

Review

The *Vie Cave* Geomorphological Site in Southern Tuscany (Italy): Problems of Decay and Conservation

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Abstract: The *Vie Cave* are a suggestive network of roads deeply entrenched in the rock, dating back to the Etruscan civilization; these ancient roads connect various settlements and necropolises existing mainly in the area of Sovana, Sorano and Pitigliano towns (Southern Tuscany, Italy). The *Vie Cave* are located in a peculiar geomorphological site, characterized by the presence of extensive pyroclastic deposits, which have been incised by a parallel network of deep gorges. In this paper, the geomorphological, geological and lithological setting of the *Vie Cave* area, where several Etruscan archaeological sites are found, are described. The precarious stability of the *Vie Cave* walls and the several archaeological structures carved into them, the high grade of decay shown by the constituent materials, together with the dense vegetation that has developed over the rocky scarps, are taken into account with the aim to provide a complete assessment of the conditions in which the site lies. Finally, we propose some targeted actions related to the preservation of this territory, showing so distinctive morphology, in order to protect the area from further decay to which it would be subjected if it remained abandoned.

Keywords: *Vie Cave*; geomorphological site; decay; conservation

1. Introduction

The so-called “*Vie Cave*” consist of a suggestive road network, dating back to the Etruscan civilization, which connects various settlements and necropolises located mainly in the area between Sovana, Sorano and Pitigliano towns (Southern Tuscany, Italy; Figure 1a,b). This area is characterized by the presence of extensive pyroclastic deposits erupted by the Latera volcano (about 0.38 to 0.15 Ma [1]), one of the two complexes forming the Monti Vulsini volcanic district [2,3].

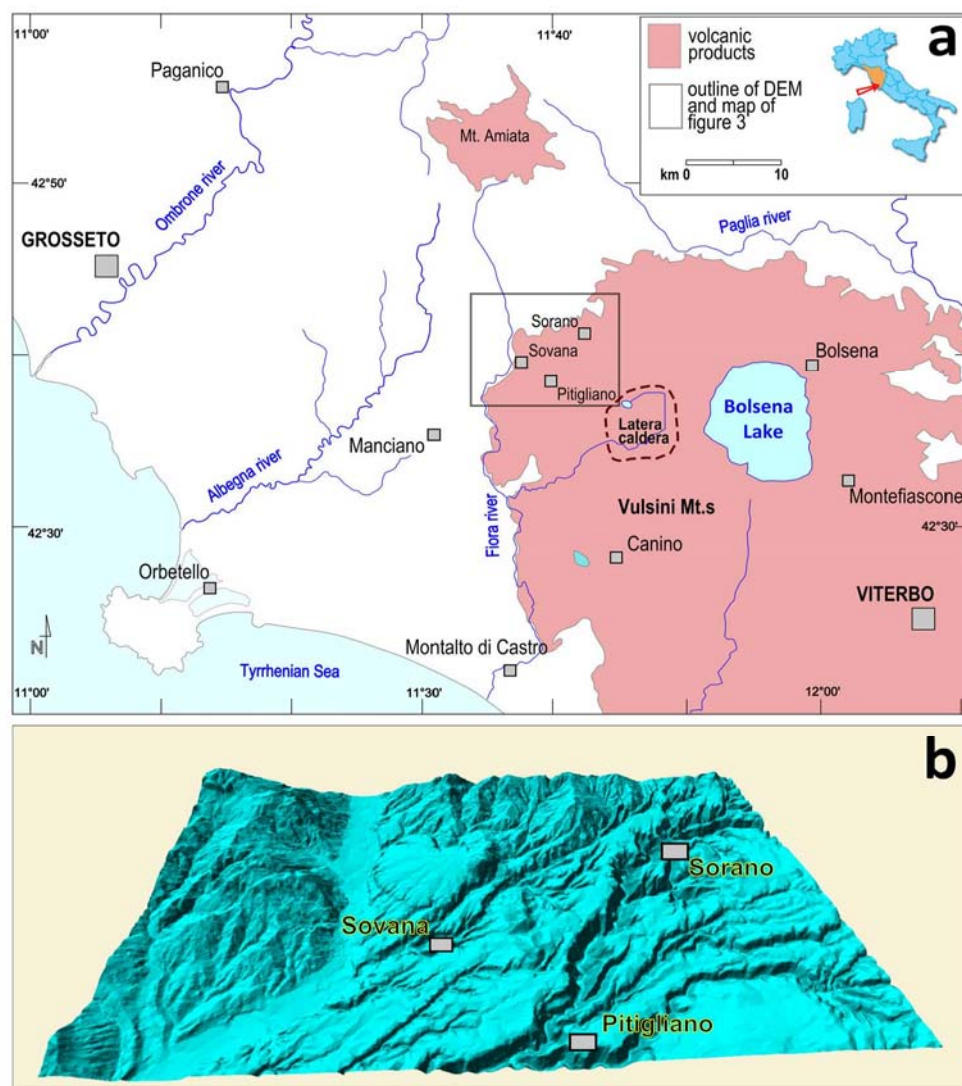


Figure 1. (a) Location map and (b) Digital Elevation Model (DEM) of the investigated area.

The almost tabular morphology of this territory is incised by deep gorges and, particularly in the left side of the Fiora River basin, long tuff spurs, bordered by steep slopes, were formed by river erosion (Figure 1b). Over these volcanic deposits, many settlements have sprung up since the Etruscan period by exploiting the morphology for defensive reasons.

