratigraphical research carried out on the Umbro-Marchean stratigraphic sequence, thanks to the data provided over the last 25 years by the Geological Observatory of Coldigioco [62].

The Umbro-Marchean Succession consists of a sequence of sedimentary rocks deposited in central Italy from the Jurassic period (starting around 201 million years ago) up to the Pleistocene (from around 2.5 to 0.01 million years ago). It represents the main document for reconstructing the geological history of the Marche Region; owing to its completeness and continuity, it is one of the most studied stratigraphic series in the world.

Schematically, there is a basal sequence not outcropping [63], related to shallow-water continental, coastal, and marine sedimentary environments (Upper Triassic, from around 237 to 201 million years ago), a sequence of pelagic environment (Jurassic-Eocene, from around 201 to 33 million years ago), and an upper predominantly turbiditic sequence (Upper Oligocene-Upper Miocene, from around 28 to 12 million years ago) [64].

In the Upper Triassic, an extensive evaporitic basin of shallow water occupied the entire Umbro-Marchean area. The end of the Triassic is accompanied by major climatic changes that are mainly marked by the disappearance of evaporitic sediments, replaced by limestone-clay sediments deposited in an extensive shallow-water platform. In the Lower Jurassic, the return to normal salinity conditions allows platform carbonate sedimentation to begin.

From the end of the Lower Jurassic (around 180 million years ago), in association with an extensional tectonic phase, the platform broke into several blocks, with the formation of horsts and graben. The shallow sea sedimentation terminates and the persistent pelagic sedimentation begins, thus levelling out this horst and graben physiography. In the deepest basins (between 1000 and 1500 m in depth [65,66]), a considerable thickness of sediment is deposited (complete succession), while in the reliefs, characterized by shallow waters, the sedimentation presents thinner thicknesses (condensed succession) and gaps that vary in time (incomplete succession).

The palaeogeographic sketch that we can derive by examining the sediments deposited during the Oligocene is particularly complicated. The orogenic process developed from the Early Miocene and first affected the inner sector of the northern Apennines. The deformation forehead, gradually migrating eastwards, was accompanied by the formation of wide tectonic depressions ('foredeeps'), where massive turbiditic successions accumulate. The Apennines' formation proceeds through the migration of the chain system toward NE, which is in the innermost, western areas of the Marche basin and is fragmented into a series of 'minor basins', while in the easternmost areas, the hemipelagic foreland basin sedimentation persists. During this migration, the Umbro-Marchean basin loses its uniformity and bends.

Towards the end of the Miocene (during the Messinian, from 7.2 to 5.3 million years ago), the Mediterranean Sea begins to dry up as it becomes isolated from the Atlantic Ocean. The basin, subject to evaporation, changes from a pelagic to an evaporitic environment and has then been reduced to a series of salt lakes. In the Upper Messinian, the Apennines begin to emerge, and a lake-sea environment characterized by brackish or alluvial facies forms in the inner Marchean basin. With the marine ingression of the Pliocene, a marine environment with the deposition of predominantly arenaceous pelites and turbidites was re-established.

In the Pliocene (from 5.3 to 2.6 million years ago), the orogenesis reaches its maximum and a series of folds and overthrusts are formed with an easterly direction; the Marchean basin is compressed with consequent uplift of the marine deposits [67,68]. Today, the orogenic belt is a mountain chain that consists of a northeast-verging fold-and-thrust belt, which has shortened an approximately 5 km thick Mesozoic-Cenozoic stratigraphic succession by about 30% [69]. The progressive deformation and emersion of the chain continued until the Quaternary period and, at the same time, the territory was shaped by exogenous agents on very different litho-structures [70], producing the current scenario, so articulated and evocative, and characterized by extraordinary geodiversity.

The lithostratigraphic and structural arrangement has conditioned the layout of the river network; it has an overall sub-parallel pattern, oriented mainly SW-NE, from the interior towards the Adriatic coast, and crosses the main calcareous anticlinal ridges before reaching the Adriatic coast [71]. This trend is also responsible for such a great variety of landscapes in a relatively small area.

A recent extensional tectonic phase mainly affects the inner western areas of the region; normal faults with an Apennine direction dislocate the previous compressional structures and result in a series of blocks lowered towards the SW. In this way, the tectonic depressions of Colfiorito, Norcia, and Castelluccio were formed, bordered on the eastern side by normal faults whose recent activity is evidenced by several earthquakes, which have caused the destruction of an inestimable heritage. The 2016–2017 sequence began in August 2016, with the first strong earthquake occurring on 24 August (magnitude 6.1), whose epicentre was located along the Tronto Valley, between the municipalities of Accumoli (RI) and Arquata del Tronto (AP). Two strong aftershocks happened on 26 October (magnitude 5.4 and 5.9) with epicentres located between the municipalities of Visso, Ussita, and Castelsantangelo sul Nera, in the province of Macerata. On 30 October, the most significant event occurred (owing to its magnitude of 6.5) with an epicentre between the municipalities of Norcia and Preci, in the province of Perugia [72]. In January 2017, there was a new sequence of four strong earthquakes of magnitude greater than M5. This set of events caused a total of about 41,000 people to be evacuated, with 388 injured and 303 dead [73].

In the North-Marchean Apennines, the lower altitude zones are mainly occupied by Plio-Pleistocene marine deposits, while the cores of the higher ridges consist of Mesozoic rocks. Figure 2 shows a geological sketch summarizing the formations of the Umbro-Marchean Succession into four large groups:

- Jurassic-Oligocene formations of the carbonate ridges, massive or stratified, and/or marly-limestone formations.
- Miocene marly-limestone, terrigenous and evaporitic formations.
- Plio-Pleistocene marine formations.

The northernmost sector of the region is affected by the Cretaceous-Pliocene formations of the so-called 'Coltre della Valmarecchia' or 'Valmarecchia Nappe', originating from the Ligurian-Piedmontese basin and overlapping the Umbro-Marchean Succession through both tectonic and gravitational mechanisms [74,75]. The strong lithological contrast between the predominantly clayey Ligurian Units and the more rigid, predominantly Epiligurian limestone blocks on top has contributed to a unique and fascinating landscape but, at the same time, fragile and unstable.

The Marche Region can also be grouped into four morpho-structural zones [76], each with a strong topographic reflection, including the following:

1. An inner zone, corresponding to the Umbria Pre-Apennine.
2. The Umbro-Marchean ridge, where the highest altitudes of Mt. Catria and Mt. Nerone are found, consists of two main anticlines separated by the narrow synforms with axes trending NW–SE: the inner anticline including Mt. Catria, Mt. Acuto, Mt. Tenetra,

Mt. Petrano, and Mt. Nerone peaks (Figure 3) and the external anticline with the Furlo Gorge.

3. The Marchean pedeapennine, which is the foothills area where the deformative structures are buried by Plio-Pleistocene deposits and by late Quaternary terrace alluvium and slope deposits.
4. The coastal zone.

