

GEOMORPHOLOGICAL EVOLUTION IN A HIGHLY DYNAMIC CONTEXT AS A KEY FACTOR IN CULTURAL HERITAGE: THE CASE OF CIVITA DI BAGNOREGIO (CENTRAL ITALY)

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EXTENDED ABSTRACT

Civita di Bagnoregio e la circostante “valle dei calanchi” (con tale appellativo sono note le contigue valli del Rio Torbido e del Fosso di Lubriano/Rigo/di Bagnoregio in destra della Media Valle del F. Tevere) costituiscono un’area di incantevole fascino paesaggistico con peculiari caratteristiche geomorfologiche e geologico-stratigrafiche. L’assetto geologico è rappresentato da una successione di depositi piroclastici del Pleistocene medio, costituenti una placca rigida, che ricopre sedimenti argilloso-limosi di origine marina del Pleistocene inferiore, soggetti ad intensa deformazione ed erosione. L’azione della gravità e degli agenti esogeni in questo particolare contesto geomorfologico (una “mesa” circondata da ripidi pendii) determina il verificarsi di diversi fenomeni di instabilità, che nel tempo hanno modellato l’aspetto peculiare della rupe, portando al suo progressivo restringimento. Il particolare assetto del rilievo collinare, bordato da alte scarpate e versanti molto acclivi, ha costituito un fattore propizio per l’insediamento dell’uomo grazie alla facile difendibilità. In passato la rupe era in continuità morfologica verso ovest con l’entroterra (dove oggi si trova il ponte di accesso al borgo), ma negli ultimi secoli tale area è stata rapidamente rimodellata dai movimenti franosi. La vita delle diverse comunità insediate sulla sommità della rupe che si sono succedute nel tempo (i frammenti di manufatti più antichi rinvenuti sono stati riferiti al Bronzo Recente), è sempre stata quindi intimamente legata alle caratteristiche geomorfologiche e geologiche del sito, che ne hanno condizionato in modo profondo, costante e anche drammatico, la quotidianità.

Dalla fine degli anni ‘80, l’area di Civita di Bagnoregio è oggetto di numerose campagne di studio e di interventi per la stabilizzazione delle aree più a rischio. Oggi la vita nel borgo è radicalmente diversa dal passato: la comunità contadina che strenuamente resisteva ad un territorio ostico e mutevole, grazie ad un’interazione consapevole, ha lasciato il posto a un insediamento a vocazione esclusivamente turistica, con centinaia di migliaia di visitatori all’anno. Le particolari caratteristiche geomorfologiche del territorio, per la profonda e incessante dipendenza da esse che ha condizionato la vita degli abitanti della rupe dalla Protostoria al XX secolo, appaiono quindi costituire il fattore alla base dell’identità, della memoria e della storia (il “patrimonio culturale”) delle comunità insediate sulla rupe. La tutela del “patrimonio geomorfologico” in un tale contesto appare pertanto costituire il primo e fondamentale passo per la conservazione del patrimonio culturale della “comunità di Civita”. Il particolare dinamismo dei processi di instabilità richiede metodi di studio e approcci ai problemi specifici appositamente elaborati e messi in atto nell’ambito di una strategia di pianificazione a lungo termine. Uno studio geomorfologico su una ampia scala temporale costituisce un indispensabile contributo per un’analisi dettagliata del territorio, sulla base della quale è possibile indirizzare lo sviluppo delle strategie più efficaci e risolutive per la tutela dell’area. Il presente studio è stato realizzato grazie alla borsa di studio “The Cultural Landscape of Civita di Bagnoregio” concessa dal The Civita Institute nel 2023 (<https://www.civitainstitute.org/4463/the-cultural-landscape-of-civita-di-bagnoregio-fellowship.html>). La missione del The Civita Institute (con sede a Seattle, USA) è quella di ispirare e promuovere una comprensione interdisciplinare delle qualità uniche dei borghi rupestri (*hilltowns*) italiani attraverso la promozione della tutela storica e culturale, lo studio e la divulgazione, la creazione artistica e lo scambio culturale (<https://www.civitainstitute.org>).

ABSTRACT

The paper illustrates the 2024-geomorphological setting of the Civita di Bagnoregio area (Central Italy, Lazio region), defined on geomorphological survey, drone footage examination and bibliographic data analysis. It also emphasizes how the peculiar and enchanting geomorphological features of this area (the ‘geomorphological heritage’) has deeply conditioned the lives of the inhabitants from Protohistory to the 20th century, therefore appearing to constitute the primary shaping factor of the identity, memory, and history (the ‘cultural heritage’) of the communities settled on the cliff through time.