The need to build a road network connecting the major settlements had to face the problem of overcoming the height difference between the bottom of gorges and the plateaus above them, which obliged the Etruscan to dig long cuts into the tuff cliffs. These stretches of roads, locally called *tagliate* (cut roads), *cave* or *cavoni* (dug roads), are often very narrow (3–4 m) with vertical sidewalls up to 20 m high and so they were necessarily constructed taking into account the morphology and the mechanical characteristics of the pyroclastic deposits.

Over the years, many of these pathways have lost one of their function, *i.e.*, that of connecting the bottom of the gorges to the agricultural lands on the plateaus. This fact was due to several reasons: the roads were too narrow and steep for the modern agricultural vehicles, they were often completely blocked by large rock falls and, in the meantime, new roads had been opened; as a consequence, the condition of abandonment or the lack of regular maintenance has favored their complete wild naturalization. This represents the greatest challenge for the conservation of these geomorphological and archaeological sites but it also represents the natural evolution affecting the rock cliffs. In the past, the constant maintenance, realized through the canalization of runoff water, both on the bottom of the paths and in the areas overlying the walls, has allowed controlling and slowing down rock fall phenomena that otherwise, over 2500 years, would have completely obliterated these sites. Today these paths, with a lush vegetation of ferns and mosses growing on the walls and a weak sunlight passing through a green ceiling, represent one of the most evocative sites of the region. In 2004, the World Monument Found promoted the *Vie Cave* site as assets of global interest to be protected: this important recognition represents an incentive to the active protection of this unique heritage.

In this paper we describe the geomorphological, geological and lithological setting of the *Vie Cave* area, in order to give a complete assessment of the conditions in which the site lies. Particular attention is paid to the precarious stability of the tuff walls and the archaeological structures carved into them, the high degree of decay that the constituent materials show, together with the dense vegetation that has developed over them. In addition, we propose some targeted actions aimed to the preservation of this territory, which displays such distinctive and unique morphology.

2. Geological and Geomorphological Setting

The *Vie Cave* area is located in the Vulsinian volcanic complex, in the Northern part of the Roman Comagmatic Province. This area was affected by extensional tectonics from the Miocene to the Quaternary period and by an intense volcanic activity started in the Middle Pleistocene [4,5]. The proper Vulsinian magmatic district includes more than 100 eruptive centers, distributed around a volcano-tectonic depression, partly filled by Bolsena Lake (Figure 1a). The pyroclastic products and the minor lava flows of the multi-center Monti Vulsini volcanic district occupy an area of about 2200 km² and were emplaced from about 0.6 to 0.15 Ma BP [6].

In this district we can distinguish four different volcanic complexes [2,3]: Paleo-Bolsena, Bolsena, Montefiascone and Latera; the *Vie Cave* area is situated in the zone where the Latera stratovolcano emplaced extensive pyroclastic units and some lava flows. In the Latera typical stratigraphic sequence (Figure 2), seven pyroclastic formations, Canino Formation, Farnese Formation, Sovana Formation, Sorano Formation, Grotte di Castro Formation, Onano Formation and Pitigliano Formation, have been

recognized [6]. A brief description of the Latera stratigraphic column, from bottom to top, is here reported in order to better understand the relationships between stratigraphy and morphological setting.

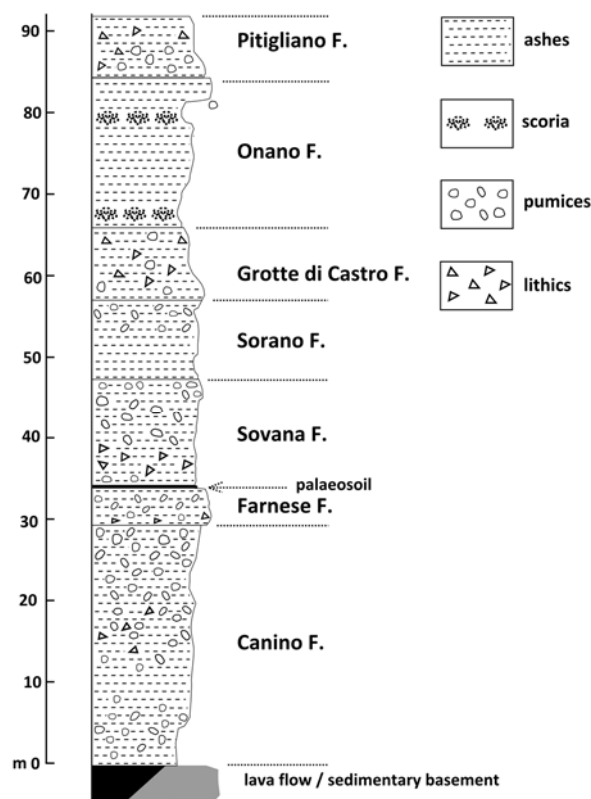


Figure 2. Schematic stratigraphic column of the Vulsianian pyroclastic succession in the study area (strathigraphic data after [7], simplified). In the figure are reported the different pyroclastic formations.