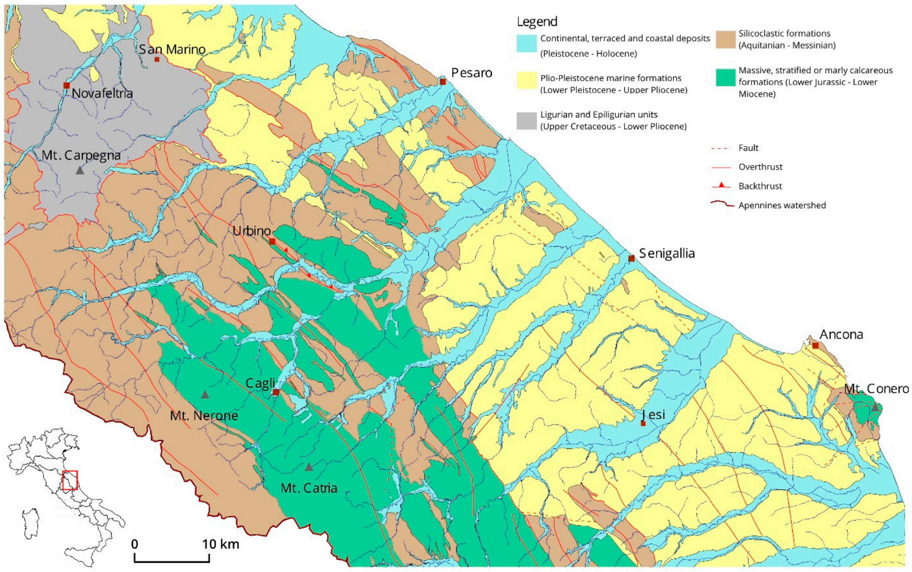


**Figure 2.** Simplified geological and structural map of the northern Umbro-Marchean Apennines (modified after [77]).


**Figure 3.** Perspective view of the Mt. Catria–Nt. Nerone ridge (looking towards NNW) along an anticline structure (Google Earth Pro on 11 April 2023).

## 3. Methods

In 2022, a Working Group represented by SIGEA (Italian Society of Environmental Geology) Marche, the regional Universities of Urbino (PU) and Camerino (MC), and the Order of Geologists of the Marche Region met with the aim of drawing attention to the theme of geosites and geodiversity in the Marche Region. The Working Group drew up a proposal aimed at raising the awareness of the Regional Offices-Services and Administrators: a proposal for a regional law has been submitted for the protection and enhancement of an extraordinary asset, which must be strengthened and protected.

The aim was to produce a document for regional administrators to encourage the protection of geological heritage, starting from the first concepts expressed by Wimbledon, "a geosite can be defined as an area or territory in which geological or geomorphological interest can be identified for conservation purposes" [1], and Grandgirard, "of particular importance for the understanding of the Earth's history, climate and life" [78,79], leading to Gordon's statements "there are many connections between geoheritage and cultural heritage that provide a basis for geotourism activities" [10].

The presented document proposes a census of the Marchean geosites, accompanied by their geolocation and data sheets containing images; geological, geomorphological, naturalistic, and cultural information; as well as proposals for geo-tourist itineraries [80]. Currently, the list contains 197 geosites, distributed throughout the region and distinguished into two types: point (small-size isolated single landform or object, related to one dominant genetic process) and areal, representative of a larger zone containing two, or more, point geosites and constituting a composite or complex geosite (group of landforms related to one or more dominant genetic process), following the categories proposed by Coratza et al. [81].

Based on this work, the geosites in the study area have been reviewed, numerically implemented, and qualitatively analyzed. These geosites are proposed here for the first time to characterize a territory with great potential for attraction and development.

The collection and management of information on geodiversity is considered a key step in adopting an effective strategy for the conservation and governance of an area. Furthermore, the preparation of effective geosites inventories is crucial to support geoparks strategies. In agreement with the method proposed by Pereira and Pereira (2010), two main stages were carried out in this work: inventory and quantification. The inventory stage has included the identification of the potential geosites (based on their scientific and additional attributes), the qualitative assessment, and the geosite selection and characterization, while the quantification stage has included the numerical assessment and analysis of results [82].

The first phase of recognition and selection of the sites started from a literature review and field surveys, which lead to a list of potential geosites. From the resulting database, a final list of geosites was compiled following the main criteria: scientific values, additional values, and management criteria.

Various methodological procedures for inventorying and evaluating geosites are available in the scientific literature on geoheritage [4,40–57,82–92] and the bibliography cited therein.

In this work, the first selection of the most interesting sites of the study area was conducted through the application of qualitative procedures, as suggested by Pereira and Pereira (2010); Table 1 [82].

**Table 1.** Criteria used in the qualitative assessment of geosites (modified from [82]).

| Scientific Value Criteria | Additional Value Criteria | Management Criteria |
|---|---|---|
| • Rarity (Ra)<br>• Representativeness (Re)<br>• Integrity (In)<br>• Diversity (Di)<br>• Scientific knowledge (Sk) | • Cultural (Cu)<br>• Ecological (Eco)<br>• Aesthetics (Aes) | • Accessibility (Ac)<br>• Visibility (Vi)<br>• Vulnerability (Vu) |

Several quantitative evaluation methods have been proposed [86,89,93,94] but, to date, there is still no globally accepted method. In this study, some selected geosites (through a qualitative evaluation) were quantitatively assessed using a method recently proposed by Ferrando et al. (2021) [95], following Brilha's insights [83]. This procedure was adopted for its simplicity and clarity: the assessment of geosite value is based on the quantification of its scientific value (Vs), additional value (Va), and potential for use value (Pa).

As is well known, a quantitative evaluation of geosites has the undoubted advantage of increasing the level of objectivity, thanks to the numerical quantification of each factor through indicators.

Each of these three values is the result of the quantification of different parameters. For example, scientific value is derived from the quantification of integrity, representativeness, rareness, and secondary interest, where integrity is measured with the following scores: 1 = poor conservation; 2 = partial damage, integrity not preserved; 3 = partial damage, preserved integrity; 4 = good conservation; 5 = very good conservation. A score between 1 and 5 is given for each parameter, and the average of each set of parameters is calculated. The averages are finally combined to determine a score (Q value), where the scientific value is given three times more weight than the additional value and the potential for use, as summarized in Table 2 (see [95] for details of the method).

**Table 2.** Quantitative evaluation method (after [95]).

| Scientific Value (Vs) | Additional Value (Va) | Potential for Use (Pa) |
|---|---|---|
| • **Integrity (INT)**<br>• **Representativeness (REP)**<br>• **Rareness (RAR)**<br>• **Secondary Interest (SEC)** | • **Aesthetic Value (EST)**<br>- Naturalness (Na)<br>- Panoramic quality (Pq)<br>- Colour diversity (Cd)<br>- Vertical development (Vd)<br>• **Cultural Value (CUL)**<br>- Historical Importance (Hi)<br>- Archaelogical importance (Ai) | • **Accessibility (ACC)**<br>• **Interpretative potential (PIN)** |
| **Q = (3Vs + Va + Pu)/5** | | |
| A score between 1 and 5 was attributed to each parameter.<br>**Q** = weighted average of the three total values | | |

## 4. Results and Discussion of Selected Geosites

The selected geosites are of high scientific interest, thanks to their characteristics of rarity, representativeness, integrity, diversity, and scientific knowledge. Most of them also possess important additional values (cultural, ecological, and aesthetic) and the right management requirements, the latter being essential to ensure the possibility of the appropriate use of geosites.

The result of this selection is a list of 44 geosites included in the study area, organized from north to south, as shown in Table 3. Next to the name of each geosite and its location (municipality, province, and WGS 84 X-Y coordinates), the main genetic process is indicated, although many of them result from a combination of different processes and can therefore be considered complex geosites [81].

Seven of the 44 geosites listed in Table 3 were chosen (highlighted in bold) for the high significance of their qualitative assessment (shown in Table 4) and were presented in detail in this paper, to represent the study area. They are the *San Lazzaro Giants' potholes* (geosite 5), the *Furlo Gorge* (geosite 13), the *Piote of St. Antony* (geosite 19), the *Fondarca natural arch* (geosite 31), the *Mt. Petrano–La Roccaccia flatiron* (geosite 38), the *Mt. Tenetra natural amphitheatre* (geosite 40), the *Mt. Catria–Bevano Pleistocene glacier* (geosite 42).