KEYWORDS: *Civita di Bagnoregio cliff, Central Italy, Lazio region, cultural heritage, landslides, geomorphological evolution, geomorphological heritage.*

INTRODUCTION

The ‘geomorphological heritage’ (CORATZA & HOBLÉA, 2018 and references within) in Civita di Bagnoregio (Central Italy, Lazio region; Fig. 1, Fig. 2) has deeply influenced the spatial and behavioural adaptation strategies of the inhabitants to the challenging and unstable territory in order to ensure survival, thereby primarily contributing to the development of local cultural identity (ATTILI, 2020 and references within). In particular, geomorphological processes have constantly, and even dramatically, shaped not only the physical landscape but also the life of the established communities on the cliff from Protohistory (the oldest artifact fragments date back to the Recent Bronze Age; SCHIAPPARELLI, 2008) to the 20th century. It is imperative to highlight how, for a long time, the farming community played an indispensable role of territorial safeguard through a daily work of land maintaining, a role that was irretrievably lost with the gradual depopulation of the village and the consequent abandonment of the countryside, as admirably described in ATTILI (2020): “...*Il borgo di Civita, che svetta fiero in cima alla sua rupe, sarebbe oggi solo un cumulo di detriti in assenza di una comunità operosa capace di costruire e preservare il proprio spazio di vita ... Si tratta di un’operosità incessante e minuta, volta a cicatrizzare le ferite di una terra fragile...*” (“...*The town of Civita, soaring proudly atop its cliff, would today be just a pile of debris in the absence of an industrious community capable of building and preserving its living space ... This is a ceaseless and minute industriousness, aimed at healing the wounds of a fragile land...*”).

The geomorphological setting of the hill, characterised by steep slopes and high escarpments (condition induced by the presence of the volcanic caprock; SCHEIDEGGER, 1961), has historically offered favourable conditions for human settlement thanks to its easy defensibility. However, the multiple types of landslides (in terms of movement mechanisms, speed, materials

involved, evolution over time, etc.), have had, and continues to have, a deeply negative effect on the human presence. Moreover in the past, a morphological continuity with the hinterland to the west (where the bridge is located today) was present, but in recent centuries this area has been rapidly reshaped by instability phenomena becoming a deep saddle.

Nowadays, life in the village is radically different from the past: the farming community that strenuously resisted a difficult and changeable territory, living thanks to a conscious interaction with it for a very long time, has given way to a settlement exclusively tourism-dedicated, with hundreds of thousands of visitors per year (ATTILI, 2018, 2020).

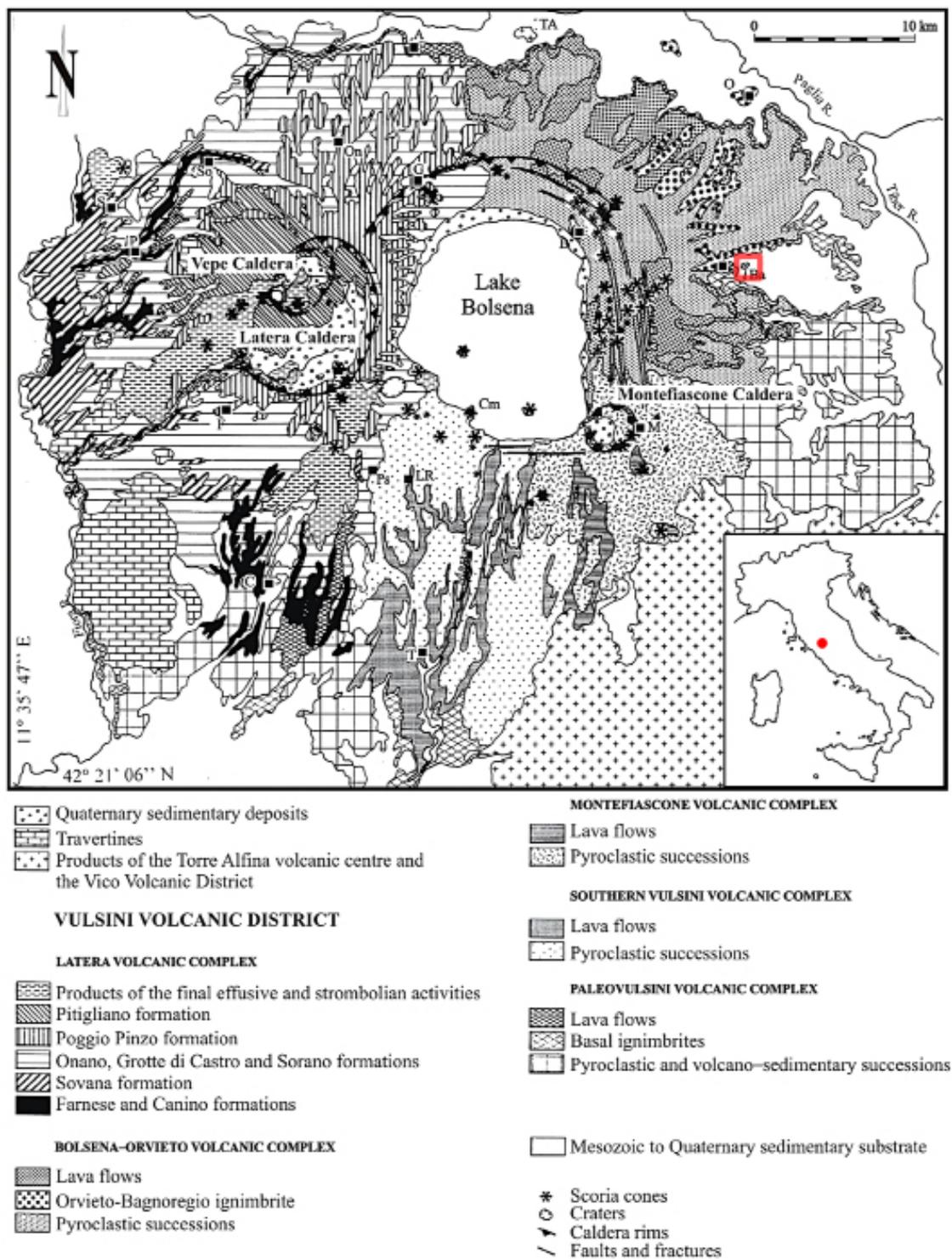
The protection of the ‘geomorphological heritage’ (BUSSARD *et alii*, 2025) in such a peculiar area subject to intense geomorphological dynamics, therefore appears to be the first and fundamental step to preserve the ‘cultural heritage’ of the multimillennial ‘Civita community’. The intense geomorphological dynamism of the territory and the complex interactions between the instability processes require specific approaches to define them as part of a long-term planning strategy. An accurate geomorphological study, conducted not only in the present but over a sufficiently long-time scale, represents an indispensable contribution to a precise and detailed analysis of the territory, on the basis of which it would be possible to address the development of the most effective strategies for the preservation of this area.