The oldest formation of the Latera volcanic complex, which lies directly on the sedimentary basement (Ligurian Units) or on the early leucitic lavas, is represented by the Canino Formation, comprehending several poorly coherent to coherent flow units. In particular, at the Canino locality, at least four different flows have been recognized: here the main, massive, unit is constituted by white pumices, lithic inclusions and a glassy matrix [7]; the thin Farnese Formation (maximum a few meters thick) consists of a non-welded, yellow to cream colored deposit characterized by the presence of a basal ash fall, surge levels and a 30 cm thick black palaeosoil at its top; the Sovana Formation comprehends two different pyroclastic flow units: the lower unit consists of a poorly coherent, light grey deposit of pumices, displaying leucite and sanidine phenocrysts, whereas a massive coherent deposit, made of a red-yellowish matrix containing large pumices, forms the upper unit; the Sorano Formation consists of two pyroclastic flow units, a lower ash deposit containing aligned white pumices and an upper pumice flow displaying fragments of sanidine, biotite and clinopyroxene crystals; the Grotte di Castro Formation (about 10 m thick) generally overlies the Sorano Formation and it is overlain by the Onano Formation; it displays a Plinian fall at its base, followed by compact lapilly rich layers and pyroclastic flow units. The Onano Formation, which forms the ground surface of the Pitigliano Formation, is constituted by two units displaying different lithological and depositional characteristics: a lower pyroclastic flow and

an upper sequence of airfall and pyroclastic surge deposits; and finally, the Pitigliano Formation represents the youngest deposit of the Latera volcanic sequence and it displays a complex sequence comprehending an airfall, a pumice deposit, a flow deposit, an ignimbrite strongly welded and a pyroclastic flow containing glassy matrix.

A more detailed description of these formations is reported in several papers, e.g., [6–9] and references therein.

The main volcanic edifice has been modified by post volcanic collapses that have formed two major calderas: the Bolsena and the Latera, whereas secondary volcanic edifices occur mainly in the southeast side of the Vulsinian edifice, around the area of Montefiascone [10], and now consist of some minor volcanic depressions.

Overall, we can distinguish two different morphological sectors: (i) the caldera depressions and (ii) the surrounding low-gradient slopes. These two sectors have been affected by a different morphological evolution as a response to their different geological and topographical features.

The Bolsena caldera depression is presently occupied by a lake about 12 km wide and 151 m deep, now mainly affected by depositional processes. The caldera ridge runs at an elevation between 500 and 650 m asl (average about 560 m asl) and consists of a ring of rounded hills internally bordered by steep slopes facing the inner lake.

The Latera caldera is only partially preserved and is presently occupied by a small lake, whereas lacustrine deposits testify the occurrence of an ancient larger lake (Figure 3). The area of interest for this study concerns the northwest side of this volcanic edifice and mainly the more external slopes, which as a whole form a gently dipping surface with a mean steepness of about 2%–3%. Currently, the peripheral slopes resemble a low-gradient homoclinal relief. This sector is cut by an almost parallel network of streams (Figures 1b and 3) that have carved deep valleys bordered by vertical walls, formed by pyroclastic rocks, often displaying the morphology of gorges.

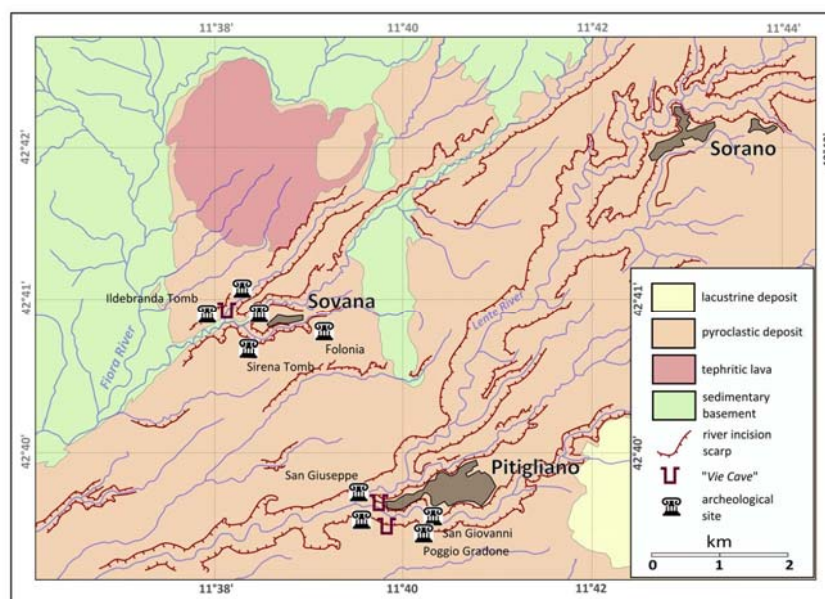


Figure 3. Geological and morphological sketch map of the Pitigliano-Sorano-Sovana area where most of the *Vie Cave* are located. Most of the main archaeological sites occur along the cliff of major river incision scarps.

The river network here has a parallel pattern because it was formed on a primary topographic surface with a regular gradient. Major deviations from this regular pattern are due to secondary cones formed on the flank of the volcanic edifice. Minor deviations are due to recent stream capture, often controlled by a post-volcanic tectonic activity [10,11].