**Table 3.** Geosites inventory in the study area. In bold, the seven selected geosites. Next to the name of each geosite, the location (municipality, province, and X-Y coordinates) and the main genetic process are indicated. Coordinates system refers to WGS 84.

| Nr. | Geosite | Main Process | Municipality | Province | X-Coord. | Y-Coord. |
|---|---|---|---|---|---|---|
| 1 | Sasso landslide | gravitative | Urbino | PU | 12.6482 | 43.7372 |
| 2 | Isola del Piano alluvial fan | alluvial | Isola del Piano | PU | 12.7828 | 43.7368 |
| 3 | Peglio Gypsum Formation | petrografic | Urbania | PU | 12.495 | 43.6957 |
| 4 | San Lazzaro historic landslide | gravitative | Fossombrone | PU | 12.7804 | 43.6863 |
| **5** | **San Lazzaro Giants' Potholes** | **fluvial** | **Fossombrone** | **PU** | **12.7765** | **43.683** |
| 6 | San Lazzaro River Gorge | fluvial | Fossombrone | PU | 12.7761 | 43.6826 |
| 7 | Fossombrone fluvial terraces | fluvial | Fossombrone | PU | 12.7784 | 43.6812 |
| 8 | Mt. Pietralata flatirons | structural | Acqualagna | PU | 12.7049 | 43.6771 |
| 9 | Sasso waterfall | fluvial | Sant'Angelo in Vado | PU | 12.4349 | 43.6679 |
| 10 | Mt. Pietralata rill erosion areas | slope | Acqualagna | PU | 12.6788 | 43.6726 |
| 11 | Mt. Càgnero Rupelian Chattian GSSP | sedimentary | Urbania | PU | 12.4677 | 43.6467 |
| 12 | Buzzo Gorge | fluvial | Acqualagna | PU | 12.741 | 43.6498 |
| **13** | **Furlo Gorge** | **fluvial** | **Acqualagna** | **PU** | **12.7277** | **43.6476** |
| 14 | Furlo Grain Cave | karst | Acqualagna | PU | 12.7233 | 43.6464 |
| 15 | Furlo waterfall | fluvial | Acqualagna | PU | 12.7227 | 43.6458 |
| 16 | Furlo Bonarelli Level marker | sedimentary | Acqualagna | PU | 12.7112 | 43.6448 |
| 17 | Furlo fault walls | structural | Acqualagna | PU | 12.7205 | 43.6429 |
| 18 | Ca' I Fabbri landslide | gravitative | Acqualagna | PU | 12.7583 | 43.6396 |
| **19** | **Piote of St. Antony–rill erosion area** | **slope** | **Mercatello sul Metauro** | **PU** | **12.3017** | **43.6195** |
| 20 | La Pradella landslide | gravitative | Acqualagna | PU | 12.7482 | 43.6229 |
| 21 | Lago del Sole Palaeo landslide | gravitative | Borgo Pace | PU | 12.2259 | 43.613 |
| 22 | Petriccio K-Pg boundary | sedimentary | Acqualagna | PU | 12.6521 | 43.6127 |
| 23 | Gorgo a Cerbara GSSP Barremian-Aptian (propose) | sedimentary | Urbania–Piobbico | PU | 12.5554 | 43.6014 |
| 24 | Balza della Penna fault wall | structural | Urbania–Piobbico | PU | 12.5445 | 43.5976 |
| 25 | Mt. Vicino relief inversion | structural | Apecchio | PU | 12.4276 | 43.5863 |
| 26 | Biscubio Torrent rill erosion | slope | Piobbico | PU | 12.4887 | 43.5856 |
| 27 | Rio Vitoschio Gorge | fluvial | Piobbico | PU | 12.4897 | 43.5791 |
| 28 | Balza forata erosional monument | karst | Piobbico | PU | 12.5159 | 43.5725 |
| 29 | Apecchio submarine slump | gravitative | Apecchio | PU | 12.3947 | 43.5488 |
| 30 | Poggio le Guaine–Cretaceus anoxic events | sedimentary | Cagli | PU | 12.5874 | 43.5448 |
| **31** | **Fondarca natural arch** | **karst** | **Cagli** | **PU** | **12.5379** | **43.5389** |
| 32 | Giordano spring | karst | Cagli | PU | 12.5388 | 43.5369 |
| 33 | Sasso del Re-Sasso della Rocca karst erosion forms | karst | Cagli | PU | 12.5275 | 43.5361 |
| 34 | Pieia blind valley | karst | Cagli | PU | 12.5308 | 43.532 |
| 35 | Acquaviva alluvial fans | alluvial | Cagli | PU | 12.6851 | 43.532 |
| 36 | Petrano plain | structural | Cantiano–Cagli | PU | 12.6108 | 43.5208 |
| 37 | La Rocchetta relict | structural | Cantiano–Cagli | PU | 12.6196 | 43.5142 |
| **38** | **Mt. Petrano–La Roccaccia flatiron** | **structural** | **Cantiano–Cagli** | **PU** | **12.6129** | **43.5062** |
| 39 | Cabernardi Sulfur mine | mineralogic | Sassoferrato | AN | 12.8626 | 43.5026 |
| **40** | **Mt. Tenetra natural amphitheatre** | **periglacial** | **Cantiano–Frontone** | **PU** | **12.6529** | **43.485** |

**Table 3.** *Cont.*

| Nr. | Geosite | Main Process | Municipality | Province | X-Coord. | Y-Coord. |
|---|---|---|---|---|---|---|
| 41 | Mt. Mura fault wall | structural | Serra Sant'Abbondio | PU | 12.752 | 43.4711 |
| **42** | **Mt. Catria–Bevano Pleistocene glacier** | **glacial** | **Cantiano** | **PU** | **12.6904** | **43.4649** |
| 43 | Mt. Catria fault scarp | structural | Serra Sant'Abbondio | PU | 12.7233 | 43.4621 |
| 44 | Montelago Holocenic lake | lacustrine | Sassoferrato | AN | 12.7759 | 43.4388 |

**Table 4.** Qualitative assessment of the seven selected geosites. 5 = *San Lazzaro Giants' potholes*; 13 = *Furlo Gorge*; 19 = *Piote of St. Antony*; 31 = *Fondarca natural arch*; 38 = *Mt. Petrano–La Roccaccia flatiron*; 40 = *Mt. Tenetra natural amphitheatre*; 42 = *Mt. Catria–Bevano Pleistocene glacier*. Acronyms: see Table 1.

| Geosite | Scientific Value Criteria | | | | | Additional Value Criteria | | | Management Criteria | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ra | Re | In | Di | Sk | Cu | Eco | Aes | Ac | Vi | Vu |
| **5** | x | x | x | x | x | x | x | x | x | x | x |
| **13** | x | x | x | x | x | x | x | x | x | x | x |
| **19** | x | x | x | x | - | x | x | x | x | x | x |
| **31** | x | x | x | x | x | x | x | x | x | x | x |
| **38** | x | x | x | x | x | x | x | x | x | x | x |
| **40** | x | x | x | x | x | x | x | x | x | x | x |
| **42** | x | x | x | x | x | x | x | x | x | x | x |

The choice was made by giving priority to their unicity and diversity, able to represent, in the different genetic mechanisms, a broad and complex territory. Great importance in the selection has been attributed to the aesthetic values and management criteria (accessibility and visibility), given the main objectives of protected areas. The only geosite that does not meet all of the requirements according to the proposed criterion is *Le Piote of St. Antony*. This geosite, in fact, has features of high impact but is unknown to the scientific community. Its rarity, integrity, diversity, and strong aesthetic impact have led us to propose it as a geosite that needs to be known and protected.