GEOLOGICAL FEATURES OF THE STUDY AREA

The Civita di Bagnoregio cliff is made of various Middle Pleistocene pyroclastic deposits of Vulsini Volcanic District (VVD) (SERVIZIO GEOLOGICO D’ITALIA, 1970; BERTINI *et alii*, 1971; NAPPI *et alii*, 1982; MANCINI *et alii*, 2003-2004; PALLADINO *et alii*, 2010; NAPPI *et alii*, 2022) overlaying silty clays and clayey silts of marine origin deposited on the seabed of the Tyrrhenian Sea between the Pliocene and the Lower Pleistocene (MANCINI *et alii*, 2003-2004; FREZZA *et alii*, 2005) (Fig. 2).

The marine deposits are grey to light bluish colored, predominantly massive, locally poorly bedded and with intercalations of turbidite sands (Fig. 3): these deposits are referred to the ‘Chiani-Tevere formation’ (Chiani-Farfa Synthem), ‘sandy clays of marine environment’ unit in MANCINI *et alii*, 2003-2004 and ‘Castello Ramici member’ in NAPPI *et alii*, 2022. The Chiani-Farfa Synthem is representative of a sedimentary cycle between the Gelasian (Pliocene) and the basal Emilian (Lower Pleistocene) (MANCINI *et alii*, 2003-2004; BALDANZA *et alii*, 2011; BIZZARRI & BALDANZA, 2020). Deposits of marine origin in the Civita di Bagnoregio area have a maximum thickness in outcrop slightly lower than 200 meters, having a Santernian age and being referable to a depositional environment between the circalittoral and the transition to the infralittoral (DI BELLA, 1995; DI BELLA *et alii*, 2000-2002; FREZZA *et alii*, 2005).

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Towns and other localities: A=Acquapendente, B=Bolsena, Ba=Bagnoregio, C=Canino, F=Farnese, G=Grotte di Castro, M=Montefiascone, O=Orvieto, P=Pitigliano, S=Sovana, So=Sorano, T=Tuscania, TA=Torre Alfina, Cm=Capodimonte, LR=La Rocchetta, Ps=Piansano.

Fig. 1 - Geological sketch map of the Vulsini Volcanic District (modified after PALLADINO et alii, 2010), showing the location of the study area



Fig. 2 - Panoramic view of the northern side of the Civita di Bagnoregio cliff

After being raised up to several hundred meters due to volcano-tectonic activity, the marine deposits were covered by pyroclastic deposits erupted from two of the five Volcanic Complexes of the VVD: Paleovulsini and Bolsena-Orvieto (PALLADINO *et alii*, 2010 and references within). The volcanoes were active in the area of the present Bolsena Lake, whose depression originated from the collapse occurred in the late phase of volcanic activity (ACOCELLA *et alii*, 2012). According to a wide geochronological and geo-volcanological data-set, the Vulsini volcanic activity spanned the ~590-111 ka time interval (PALLADINO *et alii*, 2010; MARRA *et alii*, 2019, 2020; references within), with a broad spectrum of eruptive styles, intensities and magnitudes (BERTINI *et alii*, 1971; SPARKS, 1975; NAPPI & MARINI, 1986; NAPPI *et alii*, 1994, 1995, 1998; MATTIOLI & NAPPI, 1999; PALLADINO *et alii*, 2010, 2014, 2016, 2024; PALLADINO & PETTINI, 2020 and references within).