The western slopes of the Latera volcanic edifice were strongly shaped by surface water erosion, which has incised the large, slightly inclined structural surfaces with narrow and deep valleys. The erosion was mainly linear due to the lithological nature of the formations and to the presence of major fracture systems. The incisions are bounded by steep slopes and real walls that locally assume a stepped geometry due to lateral selective erosion. This process is enhanced by the alternation of well-welded, pyroclastic flow with less coherent, pyroclastic fall. The valley bottom often has an alluvial nature and may have been formed by recent flooding phenomena as a result of the Holocene eustatic raising [5].

A structural control of lineament systems, which have guided the orientation of secondary streams and caused some piracy elbows, is evident in the evolution of the river valleys. Major lineaments have mainly NW-SE and NE-SW directions according to the Northern Apennine tectonic structures. In conclusion, the morphological evolution took place initially with linear erosion and deepening of the valleys and then through slope gravitational processes. In particular, gravitational collapses were the main active geomorphological process where water runs free on slopes or infiltrates and where rock masses are fractured or affected by foot erosion or selective alteration of underlying, less coherent horizons.

3. Historical Background of the Archaeological Site

The *Vie Cave* archaeological site is located in an area that had a particular development during the Prehistory, the Classical Age and later during the Middle Age; the importance of this area was mainly due to its position along the Fiora River, which has represented one of the most important natural routes from the northern Tyrrhenian coast inwards.

The area reached the maximum economic development at the end of the Bronze Age when the most significant settlements were Pitigliano (Figure 4a), Sovana and Sorano. Despite these centers having a good natural defense, they were abandoned at the beginning of the Iron Age when the population moved to the wide plateaus. During the ninth century BC, Pitigliano and Sovana rose again over the natural fortress represented by the plateau of pyroclastic rocks bordered by the steep walls carved by the left tributaries of the Fiora River; this location played an important role in controlling the river valley [12].

Pitigliano reached the greatest development during the seventh century and represented one of the most important centers of the area, while the Sovana center never achieved a great development. The sixth century BC saw the sudden decay of Pitigliano; at the end of the century and during the next one only Sovana survived, which reached its greatest splendor during the third and second centuries BC.



Figure 4. (a) View of Pitigliano town; (b) and (c) Typical aspects of the *Vie Cave*.

During the Roman period, the entire area underwent several transformations that led to a new territorial setting. Sovana probably survived until the Imperial age as testified by the pottery and oil lamp remains [13]. The most interesting aspect of the archaeological *facies* of the region is certainly made up of its large necropolises connected and crossed by the *Vie Cave* (Figure 4b,c). Pitigliano is surrounded by four major groups of necropolises (S. Giuseppe, Valle delle Fontanelle, S. Giovanni, and Gradone) [14]. Among the various necropolises, those of Sovana, where Canino, Farnese and Sovana Formations outcrop, are particularly important; they display hundreds of tombs, sculpted in the rocks, showing architectural design typical of the Hellenistic period (Figure 5a,b). The necropolises lie all around the plateau where the ancient village of Sovana was located. Some large isolated tombs were also carved on the hill slopes. The area of the necropolises extends across about two kilometers and shows an almost continuous sequence of *dado* and *semidado* tombs. Among these, there are some monumental tombs with colonnade and aedicule with decorated frontage (e.g., Demoni Alati and Ildebranda tombs, Figure 5a,c).



Figure 5. Some examples of funerary architecture in the area of Sovana: (a) Demoni Alati tomb, (b) Sirena tomb, and (c) Ildebranda tomb.

In this area, several *Vie Cave* connect the Pitigliano, Sorano and Sovana settlements with the rupestrian necropolises and other archaeological sites.

In particular, the Sovana necropolises are crossed by the *Via Cava* called *Cavone* and are easily accessible from the main road connecting Sovana to San Martino, on Fiora River. At about 200 m from the first sector of the necropolis, proceeding in the direction of Sovana, to the right, there is another area of the archaeological park, which leads to the *Via Cava* of San Sebastian and to the Sirena tomb (Figure 4c), which was recently repaired, after an important failure [15]. Different hypotheses, such as (a) channeling of rainwater from the plains to the valleys, (b) lines of communication, (c) strategic steps designed against enemies, or (d) ceremonial paths, have been made about the function of this road network [13].

4. Factors of Decay of the Archaeological Sites

After the abandonment of the necropolises, the tombs, no longer maintained, suffered decay processes, which also resulted in the loss of almost all of the polychrome coatings; simultaneously, rock falls and linear erosion affected the routes. At the same time, the parts close to the slopes were covered by debris and soil, which have allowed the growth of shrubs and trees directly above the architectural structures of the tombs. The protruding parts of the monuments, exposed to weathering agents, have been affected by instability. In this context, the surfaces of the underground monumental have been preserved better than those outside, which over time have suffered disruptions and collapses causing heavy modifications of the original architectural features. At the time of the archaeological excavation,

the structure of the tombs is again brought to sub aerial setting and starts changing in relation to the characteristics of the rocks and to external factors as geomorphological, geological, hydraulic and climatic conditions of the area where they are located.

4.1. Lithology and Decay

The *Vie Cave* area, with its necropolises, gorges and plateaus, displays peculiar lithological characteristics closely related to the volcanic origin of the rock formations. The tombs and the routes system have been really dug/carved in the rocky outcrops, thus are easily workable. The particular morphology of the reliefs is characterized by the presence of steep slopes suitable for the realization of sepulchral elevations and hypogeal settings that are easily accessible from the outside.