Concerning the quantitative evaluation method applied to the seven selected geosites, the scores assigned to the individual categories indicated in Table 2 [95] are presented in Table 5. The final Q value, calculated for each geosite, is also shown in Table 5.

**Table 5.** Scores assigned to the individual categories for the seven selected geosites. 5 = *San Lazzaro Giants' potholes*; 13 = *Furlo Gorge*; 19 = *Piote of St. Antony*; 31 = *Fondarca natural arch*; 38 = *Mt. Petrano–La Roccaccia flatiron*; 40 = *Mt. Tenetra natural amphitheatre*; 42 = *Mt. Catria–Bevano Pleistocene glacier*. Acronyms: see Table 2.

| Geosite | Scientific Value (Vs) | | | | Additional Value (Va) | | | | | | Potential for Use (Pa) | | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | EST | | | | CUL | | | | |
| | INT | REP | RAR | SEC | Na | Pq | Cd | Vd | Hi | Ai | ACC | PIN | |
| **5** | 5 | 5 | 3 | 4 | 5 | 4 | 5 | 5 | 4 | 2 | 5 | 5 | 4.38 |
| **13** | 5 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4.82 |
| **19** | 5 | 4 | 3 | 3 | 5 | 4 | 3 | 3 | 5 | 2 | 4 | 5 | 3.88 |
| **31** | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 4 | 5 | 4.87 |
| **38** | 5 | 5 | 5 | 3 | 5 | 5 | 4 | 5 | 4 | 2 | 5 | 5 | 4.37 |
| **40** | 5 | 4 | 4 | 4 | 5 | 5 | 4 | 5 | 5 | 1 | 5 | 5 | 4.38 |
| **42** | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 3 | 1 | 5 | 4 | 4.45 |

The calculated Q values, varying from 3.88 and 4.87, indicate geosites of high importance, considering their scientific, additional, and potential-for-use values.

Regardless of the scientific value, the seven geosites show very good conservation and high representativeness. They are rare at a regional, national, or international scale, and all of them show secondary interests of relevance. Remarkable aesthetic values are evidenced by high and very high scores, while cultural values, almost always present in these sites, are sometimes not connected to geological and geomorphological features. The sites are accessible by people with normal or limited movement capacity and the main scientific processes of the sites are easily understandable to everyone.

### *4.1. The San Lazzaro Giants' Potholes*

The Metauro River, crossing the anticlinal ridge of the Cesana Mountains at the height of the village of San Lazzaro di Fossombrone (PU), runs through a suggestive and narrow gorge for about 500 m. It is incised in the Mesozoic cherty limestones of the Maiolica Formation, with a sub-horizontal layout (Figure 4a).


**Figure 4.** (**a**) The San Lazzaro Gorge and the Diocleziano Bridge. The maximum height of the face is 10 m. (**b**) The San Lazzaro Gorge and the Giants' Potholes seen from the Diocleziano Bridge. The maximum width of the riverbed is about 8 m. (**c**,**d**) The Palaeo potholes. The major axis of the cavities is 1.20 m and 70 cm, respectively.

Looking out from the Diocleziano Bridge, an ancient Roman bridge overlooking the gorge, one can observe large cylindrical cavities carved into the limestone, the so-called 'giants' potholes' (Figure 4b), so developed as to be marked as a site of natural and tourist interest and among the most fascinating geosites in the Marche Region.

The swirling, swift action of the current, forced through the narrow, deep gorge, generates subcircular, deep river morpho-structures: the giants' potholes. The turbulent motion of the water in contact with the bottom or the walls causes the pebbles carried by the current to swirl, exerting a powerful abrasive action. The insistence of vortices at the same point creates small concavities that represent the embryos of the future potholes; as the drilling action continues, the current laden with pebbles increases the size of the pothole until it also assumes considerable dimensions [96].

The form is extinguished by the opening of holes in the walls or by excessive deepening. In this case, the pebbles are trapped in the bottom of the pothole, thus forming a gravelly floor that makes erosive action ineffective.

The potholes under the Diocletian Bridge are particularly developed; in fact, they were able to form and preserve themselves owing to the high velocity and turbulence of the river current during flood phases and the considerable hardness of the Maiolica limestones. The largest potholes appear on the true left of the river, characterized by a diameter of up to three meters; a little further upstream, various shapes with smaller diameters appear. At higher altitudes, numerous concavities can be observed on the walls of the gorge, which can be considered at least in part as 'paleo potholes', almost completely dismantled by river erosion (Figure 4c,d).

This site also conceals a curious peculiarity: buried by alluvium to the left of the Metauro River, there is a narrow but deep incision in the Maiolica Formation. It extends for about 3 km from the locality of 'San Lazzaro' towards the town of Fossombrone. The buried incision, embedded in the same formation, represents a fossil gorge, similar to the present one in width and depth [97].

### 4.2. The Furlo Gorge

The Furlo Gorge is a complex areal geosite of the Furlo National Reserve, which includes several point geosites (small-size isolated single landform or object) of great scientific and aesthetic significance [81,98]. The gorge is one of the best examples of the many canyons that strongly characterize the Apennine landscape of the Marche region, cross-cutting the calcareous ridges (Figure 5a). The Furlo Mounts are also characterized by a large anticline structure with a core of Jurassic rocks outcropping on the sides of the gorge (Figure 5b). The extensive and abundant Upper Jurassic-Paleogene outcrops of the Umbro-Marchean stratigraphic Succession, together with excellent fossil localities and well-exposed tectonic structures, give this site a crucial geological-paleontological interest.

The entire site contains many key landforms, fundamental for understanding the geomorphological history of the area and very significant from an aesthetic point of view (Figure 5c). This heritage is the source of spectacular landscapes, set in a context of considerable historical and archaeological significance such as the Roman Via Flaminia that runs through the gorge.

The gorge is cut by the Candigliano River (Metauro River basin), which allows the exposure of the massive and stratified limestone and marly-limestone formations of the Umbro-Marche Succession. The Furlo Gorge crosses the anticlinal relief of the Pietralata-Paganuccio Mountains, right at its axial culmination, underlining a crucial fault-related structural control on its genesis [81].

The Furlo Gorge is a magnificent example of a cross-gorge (the river cuts across the anticline), a very characteristic and rather common shape in the Apennine landscapes of the Marche Region. This site plays a fundamental role in understanding the evolution of the Marche landscape, in particular the genesis of the gorges, transversal to the tectonic structures. Characterizing and peculiar geomorphological elements are located and described within it, which constitute fundamental components for the interpretation of the landscape and contribute to the scenic beauty of the geomorphosite. The Furlo Gorge develops along a dominant SW–NE joint direction, just corresponding with a pronounced axial culmination of the anticline [68], as shown both by geologic data and the morphostructural layout. Moreover, a second narrow canyon (the Buzzo Gorge, Figure 5a) parallel to the main one cuts the outer flank of the anticline ridge less than 1 km southeast of the Furlo Gorge. The unusual structural position and the occurrence of a second smaller canyon led to interpret the Furlo Gorge as the result of capture mechanisms, rather than superposition followed by antecedence, as previous research had argued [71].


**Figure 5.** (**a**) Overview of the Furlo Mts. and the Furlo Gorge, seen from the SW. On the left, the Buzzo Gorge is visible. (**b**) Aerial view of the Furlo Gorge vertical walls. (**c**) One of the characteristic landforms of the area: pinnacle. The height is about 20 m. (**d**) Debris fan in the valley floor, covered by vegetation.