The top of the Civita di Bagnoregio relief is made up of the lithoid tuff of the 'Orvieto-Bagnoregio ignimbrite' (OBI) (333±4 ka; NAPPI *et alii*, 1995) (Bolsena-Orvieto Volcanic Complex) (Fig. 4): a massive ashy ignimbrite with variable thickness, mainly cemented by matrix zeolitization, bearing from scarce to abundant heterometric dark scoria, small pumices, small crystals of analcimized leucite and microliths. Volcanological and depositional features of the OBI are well studied (NAPPI *et alii*, 1982, 1994, 1995; CAPACCIONI & SAROCCHI, 1996; PECCERILLO, 2012; GENTILI *et alii*, 2014; PALLADINO & PETTINI, 2020 and references within), as well as its geotechnical and seismic ones (IACURTO & PRIORI 1995; ENEA, 2001; ROTONDA *et alii*, 2002; TOMMASI *et alii*, 2013A, 2013B; VERRUCCI *et alii*, 2015; CERCATO *et alii*, 2020, 2025; BOLDINI *et alii*, 2025 and references within). The top of the OBI unit is slightly inclined eastward and it is widely reshaped by the anthropic activity related to the urban settlement evolution; the base of the deposit is instead strictly dependent on the paleomorphology (top of the underlying stratified pyroclastic deposits) that has conditioned the thickness of the sequence.

Underlying the ignimbrite there is a thick and highly stratified pyroclastic succession ('Gruppo di Civita di Bagnoregio' in NAPPI *et alii*, 2022) composed of mainly decimetric alternating layers of tephra and tufa: scoriae, pumices, lapilli, from fine to coarse variously compact ashes, and probably some re-worked horizons (Paleovulsini and Bolsena-Orvieto volcanic complexes). Some layers are separated by paleosols and erosive surfaces; others have loading deformations. Age ranges from 589±8 ka (BARBERI *et alii*, 1994) / 576±6 ka (NAPPI *et alii*, 1995) to 352±4 ka ('Ponticello' marker eruption; NAPPI *et alii*, 1995). In the lower part of the stratified pyroclastic succession, two successive paleosols constitutes a single brown layer of about 2 meters-thickness (DI BUDUO *et alii*, 2024) and are interposed between the oldest banks of Paleovulsini pumices and the pyroclastic flow deposits known as 'Nenfri' (505±6 ka, NAPPI *et alii*, 1995). In the western sector of the cliff the layers have an eastward dip with gradually decreasing inclination eastward from a maximum of about 25°-30° (bridge abutment, anti-dip slope) to become sub-horizontal in the central sector. In the eastern sector of the cliff, the lower part of the stratified pyroclastic succession has a light westward dip direction.



Fig. 3 - Panoramic view of the eastern side of the Civita di Bagnoregio area, with the typical 'calanchi' (badlands) on the clay-silt deposit of marine origin (Pliocene - Lower Pleistocene)



Fig. 4 - Panoramic view of the southern side of the Civita di Bagnoregio cliff: 'Orvieto-Bagnoregio ignimbrite' (OBI) at the top of the relief, overlying a highly stratified pyroclastic succession (Middle Pleistocene)



Fig. 5 - The reduction of the urban area Civita di Bagnoregio caused by landslides, on the basis of historical information: a) position of major landslides in the last 6 centuries; b) building destroyed between 1695 and 1829; c) building destroyed between 1829 and 1869; d) building destroyed after 1869; ?) uncertain date. B: St. Bonaventura native home (consecrated as a church in the XVI century). V: St. Vittoria church; P: St. Peter church (redrawn after: RAMACCI, 1974; MARGOTTINI & SERAFINI, 1990; SCIOTTI *et alii*, 1997). Base: current cadastral map; graphic scale

GEOMORPHOLOGICAL FEATURES OF THE STUDY AREA

The area of Civita di Bagnoregio is characterized by a peculiar morphological arrangement due to the geological features (pyroclastic deposits overlaying clayey-silty marine sediments with high contrast of erodibility) and to the variety of geomorphological processes that have occurred over time. First and foremost, the activity of the drainage network with Rio Torbido River on the south side and Cireneo ditch and Lubriano/Rigo/Bagnoregio ditch on the northern one which deepened the slopes and isolated the mesa on which Civita stands, separating it from the volcanic plateau. Afterwards, the action of gravity and water runoff and their profound interaction with slope-river dynamics causes various complex instability phenomena, which over time have shaped the enchanting appearance of the cliff (constituting a ‘mesa’, with a progressive narrowing; Fig. 2, Fig. 4, Fig. 5) and of the surrounding area (the so-called ‘badlands valley’; Fig. 3). However, it should be noted that the same conditions that generate natural hazards have become an outstanding aesthetic value also enriched by notable biodiversity features (DI BUDUO *et alii*, 2015).