The stone surfaces of the main architectural elements were also partially protected from the atmospheric agents by the presence of polychrome decorations made of plaster or compact painted surfaces having low permeability.

The common characteristics of the rocks is to be easily dug, even with rudimentary tools, so that it was simple to create sepulchral area of considerable size and excavate entrenched routes. The *dado* tombs were generally dug into the more consistent lithotype (tuffs), while the hypogeal settings were dug in the more friable volcanic ashes.

Volcanic deposits (Figure 6a,b) cropping in the area have mineralogical, physical and textural characteristics influencing the conditions of stability of the structures. The rocks are characterized over all, by a high porosity (variable between 40%–60%) and a high saturation index (variable between 75%–95%) for the presence of zeolites and/or clay minerals having expandable lattice [16]; these characteristics determine an easy decay (e.g., Figure 6b) of the material.

In addition to the internal properties of the rock, it is necessary to take into account the external factors, as the variability of temperature and humidity affecting the artifacts. As a result, macroscopic forms of physical, chemical and biological decay are clearly visible on the surface of the *Vie Cave* rock walls and monuments [17].

The physical decay can be due to the freeze thaw cycles and to the presence of mineral phases such as zeolites. Indeed, inside the rock, the fluctuating temperatures and humidity can determine volume variations of these minerals and, consequently, the occurrence of tensions favoring the decohesion of the material. The decohesion is also favored by microfractures due to manufacture and to the particular textural characteristics of the material (the glass matrix containing the phenocrysts). The effect of the chemical decay is particularly evident where clay minerals with expandable lattice are present (e.g., smectite and chlorite-vermiculite), due to the action of water favoring hydrolysis processes. Moreover, the clay minerals can also determine physical alterations due to their particular chemical-crystallographic structure [14].

Furthermore, biological patinas (mosses and lichens) due to the environment humidity and to the porosity of the stone substrate play a relevant role on chemical and physical alteration. First the lichens develop physical action due to the contraction and extension of the thalli under varying humidity conditions; thereby lichens are able to detach the mineral grains of the substrate. The chemical weathering can be induced by the formation of carbonic acid and the consequent formation of oxalic acid, which contribute to the disintegration of the material. However, the biological patina, although is

often disruptive, may also have a protective function; in fact, it partially protects the rock from weathering and its removal would leave the material more disaggregate and more deteriorated. In addition, the fertility of the soils of volcanic origin facilitated the growth of higher plants, which caused great damage (mainly due to disintegration and fracturing) to the structures.

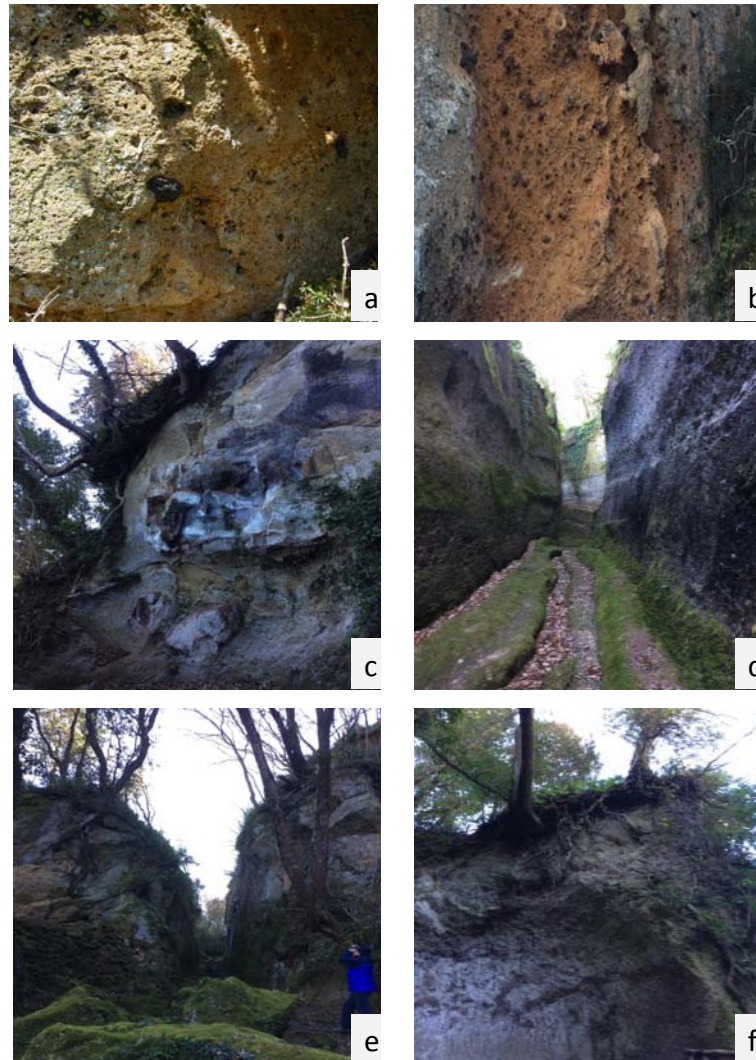


Figure 6. (a,b) Particulars of outcrops of volcanic deposits showing orange colored matrix, and black clasts of pumice; (c) welded grey volcanic deposits in a fractured wall of a *Via Cava*; (d) typical morphological features of a *Via Cava*; and (e) junction of a *Via Cava* with a cliff constituted of ignimbrites. The rock mass is unstable (see the boulders of an ancient fall). (f) Particular of an altered and unstable scarp with vegetal cover.