The side walls of the gorge rise more than 500 m above the valley floor: their persistence, continuity, and shape depend on the massive resistant limestone that constitutes them. Overhanging cliffs and minor rectilinear scarps, degradation niches, crests, and spurs aligned along fault-traces occur all along the canyon. Minor karst (solution flutes and pits) and paleo-karst features (remnants of small tunnels) are also evident, in particular close to the "Grotta del Grano" (i.e., "Wheat Cave") site, so called because of the discovery of ancient wheat stocks. Higher up, small, suspended valleys carved by intermittent streams flow into the gorge; they are dry for most of the season, and after intense rainfall they give rise to suggestive waterfalls. Along the sides of the valley, characterized by the steep morphology of the rock cliffs, there is abundant evidence of landslides of various sizes, consisting of large accumulations of boulders on the bottom walls (Figure 5d). Even in Roman times, repeated landslides affected the road through the gorge, encouraging the Romans to dig two tunnels in the rock.

A dam, built between 1919 and 1922, creates an artificial lake inside the gorge.

In this site, the geological and biological components integrate with historical and archaeological ones. Because, in the past, the gorge was the main connection between the Adriatic coast and the Apennine Mountain passes [99], it preserves notable construction works of the Roman consular Via Flaminia (e.g., over 300 m of walls, ca. 1500 $m^3$ of cut-off rocks and two tunnels, with one of them, the Vespasiano tunnel from 76 BC, still in use).

On the top, a dense vegetation is found, typical of the Mediterranean area (e.g., *Ilex elce*, *Fraxinus ornus*, and *Ostrya carpinifolia*) and inhabited by a wide variety of animal species. On the steep walls of the gorge, the eagle (*Aquila chrysaetos*; Linnaeus, 1758) finds refuge, whose nest, located on a natural hollow, is up to six meters in diameter.

### *4.3. The Piote of St. Antony–Rill Erosion Area*

The Le Piote locality is located in the basin of the Sant'Antonio stream, a small watercourse that enters into the Metauro River near the village of Mercatello sul Metauro (PU). The area is geologically characterized by the Marnoso-Arenacea Formation, which in this site shows a mildly inclined stratification. This layering conditions the morphology of the landscape, characterized by asymmetrical valleys and watersheds with sharp ridges.

The monotonous morphology of the Marnoso-Arenacea Formation is broken up by landscape shapes that make it an unusual and picturesque place. The slope is heavily denuded and eroded by processes of aerial washout and concentrated runoff (Figure 6a) and its gradient is determined by the surfaces of the layers, which emerge weakly inclined in the slope direction. The alternation of more resistant sandy strata with more erodible marly ones results in highly selective water erosion, thus creating characteristic steps with an irregular profile.

Thin soils form in the most exposed sandy parts, allowing the development of scattered grassy stretches on the slope, which give rise to characteristic rounded green shapes, called "piote", from which the locality name originates (Figure 6b). When the sandy layer is completely removed by erosion, the washing waters quickly carve the underlying marly layer, which takes on a characteristic dome shape (Figure 6c).

The weathering processes acting on the diverse lithologies, which are differently fractured, shape original microforms that make this place a small museum of natural sculptures (Figure 6d,e). On marly surfaces characterized by convoluted laminations, for example, a particular kind of mechanical degradation is produced that splits the thin laminations, giving the surface a typical microsculpture.

The 'piote', or grassy clods of land, are also the protagonists of an ancient local practice (probably dating back to the 4th century BC): special dome-shaped wooden structures, called 'Carbonaie', can sometimes still be seen in these places, especially in winter, used to produce natural charcoal from wood (Figure 6f). The draught and slow combustion of the charcoal pile depended on the correct execution of the structure; the wooden structure was covered with 'piote' (clods of soil) and dry leaves, which, being waterproof and poorly inflammable, allowed for slow combustion, thus achieving a better quality of charcoal.


**Figure 6.** (**a**) Drone view of the slope eroded by aerial washout. (**b**) The so-called "Piota", indicating grassy clods of land. Its major axis is approximately 30 cm. (**c**) Dome shapes on marls. (**d**,**e**) Forms of erosion related to weathering processes. (**f**) Dome-shaped wooden structure to produce natural charcoal called "Carbonaia".

### 4.4. The Fondarca Natural Arch

The southwestern slope of Mt. Nerone (geosite 31 in Figure 1), where the Giordano River basin is located, shows a peculiar morphology, different from the landscape of the surrounding hills. In this sector, in fact, the anticlinal structure of the ridge is dislocated by faults allowing the outcrop of the Jurassic Calcare Massiccio Formation at the core of the structure.

It is well known that this geological formation could easily be subject to chemical dissolution by water [26]; all of the most important karst systems in the region are in fact developed on it (e.g., the famous Frasassi caves). Hidden by dense vegetation, relict karst forms emerge on the entire slope, forming an overall 'City of Rock' of extraordinary beauty (Figure 7a).


**Figure 7.** (**a**) Overview of the southwestern side of Mt. Nerone: the 'City of Rock' of the Giordano River basin. (**b**) *Sasso della Rocca* (on the left) and *Sasso del Re* (on the right). (**c**) Aerial view of the Fondarca natural arch, representing the remains of a large collapsed cave.

Further upstream, the landscape becomes gentler and the Pieia basin opens up, representing what remains of a 'blind valley'. Here, surface waters have channelled into underground cavities, leaving the valley filled with debris and deprived of the watercourse that shaped it. In this landscape stand the isolated pinnacles of Sasso della Rocca and Sasso del Re (Figure 7b), witnesses to the ancient morphology. They are separated by the Fosso del Breccione, which owes its name to the large amount of debris it carries and deposits during particularly intense weather events.

All of these forms were part of an underground karst system, now dismantled by the slow process of uplift of the ridge. The surface hydrography probably disappeared during the Upper Pleistocene, taking the underground route. Evidence of the development of a still active underground complex is provided by the resurgence of the Giordano stream, which flows southeast of Pieia.

The remains of the underground routes have subsequently been reshaped by subaerial erosion, with the collapse of the caves' ceilings at times and preserving the strongest parts, which remained as evidence of the ancient ways. One of the most impressive landforms is the Fondarca Arch, an imposing natural bridge more than 30 m high and about 15 m wide, which constitutes the remains of a large collapsed cave (Figure 7c).

The site is also of historical and archaeological importance, as prehistoric artefacts, related to religious rituals, have been found at the bottom of the cave, testifying to human frequentation since the Bronze Age [100].

### *4.5. Mt. Petrano–La Roccaccia Flatiron*

Flatirons are sub-triangular prismatic shapes resembling the tip of an iron, hence the name. Mt. Petrano has an altitude of 1162 m and is easily distinguished in the landscape by its characteristic flattened top, recognisable even from a great distance. Mt. Petrano lies between Mt. Catria to the south-west (Figure 8a) and Mt. Nerone to the north-east (Figure 8b), separated by the gorges of the Burano and Bosso streams, respectively, that cross the mountain ridge [101].

The impressive panorama from Mt. Petrano encompasses a large territory, offering spectacular views of the major peaks around it and across the whole province of Pesaro and Urbino, as far as the province of Rimini, the Republic of San Marino, and the Adriatic Sea.

The relief is a beautiful example of an anticlinal ridge [82]: the morphology of Mt. Petrano follows the broad anticline perfectly, and no tectonic dislocation seems to disturb the regularity of the fold, exposing it in its full and awesome natural magnificence. The sedimentary rocks outcropping in the ridge are represented by an alternation of more or less cohesive lithologies: the upper surface, which is broad, smooth, and almost flat, consists of carbonate rocks of the Maiolica formation, which are very resistant to degradation. In contrast, the rocks of the Marne a Fucoidi Formation, which lies on the Maiolica Formation, are more degradable as they consist of marls and clays. Finally, the overlying rocks are more resistant and consist of the hard limestones of the Scaglia Bianca and Scaglia Rossa Formations [62]. Surface run-off water promotes selective erosion processes and the formation of sub-triangular prismatic shapes: the flatirons (Figure 8c).