After the raising of the area (upper Lower Pleistocene) with the consequent emersion of the marine deposits and the westward retreat of the sea, the great climatic variations during the Middle

and Upper Pleistocene (LISIECKI & RAYMO, 2005 and references within) intensely conditioned the geomorphological dynamics, with the alternation of erosion and alluvial phases that were chronologically and physically interposed to the volcanic and tectonic activities. Along the north and east margins of the VVD, erosion has in fact partially or totally isolated small reliefs on which man has settled even since the Bronze Age (DI GENNARO, 1986; SCHIAPPARELLI, 2008; RIVA, 2010), witnessing a deep and constant connection between landforms (and their conservations over time) and human settlement, such as to lead to the use of ‘anthropogenic mesas’ term (MARGOTTINI *et alii*, 2017). These small reliefs are distributed in Tuscany, Umbria and Lazio, with numerous urban centers designated as the ‘tuff towns’, e.g. Pitigliano, Sovana, Sorano, Orvieto, Porano, Bagnoregio, Lubriano, Castiglione in Teverina, Civitella D’Agliano *etc.*

The geomorphological evolution in the area of Civita di Bagnoregio is expressed by complex interacting phenomena that can ascribed to:

- the features of the geological deposits (which also influence the hydrogeological setting);
- the uplift and tectonic displacement of large areas that occurred particularly from about 330 ka (MARRA *et alii*, 2019 and references within);

- the intense deepening of the valleys that occurred during the last glacial period (last glacial maximum around 26-19ka; CLARK *et alii*, 2009 and references within);
- the probable presence in this area of tectonic discontinuities of undefined kinematics with various orientations referable to neotectonic lineaments (BARBERI *et alii*, 1994; DI FILIPPO *et alii*, 1999; CIOTOLI *et alii*, 2003; MANCINI *et alii*, 2003-2004; DELMONTE *et alii*, 2014; MARRA *et alii*, 2019).

Since the end of 1980s, the area of Civita di Bagnoregio has been investigated in order to study the cliff evolution, to characterize geological deposits, to define the slope instability phenomena and geological hazards, and to carry out interventions to stabilize the areas with the higher values of risk (LATTANZI & POLCI, 1988; MARGOTTINI & SERAFINI, 1990; NAPOLEONI, 1991; IACURTO & PRIORI 1995; SCIOTTI *et alii*, 1997; ENEA, 2001; DELMONACO *et alii*, 2004, 2008, 2009; GARBIN *et alii*, 2013; GISOTTI & MARGOTTINI, 2017; CERCATO *et alii*, 2020, 2025; DONATI *et alii*, 2022; BOLDINI *et alii*, 2025; LEMAIRE *et alii*, 2025; MARGOTTINI *et alii*, 2025; BIANCHINI *et alii*, 2025).

The marine clay-silt sediments underlying the pyroclastic deposits are subject to an intense slope dynamic, although they are under a certain depth in overconsolidation conditions due to stress unloading following marine emergence and erosion (a reduction in thickness of about 150 meters has been estimated at Orvieto by BOZZANO *et alii*, 2008). Along the surface these deposits are subject to swelling, resulting in alteration of the microstructure and degradation of the mechanical features of deformability and resistance. From a rheological point of view close to the topographic surface, the over-consolidated pelitic deposits (stiff clays) tend to acquire the behaviour of normal consolidated deposits (softened clays, NAPOLEONI, 1991; DELMONACO *et alii*, 2004; GARBIN *et alii*, 2013 and references within). A similar situation is in Orvieto (Umbria region), where the layer of softened clays plays a crucial role in the gravitational evolution of the cliff (BOZZANO *et alii*, 2008 and references within).

The tuffaceous plate is affected by two types of stress, which together contribute to its morphological evolution over time, as occurs in other similar situations (AGNESI *et alii*, 1978; CECERE & LEMBO FAZIO 1986; CANUTI *et alii*, 1990; SCIARRA & CALISTA, 2001; BOZZANO *et alii*, 2005, 2013; DONATI *et alii*, 2024, and references within) (Fig. 6):

- stress release, that is lateral stress induced by erosion that leads to the progressive cutting of the scarps;
- stress relief, acting on the entire rock mass, induced by the deformation of the underlying marine deposits, more deformable (elasto-plastic behaviour) than the pyroclastic soft rocks.

So, the deformation of the marine clay-silt deposits amplifies the disarticulation of the overlying tuffaceous mass, that takes place gradually with the progressive opening of extensional fractures variously oriented.

The following factors also act negatively, resulting in the widening and propagation of fractures (Fig. 6):

- water infiltration (resulting in the chemical and physical weathering of the surfaces along the discontinuities with the consequent reduction of the shear strength of the mass),
- thermoclastism,
- cryoclastism,
- the action of plant roots.

Moreover, the presence of poorly permeable intervals in the stratified pyroclastic deposits (cineritic layers) may result in the saturation of some sectors of the mass rock in an unpredictable extent and time, with more or less negative local effects on stability. In the OBI unit some fractures may have occurred just after the deposition of the pyroclastic flow because of cooling contraction. The OBI unit is characterized by an extensive and complex network of hypogea on several levels, also expanded and/or modified over time, witnessing more than two thousand years of underground use of the tuff (DI BUDUO *et alii*, 2017). In these cavities, persistent discontinuities in inner part of the relief are visible, leading to suppose the possible occurrence of active global deformations of the cliff most likely due to:

- the intense deformation and erosion of the marine deposits at the base of the cliff perimeter (which has a very limited north-south extension), resulting in the opening of extensional fractures throughout the rock mass;
- a mechanism of lateral spreading, typical of morphological situations with high energy of relief in which a rigid cluster rests on deformable deposits (CRUDEN & VARNES, 1996; BOZZANO *et alii*, 2013 and references within).