As a consequence, the *Vie Cave* material is highly interested by different decay processes determining instability phenomena, which can be distinguished in “recent” instabilities and old “reactivated” instabilities.

4.2. Hydrogeology and Slope Stability

Despite the high porosity, pyroclastic deposits have a very low primary permeability. Pores are often isolated and water can pass through them with difficulties. Furthermore, chemical alteration of volcanic ashes and scoriae produces clay minerals making the rock surfaces impervious to infiltration. Thus,

permeability is mainly due to fractures that are large enough to not be filled by clay minerals and soils. The archaeological sites have been monitored for a period of time, including both the dry and wet season. The presence of humidity in the hypogea setting is unavoidable and the cycles of condensation and evaporation are accompanied by the dissolution and crystallization of soluble salts.

Top flat surfaces are deeply weathered and soil mantle is thick. Vegetation is abundant and usually it consists of evergreen plants. Rainfall is mainly intercepted by leaves and low vegetation and ultimately by soil. Only during very intense storms the runoff is relevant and the *Vie Cave* often act as streams (Figure 6d).

Infiltration water is stored in open fractures and preserved for a long time. During the dry season (usually from June to October), rainfall is very scarce, so trees need to push their roots very deep along fractures to look for underground humidity. Conversely, where agricultural activity occurs, periodically (mainly in winter) there is no vegetation cover able to intercept rainfall and water flows on surface being minimally adsorbed by the terrain.

Along the rim of the plateaus, fractures are frequently opened up due to gravitational release, so running waters are captured and continue their flow underground. A belt of small occasional springs often occurs at the base of the external walls of the plateaus, usually where a lithological change exists, triggering selective erosion and instability phenomena.

The geotechnical properties of the pyroclastic deposits vary widely depending on the degree of cohesion of the rock and its fracturing. Therefore, it may have some levels of tuff with good mechanical properties making them an excellent building material, together with ash horizons displaying very low geotechnical characteristics.

The alteration phenomena are widespread in the rock walls of the natural slope. In addition to the phenomena of physical-mechanical decay along the fractures and the activation of cracking processes, situations of surface chipping and levels of fragmented rock are frequent, due to phenomena of alteration, disaggregation and exfoliation. These phenomena are clearly related to the lithological characteristics of the rocks (porosity, saturation index, cohesion, *etc.*) that vary even at sub-meter scale. In most cases there is a match between the processes of decay of the rupestrian monuments and those involving the geomorphological context and geotechnical dynamic of the slope where the water infiltration, the cycles of wetting/drying and vegetation play a key role in macroscopic alteration [16].

The wall monuments are dug in rock horizons showing the most suitable geotechnical properties and their architecture is clearly determined by the structural characteristics of the outcrops; the Etruscans have demonstrated a high skill in exploiting the natural characteristics of rock masses, but, nevertheless, there are various situations affected by decay or collapses [17].

A different case is that of the several *Vie Cave* that were made according to engineering criteria such access roads to urban settlements placed on summit flat. In this case the paths and cross-shape are more obliged and there are several cases where these excavations have affected areas where the geotechnical properties of the rock are poor. Furthermore, the need to follow zigzag paths, in order to make the gradient of the road gentler, leads the walls of the *Vie Cave* to cut with variable angles the main systems of fractures. Taking into account this problem, very critical areas subject to collapse, essentially through mechanisms of sliding and toppling, can be present.

4.3. Botanic Aspect

The Tuscan tuff plateau has been the subject of floristic studies of some importance only in recent times. In fact, if we exclude the first botanical paper of Santi [18] and the short notes of Pampanini [19] and Negri [20], only recently more detailed botanical studies have been published [21]. The studied area has a sub-Mediterranean climate with rainfall of *ca.* 900–1000 mm per year and average temperatures of 13–14 °C. This results in a forest vegetation mainly characterized by deciduous formations (e.g., Figures 6c,e,f and 7a–e), and subordinately by mixed forests of deciduous and sclerophyllous formations [22,23]. The most interesting floristic aspects can be found within gorges, because of their particular microclimate showing relatively cool temperatures and high humidity due to the thermal inversion and abundance of water, respectively. These conditions were able to preserve patches of beech thermophilic forest having a glacial-relict origin [20,23–27].

The main plant formations present in the study area can be summarized as follows:

- (a) Mesic deciduous forests in which it is possible to distinguish two different types, the first deals with the lower portions of the valley gorges and is characterized by *Carpinus betulus*, *Fagus sylvatica*, *Castanea sativa*, *Tilia platyphyllos*, *Ulmus glabra*, *Acer pseudoplatanus*, and *Corylus avellana*. The herbaceous layer is constituted by sciafilo-hydric species. The second type includes forests occupying higher positions on the slopes and in which prevails the *Quercus cerris*.
- (b) Deciduous thermophiles forests, which occupy the higher portions of the valley gorges; the dominant species are represented by *Quercus cerris* and *Quercus pubescens*, but *Ostrya carpinifolia*, *Fraxinus ornus*, and *Tilia cordata* are also present.
- (c) Mixed forests of deciduous and sclerophyllous trees located on the edge of the valley gorges; xeric and thermophilic formations are prevalent, in particular *Quercus ilex* (Figure 7d), which is typically associated with other species such as thermophilic *Acer monspessulanum*, *Quercus pubescens*, and *Fraxinus ornus*.
- (d) Shrubs (Figure 7f), which represent evolutionary stages of abandoned pastures or occupy the edges of meadows, woods and cultivated lands. They are also found in ruderal environments. The composition is related to the different microclimate or soil conditions. Typical species are constituted by *Cornus sanguinea*, *Spartium junceum*, *Cytisus scoparius*, *Prunus spinosa*, *Crataegus monogyna*, and *Erica arborea*.
- (e) Lawns, which mainly occupy flat areas and can be distinguished in different types, depending on the need of water and soil. The most common type consists of pastures subject to mowing and displaying as typical species those belonging to the class *Molinio-Arrhenatheretea* and *Festuco-Brometea*.