The streams descending from the flat summit of Mt. Petrano follow directions related to the different rocks' erodibility and fracturing, eventually producing the characteristic morphologies of the flatirons. Observing these spectacular shapes is a unique experience, resembling being inside a natural laboratory, and the resulting landscape is a true work of art. Flatirons represent fairly common landforms in the anticlinal ridges of the Apennines, and are here, on the flanks of Mt. Petrano, among the best-exposed examples; the most significant in this area is the one called La Roccaccia (Figure 8c). The small relief of La Rocchetta (1163 m), which rises above the structural surface of Mt. Petrano, has the same origin: it represents a remnant of the ancient structure that has been removed by erosion. From the top of this hill, the visitors can benefit from an impressive 360° panoramic view over much of the northern Marche Region and part of the Umbria Region (Figure 8d).

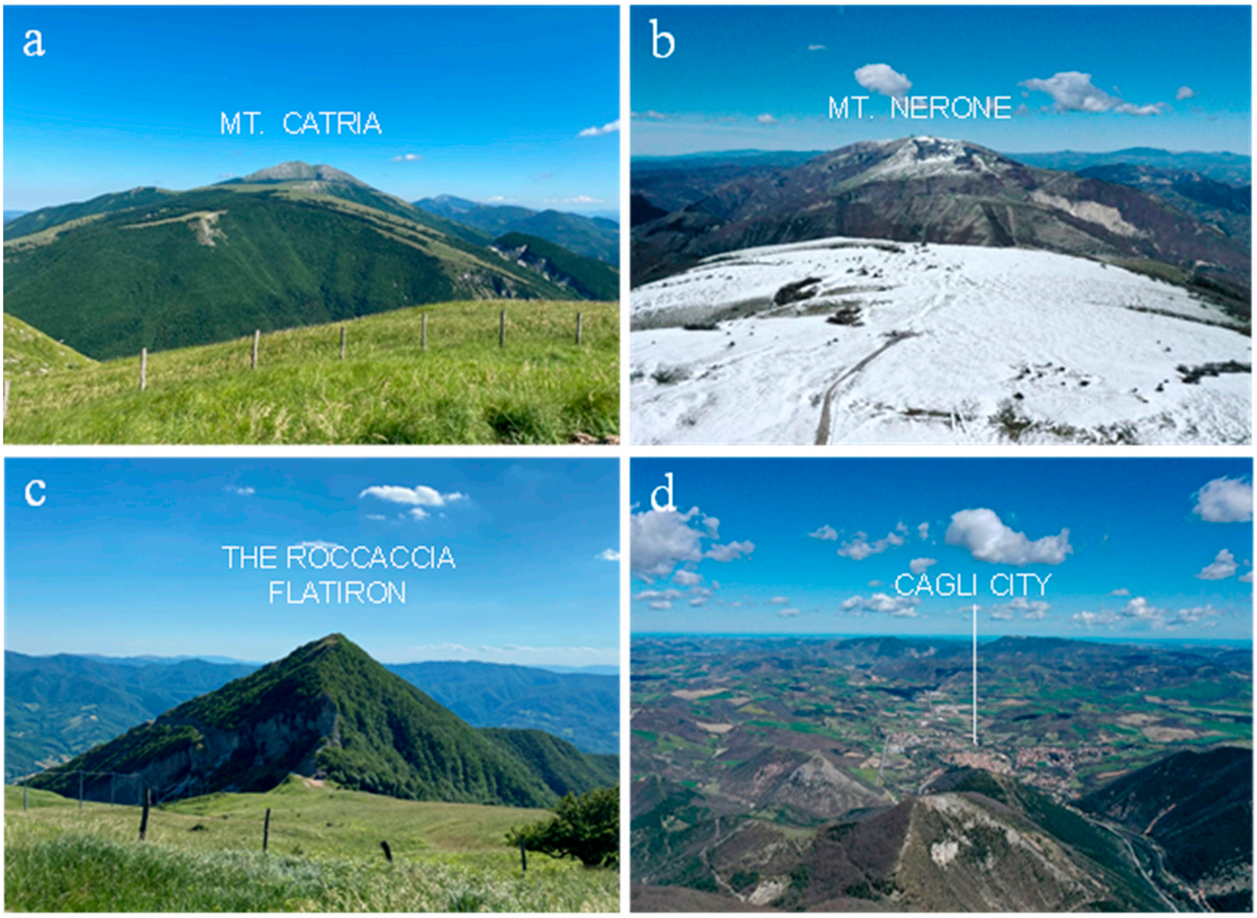


**Figure 8.** (**a**) View of the anticlinal ridge towards Mt. Catria, seen from Mt. Petrano. (**b**) View of the same anticlinal ridge towards Mt. Nerone, seen from Mt. Petrano. (**c**) The Roccaccia flatiron on the southwestern flank of Mt. Petrano. (**d**) Panoramic view towards the Adriatic Sea from Mt. Petrano.

Cagli, an interesting village at the foot of Mt. Petrano, was inhabited in the past by Umbrians and Romans and was among the cornerstones of the Byzantine Pentapolis (with Fossombrone, Gubbio, Jesi, and Urbino). In the 13th century, the village was burnt by Ghibellines and then rebuilt by Pope Nicholas IV (1289 AD), on the plateau below the previous settlement. It was then incorporated into the borders of the Duchy of Urbino: in fact, Federico da Montefeltro (Duke of Urbino) had it fortified in 1481 AD, with the construction of an imposing fortress. The fortress, which has unfortunately disappeared today except for a few ruins, is connected by an underground passageway to the imposing Torrione, which still stands in the valley and is home to a recent Contemporary Sculpture Centre.

### *4.6. The Mt. Tenetra Natural Amphitheatre*

The Tenetra stream basin is in the sector of the Umbro-Marchean Apennines consisting of the ridge extending from Mt. Nerone (1525 m) to Mt. Catria (1701 m). Geologically, it is a chain of folds and faults mainly oriented in the NW–SE direction, consisting of the Meso-Cenozoic limestone and marly limestone rocks.

The fold structure gives the landscape typical and clearly recognisable morphologies, especially in areas characterized by alternating lithologies. Selective erosion, in fact, produced by run-off and channelled water, acts in the landscape by forming relatively narrow and elongated ridges and depressions, roughly parallel to each other (Figure 9a).


**Figure 9.** (**a**) Overview of the Mt. Tenetra and the Tenetra Stream basin. (**b**) Vertical view of the Tenetra Stream basin (Google Earth Pro on 11 April 2023). (**c**) Topographical mapping of the area (*Catasto Pontificio*, 1816).

To understand the morphology of these areas, it is necessary to consider the erosion resistance of the outcropping rocks and the inclination of the sides of the folds. Among the landforms that make up the varied landscape of the area, the most distinctive are the flatirons, sub-triangular reliefs produced by erosion on rocks of different resistance.

Another significant peculiarity of this area is the presence of forms and processes of glacial origin: in the nearby basin of the Bevano stream, forms and deposits, now relict, of glacial origin have been found [101,102]. In the basin of the Tenetra torrent, there are nivo-morainic detrital accumulations, very similar to moraines but smaller in size. The combination of these morphologies, associated with forms of fluvial and slope origin, produce a landscape of great variety and beauty that make it one of the most fascinating areas in the Province of Pesaro and Urbino. The Tenetra torrent forms a wide depression bordered by a watershed that runs along the summit of the homonymous relief and descends to the village of Cantiano (geosite 40, Figure 1). The latter rises on the terraced alluvial plain of the Burano Torrent, which further downstream flows into the Candigliano Torrent near Cagli.