At the foot of the slopes there is also the erosive action made mainly by the streams in the north of Civita (Cireneo ditch and Lubriano/Rigo/Bagnoregio ditch).

In addition, the southern slope of the Lubriano cliff (north of Civita) was affected by a large landslide with a multi-temporal reactivation style (BOZZANO *et alii*, 2012), which significantly diverted the ditch toward the Civita cliff, accelerating the instability of the north-eastern slope. The last significant reactivation dates back to 1114 (MARGOTTINI & SERAFINI, 1990).

In relation to the above-mentioned processes, the types of landslides occurring in the Civita di Bagnoregio area are the following.

Along the non-stabilized sectors of the cliff's edge:

- rock falls (common),
- topples (less common),
- detachment of rock fragments (very common).

On the clayey slopes:

- solifluction and soil creep (very common);
- mudflows (very common and characterized by small thickness, frequent repetition and evolution in widening and retrogradation);
- translational slides (less common);

- rotational slides of larger and deeper portions of the slope (infrequent);
- complex landslides, in which at least two types of movements occur in sequence (VARNES, 1978; CRUDEN & VARNES, 1996; HUNGR *et alii*, 2014; CRUDEN & LAN, 2015; *e.g.* a rock fall that evolves in a mudflow-debris rich, less common).

The stratigraphic and orographic setting of the valleys around Civita di Bagnoregio has led over time to a marked tendency for the development of badlands or ‘calanchi’ in Italian language (ALEXANDER, 1980; MORETTI & RODOLFI, 2000; DELMONTE, 2017; references within). These features are well evident especially on the south side of the watershed between Rio Torbido River (south) and Lubriano/Rigo/Bagnoregio ditch (north). On the south-facing slopes the most frequent cycles of sun exposure lead to greater and faster dehydration of clays and to a consequent increase in surface erosion susceptibility (DELLA SETA *et alii*, 2009; DELMONTE, 2017) (Fig. 3). Noticeable slope steepness favours diffuse mudflows, which strongly contribute to the removal of considerable volumes of sediment (DELLA SETA *et alii*, 2009). In the area of Civita di Bagnoregio geochemical and geomorphological inquiries have shown that the river drainage network of Rio Torbido is strongly influenced by regional neotectonic lineaments, and the aspect of the basin areas have structural conditioning (BARBERI *et alii*, 1994; DI FILIPPO *et alii*, 1999; CIOTOLI *et alii*, 2003; MANCINI *et alii*, 2003-2004; DELMONTE *et alii*, 2014; MARRA *et alii*, 2019).

A strong river streams deepening has occurred in consequence of sea-level lowstands (*i.e.* during the last glacial maximum; CLARK *et alii*, 2009; HANEETH *et alii*, 2009) and volcanotectonic uplift during the Middle Pleistocene (MARRA *et alii*, 2019 and references within).

METHODOLOGY

Analysis of the bibliographic resources

A bibliographic analysis was conducted on the extensive body of scientific literature concerning the study area, produced since the late 1980s (references in the previous paragraphs). In addition, the geomorphological study of the different sectors of Civita di Bagnoregio slopes has been also conducted with the abundant documentation collected between 2012 and 2022 as Conservator and Curator of the Geological and Landslides Museum based in the town (MARGOTTINI & DI BUDUO, 2017; 2022), enabling the reconstruction of the instability phenomena evolution in recent years.

Geomorphological survey

The geomorphological survey was conducted at a 1:1.000 scale, enabling high-resolution mapping of surface morphologies and process-related features. The survey focused on the recognition and classification of landforms, with particular attention to slope deformation features, types of mass movements, and their current state of activity. In open and accessible areas, landforms were directly observed and interpreted in the field, allowing for detailed