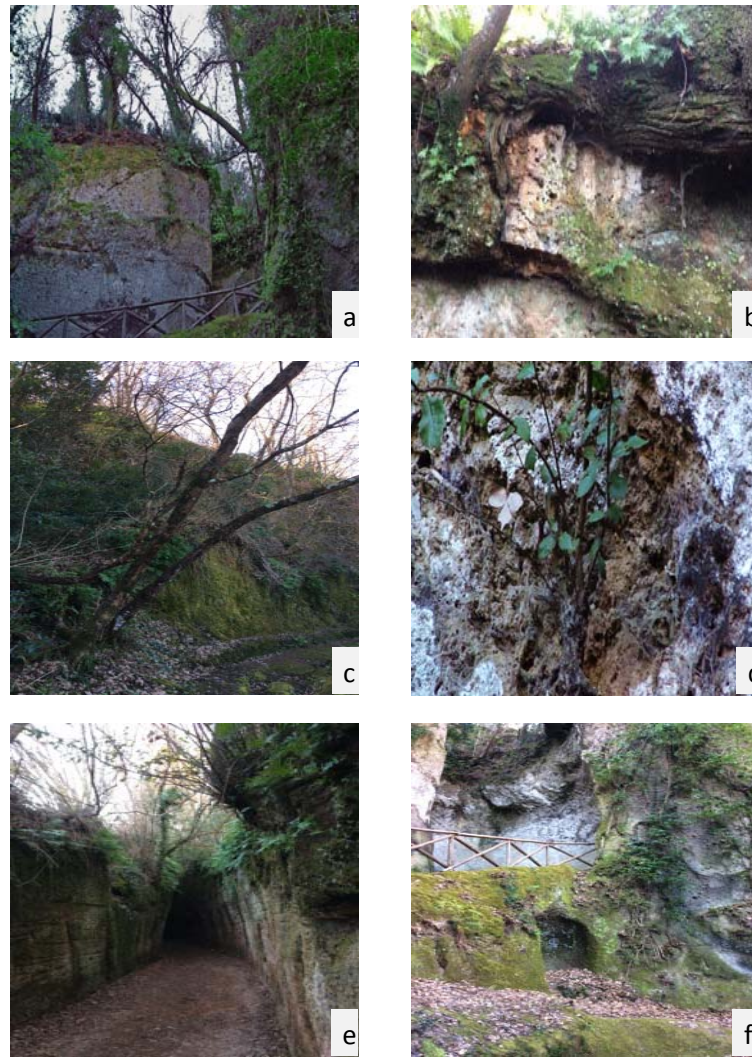


Figure 7. Relationship between vegetation and *Vie Cave* rock walls. (a,c,e) different develop positions of trees and (f) of shrubs; (b) particular jointed root in rock mass; and (d) *Quercus Ilex* growing in a fracture of the rock wall.

Some of the vegetal formations identified in the study area, have been included in habitat lists in order to protect their peculiar characteristics (Directives 92/43 and 97/62 EEC, and 56/200 LR Tuscany). In particular, *Rupicolous calcareous* or basophilic grasslands of the *Alysso-Sedion albi* and *Tilio-Acerion* are considered priorities even though the most valuable formations from the ecological and floristic point of view are the beech forests found at these low altitude ravines [21,28]. As a consequence, the plant community “Sorano and Pitigliano tuffaceous gorges” has been preliminarily proposed and transposed in the archive of the Project 5bios/Re.Na.To. Tuscany Region.

5. Discussion

5.1. Risk Factors of the Geomorphological Site

The studied area represents an *in situ* monumental complex, characterized by a set of structures built in volcanic lithologies and placed in a particular geo-morphological context. Among these, the numerous

Etruscan necropolises located in southern Tuscany area of *Vie Cave* and directly related to the geolithological characteristics of the territory, are particularly relevant.

The intervention planned for the preservation must be carried out trying to prevent decay processes responsible for the erosion of the roads, archaeological monuments and walls surface and for the detachment from the walls of large block tuffs due to the action of plant roots and to the accumulation of ground at the limit of the side walls. Therefore it must be excluded a conservation involving sporadic extraordinary interventions realized directly on the surface of the stone, but a planned maintenance taking into account the risks related to the environmental context.

Considering specifically the various causes of decay of the monuments in the archaeological area, and the connecting routes, such aspects were examined after a detailed analysis and observation of the individual emergencies. The synthesis of the data collected has provided the possibility to identify the main forms of decay in the area of *Vie Cave* and to elaborate some targeted actions related to the preservation of the territory. The processing of all collected data made it possible to identify groups of risk factors affecting the conservation status of the area.