The Tenetra basin has a particular morphology that distinguishes it from all the watercourses on the same ridge. Satellite observation particularly highlights this 'concentric pseudo-circles' shape, which is linked to the structural layout, selective erosion by flowing water, and glacial action (Figure 9b).

The emerging stratum heads were well drawn and emphasized even by the cartographer who worked on the Catasto Pontificio, which dates to 1816 (Figure 9c).

The fluvio-glacial erosive processes on the ridge cut through the sequence of differently compacted layers. This mechanism is complex, because of the different consistency of the various layers producing a different erosion response. If we look at other contexts with the same structural conditions (i.e., folded chains), the evolution of the hydrographic network leads to morphologies quite similar to those visible in the Tenetra basin. The similarity is due to the same genesis, which develops in a folded structure with alternations of differently resistant rock layers. During the erosive phase, the watercourse follows the stratification and deepens to meet the most erodible formations of the succession, forming a typical 'funnel-shaped' basin.

Raphael Sanzio (Urbino 1483–Rome 1520), one of the greatest artists of the Italian Renaissance, inserted the amphitheater of Mt. Tenetra in the background of his famous painting 'The Deposition of Christ' [103]. Raphael probably participated in the performance of the 'Turba' in Cantiano, a small village at the foot of Mt. Tenetra, and was impressed. The first performance dates back to 1260. Since then, the procession of the Passion and Death of Jesus Christ has taken place almost every year through the streets of the village, which on this occasion is transformed into a real theater where the visitor becomes an active part of the spectacle. Even today, as Raphael saw it, behind the main square of the village, Mt. Tenetra serves as a spectacular natural amphitheater.

### *4.7. Mt. Catria–The Bevano Pleistocene Glacier*

On the south-western flank of the Mt. Catria ridge lies the basin of the Bevano torrent, a wide depression bordered by a watershed, which runs over the peaks of Mt. Catria and Mt. Acuto and down to the village of Chiaserna (Figure 10a). The rock formations outcropping in this valley belong to the Umbro-Marchean Succession, ranging from the Jurassic (Calcare Massiccio Formation) to the Oligocene (Scaglia Cinerea Formation).

The Bevano valley represents an area of great importance for the geoheritage of the Apennines, as it contains unique geological, palaeontological, and geomorphological sites. It is a site of primary importance for research into Pleistocene climate variations, as relict forms and deposits of glacial origin have been found. Among the most significant are the moraine embankments that still retain their original form despite their formation dates thousands of years ago. The glacier deposited huge amounts of detritus at the edge of the valley, which it had taken from the feeding zone. Long, narrow ribbons were thus formed with the characteristic asymmetrical shape that limited the glacial valley.

The erosive forms are present especially on the upper part of the glacial complex, although less evident because they are more exposed to subsequent erosion and because they are incised on easily degradable rocks: these are over-excavated conches, smoothed surfaces, and edged slopes. The glacial tongue reached as far as the present-day village of Chiaserna and was over three kilometres long with separate feeding areas (Figure 10b,c). The preservation of the accumulation forms and edge scarps allows the event to be dated to the last glacial period. At higher altitudes, the glacier may have been preserved up to 15,000 years ago [102,104].


**Figure 10.** (**a**) The Bevano stream basin on the south-western slope of Mt. Catria. (**b**,**c**) The Bevano stream basin: reconstruction of the palaeo-glacier [103].

The Bevano glacier is not the only one in the north-central Apennines [105–107]; in the Umbro-Marchean ridge, it is nevertheless one of the examples that most clearly preserves glacial landforms. Mt. Nerone bears clear traces of glacial erosion and Mt. Petrano was probably the site of a magnificent highland glacier.

The area also contains punctual geosites of great scientific interest: at the locality known as 'Castellaccio', along the Provincial Road Number 52 that leads from Serra Sant'Abbondio to the Fonte Avellana Monastery, for example, crops out a succession of marine rocks of fundamental importance for understanding the Jurassic evolutionary history of the North-Marchean area. The stratigraphic section of 'Castellaccio' emerges at the core of the anticlinal structure and, in a few metres of thickness, records the tectonic-depositional events of an interval of about 30 million years, from the Sinemurian to the Bajocian. In addition to this very limited thickness, Jurassic rocks belonging to quite different sedimentation environments in terms of palaeo-bathymetry appear here to overlap in apparent continuity. Thanks to its easily accessible exposure, the 'Castellaccio' section represents one of the most representative examples of the intensive displacement of the seafloor in the Jurassic Umbro-Marchean basin [108]. Furthermore, the effects of more recent tectonics on the rock outcrops (fault walls, reversed layers, and folds) are particularly evident throughout the area, bearing witness to the post-Jurassic phases that have accompanied the structuring of the Apennine edifice.

The Monastery of Fonte Avellana is a fascinating religious site located along the Cesano River valley. The Monastery is a very suggestive place, steeped in art and history, located on the slopes of Mt. Catria, at an altitude of 700 m above sea level. Its origins date back to the late 10th century, around 980, when some hermits chose to build the first cells of a hermitage that would become the present monastery. The hermitage is mentioned in the Divine Comedy (Paradise, Canto XXI) by Dante Alighieri, who also seems to have been a guest there.

The monastery lies at the foot of the imposing eastern rock face of Mt. Catria; here, a much thicker Jurassic succession is exposed than that of the 'Castellaccio', and different facies outcrop, testifying to a different formation environment, corresponding to a structural low in the sedimentation basin.

## 5. Conclusions

Humanity cannot be saved without culture and the latter without its environment, the cradle of all social and spiritual reality. This is especially true in the Marche Region, distinguished by multiple and original landscapes, just as multiple and original are the life and work histories of the people, engaged in an industrious competition collaboration with the mountains, the hills, the sea, the waters, the soils, the spirituality of the places, and the forces of nature. The result is a harmonious layout, testimony to civilization, social organization, careful working techniques, refined models of conduction, articulated forms of settlement, and intimate and intense relations between men and the natural environment. All this with evocative scenarios that arouse amazement and interest in those who approach the reality of the Marche Region.

The present research has made it possible to highlight the predisposition of an area, and in particular of certain geosites, to be bearers of contents and experiences that can transmit geological and geomorphological values. Thus, the work needs to be set in the context of the management of protected areas with a function of the enhancement of naturalistic values, arising from a context of great geodiversity, and therefore needs to be placed in the broader context of the protected areas bordering on the neighboring territory.

The natural parks and reserves of the Marche Region constitute a precious treasure chest in which the signs of the historical relationship between nature and human activities are preserved in the most harmonious way [109].

One of the main strategic objectives in enhancing and protecting the territory is to stimulate economic activity in the context of sustainable development. This concept is particularly pertinent, in the context of a protected natural park where, taking into account seasonal tourist flows, the strategies of protection and enjoyment of the geosites included should be implemented through a synergy between the interests of local entrepreneurs and the need to protect the areas of interest themselves [110,111].

Over the last thirty years, the Marche Region has come to take care of a good percentage of its total surface area, establishing various types of protected areas to safeguard environments and landscapes of considerable scientific and cultural interest. The regional system of parks and nature reserves, in fact, today covers a total area of approximately 89,470.72 ha, which corresponds to 9.59% of the Marche Region's territory.

In the Marche Region, indeed, there has been a growing and widespread awareness of environmental issues and an increasing desire to preserve certain areas of scientific, natural, and cultural interest from industrial and building development. The protected areas established in the decade from 1987 (when the Conero Regional Park was established) to the mid-1990s (when the Mts. Sibillini National Park, the Gran Sasso and Mts. della Laga National Park, and the Sasso Simone and Simoncello, Mt. San Bartolo, Gola della Rossa, and Frasassi Regional Parks were established) have mainly contributed to the goal of protecting at least 10% of the territory.