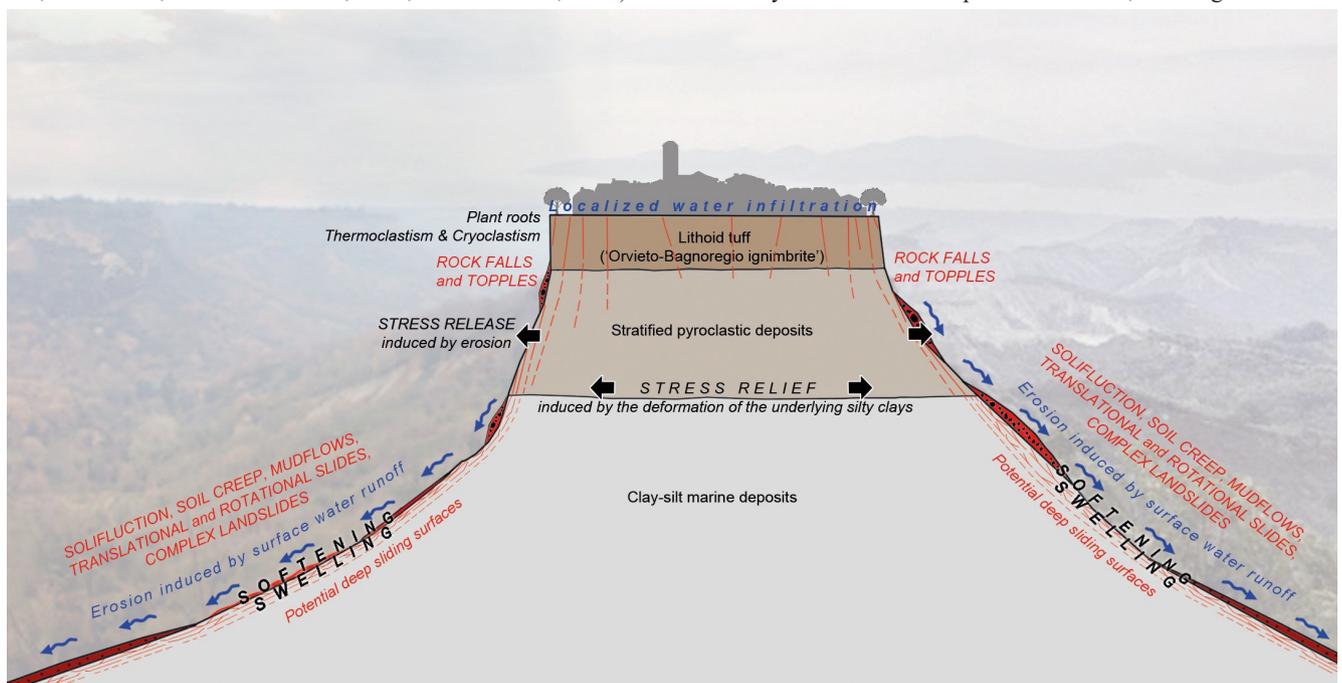


Fig. 6 - Schematic model of instability phenomena and landslide movements on the Civita di Bagnoregio relief (details in the text). The morphological and phenomenological differences between the slopes are not represented in the image