- (1) Overrunning vegetation with development of biological patina, biological colonization, biological disintegration, fracturing, detachment, efflorescence, film and swelling. These forms of decay are predisposing to landslides.
- (2) Erosion, disintegration, lack, incrustation, alveolarization, differential weathering, detachment, surface deposits, crusts, horizons of capillary rise, and presence of water. These forms of weathering can induce instability.
- (3) Instability due to deficiencies in water regulation of surface runoff.
- (4) Active instabilities with the need for specific interventions.
- (5) Structures buried or partially buried deserving of being made accessible.
- (6) Structures with presence of water for lack of drainage works.

5.2. The Actions Planned for the Preservation

The measures we propose after considering the risk factors to which the studied area is subjected are based on intervention of “naturalistic engineering” favoring conservation.

First of all, the realization of a “security zone” along the route of the *Vie Cave* has to be highlighted. Removing the tree plants located on the edges, which represent the major causes of the collapses affecting the vertical walls of the most entrenched paths, would prevent the action of disintegration and fracturing of the tuffs. Several studies have been carried out on the building damages caused by trees (e.g., [29]); in particular, many of these deal with the damage suffered by monuments in hypogeal archaeological sites from the roots of trees [30,31] and strategies for the control of invasive plants [32,33].

In the study area, detachments of materials from the tuffaceous walls are often observed; they are partly due to the presence of trees growing in the immediate proximity of the edges and, more rarely, directly on the walls; cracks and detachments of more or less substantial portions of material are caused by the roots often intruding the walls or by of the collapse of trees located on the edge of the walls.

Therefore, it is necessary to define an intervention program for the management of the vegetation. In order to choose the most suitable technique, it must take into account the heterogeneity displayed by slopes and soils. With regard to the tuffaceous walls, the main problems to be addressed are: (a) their

disaggregation due to the root action and (b) the erosion due to the action of rainwater, wind and temperature fluctuations. In order to reduce the wall degradation, we propose to cut down all the trees within a range of 4–5 m from the edge of the *Vie Cave* walls. The removal of the stumps would be advisable even with the difficulty of access by mechanical equipment, such as stump-gridding machines, and the related cost makes it almost impracticable. Furthermore, it would be recommended to remove suckers from the stumps periodically (once a year). In addition, the application of systemic herbicides, such as glyphosate, on the cut surface, may be undertaken immediately after cutting in order to reduce the recurrence of suckers. On large stumps, herbicide should be applied just inside the bark where the living tissue is located [34,35]. Finally, periodic cleaning operations of the liana (*Hedera helix*), climbing (e.g., *Clematis clematis*) and sarmentose (e.g., *Rubus ulmifolius*) plants, which often tend to cover the walls, should also be considered.

Regarding the problem of rainfall, the canalization of water in the peripheral regions above the walls is necessary in order to prevent the rainwater to be collected into the *Vie Cave*: the runoff on the surface of the walls erodes them and causes deposit of debris at the foot. In order to achieve an effective control of rainwater, it would be necessary to make an efficient canalization. In particular, it could prove to recover old but effective hydraulic works, now largely degraded for prolonged lack of maintenance.

The study of adequate drainage, without affecting the low cohesion deposits (volcanic ashes) and the implantation of herbs and shrubs that limit erosion and promote the stability of the walls, can give a significant contribution to the conservation of these highly suggestive pathways. Only in cases of high instability of the rock blocks, remedial measures using bolts, anchors (not visible) and drain holes can be designed.

Finally, the stabilization of the sides of the *Vie Cave* should not be made using wires (Figure 8a,b) as it has been done to date but rather by considering, and trying to limit, the causes that determine the failure.



Figure 8. Protection measures used to control rock falls in archaeological sites: (a) cable strands and mesh and (b) particular of mesh blanket.

6. Conclusions

The *Vie Cave* area represents a really peculiar and high-value site, both from the archaeological and geomorphological point of view. Actually, necropolises, isolated tombs, ancient villages and minor human settlement are deeply integrated with the natural features of this particular landscape and often the limits between geological objects and anthropic structures are really indefinite.

Decay of architectural and funerary monuments directly dug into the rock substrate is mainly a consequence of natural processes, such as stream lateral erosion and slope stability processes, and the modification of natural profiles of slopes has often modified the static equilibrium of bedrock. On the contrary, the use of the territory by humans has probably had a minor role in an area that has experienced mainly agricultural employment for almost 3000 years.

The World Monument Found in 2004 promoted the “*Vie Cave*” of Pitigliano, Sorano and Sovana as assets of global interest to be protected and this is an important recognition and an incentive to take actions to protect this unique heritage.

In conclusion, the preservation of this important site and of its millenarian historical remains can be achieved only through a “holistic” approach, which has to take into account all the environmental components, either natural or anthropic, according to a long-term project of territorial management.

Author Contributions

The authors Elena Pecchioni, Alba Patrizia Santo, Leonardo Piccini, Luciano Di Fazio and Carlo Alberto Garzonio contributed equally to this work (fieldwork, data discussion, figure preparation and writing the text). The paper is also based on the data obtained by the authors Fabio Fratini, Pasquino Pallecchi and Riccardo Trevisan. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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