The official List of Protected Natural Areas (EUAP) in Italy is a list compiled and periodically updated by the Ministry of the Environment and Protection of Land and Sea—Directorate for the Protection of Nature, which brings together all officially recognized marine and terrestrial protected natural areas. The list currently in force is that for the 6th Update approved on 27 April 2010 and published in Ordinary Supplement No. 115 to the Gazzetta Ufficiale No. 125 of 31 May 2010.

Table 6 shows the current protected areas and their extension in the Marche Region, as well as the number of municipalities involved.

**Table 6.** Protected areas in Marche Region. * = surface area within the Marche Region.

| Nr. | Name | Surface Area (ha) | Nr. of Involved Municipalities |
|---|---|---|---|
| 1 | National Park *Mts. Sibillini* | 51,473.98 * | 16 |
| 2 | National Park *Gran Sasso* and *Monti della Laga* | 9363.22 * | 2 |
| 3 | Natural Regional Park *Mt. Conero* | 5982.74 | 4 |
| 4 | Natural Regional Park *Mt. San Bartolo* | 1584.04 | 2 |
| 5 | Natural Interregional Park *Sasso Simone and Simoncello* | 2639.45 * | 4 |
| 6 | Natural Regional Park *Gola della Rossa and Frasassi* | 10,026.53 | 5 |
| 7 | State Natural Reserve *Mt. Torricchio* | 310.91 | 2 |
| 8 | State Natural Reserve *Abbadia di Fiastra* | 1834.28 | 2 |
| 9 | State Natural Reserve *Furlo Gorge* | 3626.94 | 5 |
| 10 | State Natural Reserve *Ripa Bianca* | 310.86 | 1 |
| 11 | State Natural Reserve *Sentina* | 174.34 | 1 |
| 12 | State Natural Reserve *Mt. San Vicino and Mt. Confaito* | 1946.69 | 4 |
| 13 | State Natural Reserve *Bosco delle Tecchie* | 196.74 | 1 |

Figure 11 shows the areal distribution in the Marche Region of EUAP, SIC (Sites of Community Importance), and ZPS (Special Protection Zones) protected areas, while the study area is highlighted in red.

It is still difficult to counter both in the political world and, in public opinion, the view of immediate profit in favor of eco-sustainable strategies, whose benefits are evident in the medium and long term, responding effectively to the need to protect and safeguard the landscape and natural heritage.

In conclusion, this work, by highlighting the numerous geosites of great scientific and additional values in the North-Marchean Region, intends to encourage and empower the initiative already undertaken a few years ago by the 'Catria-Nerone Mountain Union', in agreement with the 18 municipalities included in the area under study. The initiative has unfortunately come to a stop, perhaps also related to the difficult period experienced in recent years due to COVID-19.

We hope that the great potential contained in this area, home to 44 very interesting and scientifically recognized geosites, may awaken in the competent authorities the desire to enhance and protect this territory. All 44 of these geosites are worth protecting for their scientific and additional values and could be considered examples of "geo-morpho-anthropo-sites", which could be made available to the public for cultural purposes through the creation of appropriate scientific and educational itineraries.

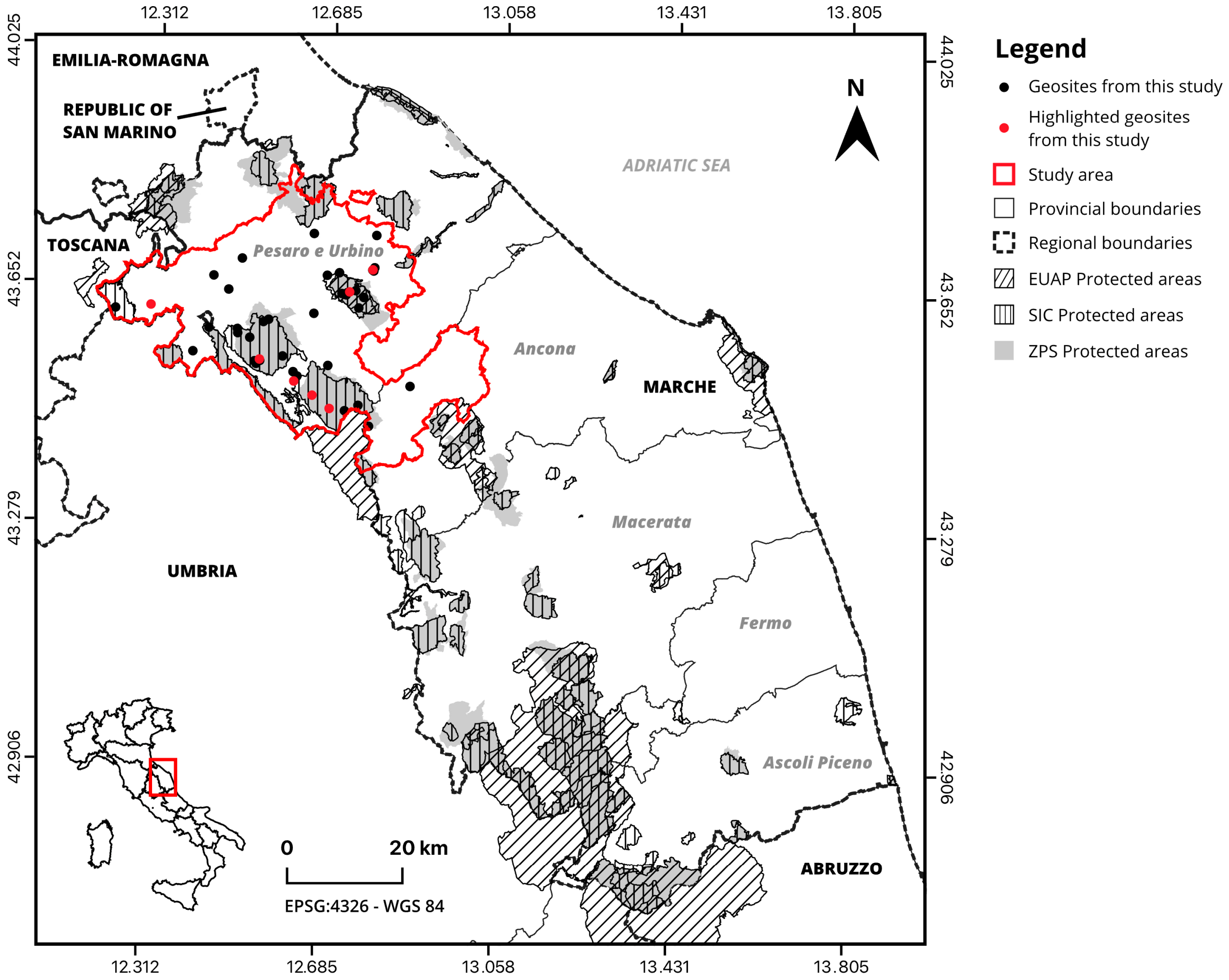


**Figure 11.** EUAP, SIC, and ZPS protected areas within the Marche Region. The study area is highlighted in red.

In particular, the selected seven geosites, owing to their scientific, additional, and potential-for-use values, well represent the great variety and the strong potential of this area. The Q-values resulting from the quantitative assessment, ranging from 3.88 to 4.87, are indicative of geosites of high scientific significance, in addition to their undoubted aesthetic value.

The right solution for the protection of this heritage might be, in conclusion, the establishment of a geopark and thus the implementation of the rules for the Environmental Action Strategy for Sustainable Development in Italy (year 2002), as indicated by the Ministry for the Environment and Land Protection.

The territory is a great resource that should first be understood in order to be effectively enhanced through the best eco-sustainable strategy, so that this extraordinary heritage, worthy of protection, can be preserved for future generations.

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