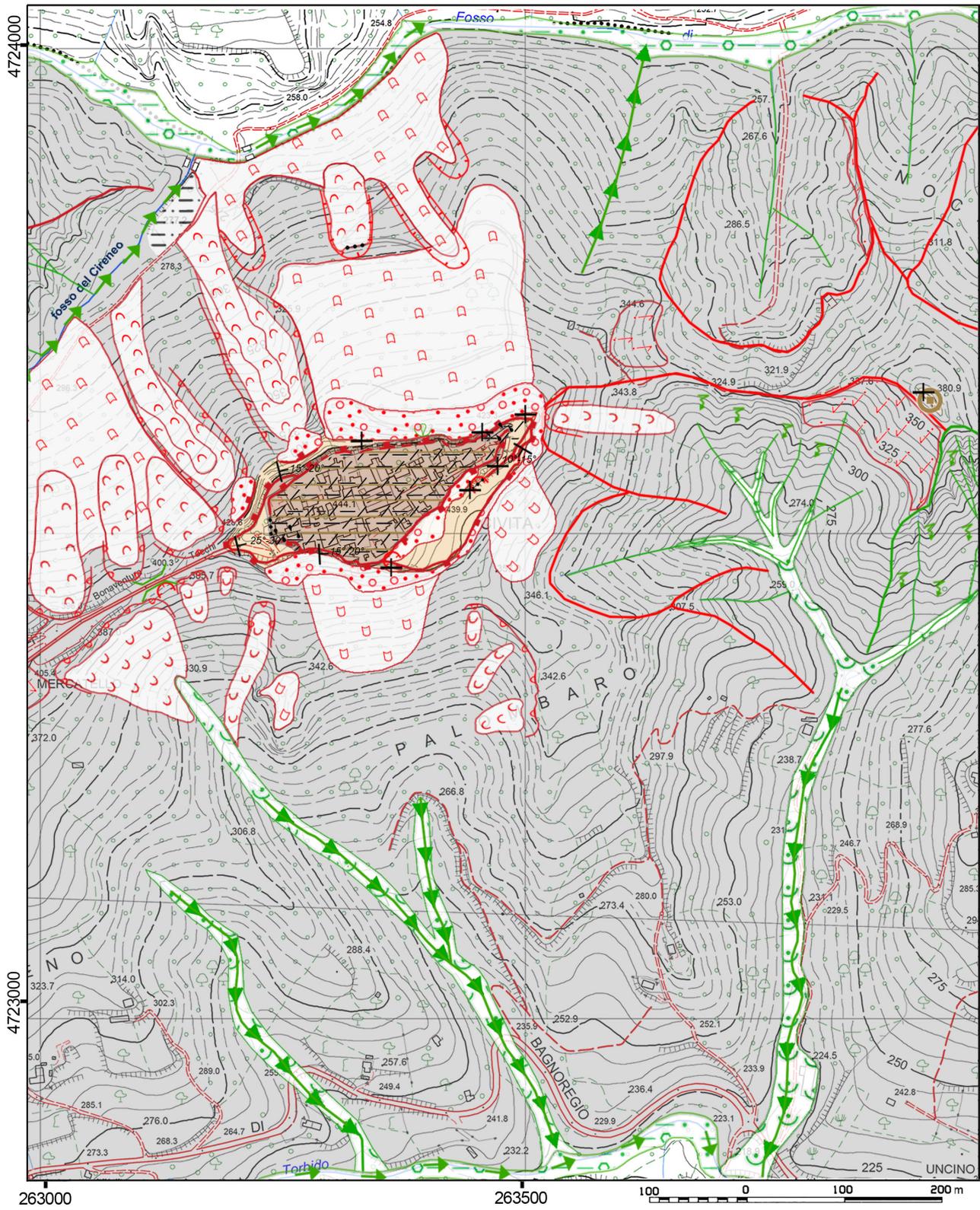


Fig. 7 - Geomorphological map

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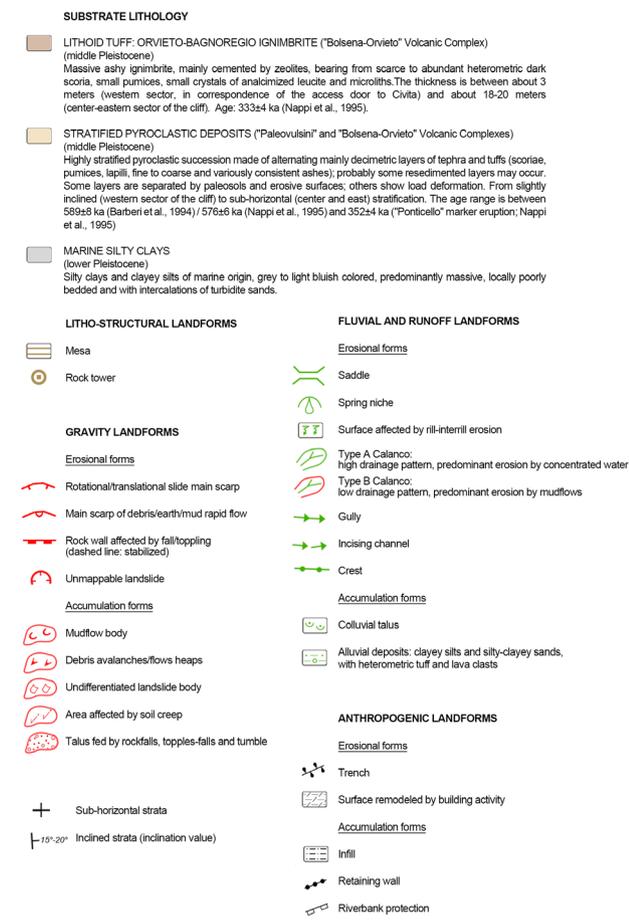
geomorphological classification. In contrast, several sectors of the study area are densely vegetated or inaccessible due to steep slopes and highly rough topography.

Drone footage analysis

The geomorphological study benefited from the analysis of drone footage made on 16th and 17th February, 2024 by the dronists team of the Red Cross - Bagnoregio Local Committee thanks to the Memo of Understanding regarding support for cultural and study activities between the Municipality of Bagnoregio and The Civita Institute.

GEOMORPHOLOGICAL MAP

The data collected from the bibliographic resources analysis, the geomorphological survey and the drone footage examination resulted in a geomorphological map (Fig. 7, Fig. 8), produced according to the Part I of the Geological Survey of Italy guidelines on the Geomorphological Map of Italy at a scale of 1:50,000 (CAMPOBASSO *et alii*, 2021).



Topographical base map: Technical-Numerical Regional Map (CTRN), scale 1:5.000, Lazio Region, 2014.

Fig. 8 - Legend of the geomorphological map

DISCUSSION

Bridge area

The fast erosion of the saddle between the 'Belvedere' of Bagnoregio and the Civita di Bagnoregio relief in the last centuries is well documented in the acts of the Municipality (LATTANZI & POLCI, 1988; MARGOTTINI & SERAFINI, 1990); in the last 4 centuries this area has undergone a progressive dismantling up to 40 meters thick (Fig. 9). The old pathway to Civita was replaced by the first bridge at the end of the 1920s, later damaged by instability phenomena and by the Germans during the retreat during the Second World War (Fig. 10). The current one replaced the first, following a remodelling of the area and it was inaugurated in 1965; its stability has been ensured for so long by the foundation poles (25 meters deep; "The Civita Bridge, 60 years of an icon" exhibition, Palazzo Alemanni, Civita di Bagnoregio, 2025-2026). The rapid evolution of this area could be related to the thinner cover of volcanic deposits along the western sector due to the dip direction of the stratified succession. The erosive action of the Cireneo ditch at the base of the north slope may also have contributed to the geomorphological evolution of the saddle. Over time measures were taken to stabilize the water stream, which now have structural lesions or are partially covered by stream deposits.

Between the 1980s and the 1990s in the north side of the saddle a wide stabilization project was realized consisting of: two rows of 11 contrasting concrete anchored structures, 16 meters long each; drainage channels and trenches (Fig. 11). On the upper part anti-erosive meshes were installed, but they did not resist to following rainfalls (Fig. 11b): so, in this area several mudflows are active and clearly in retrogradation as can be inferred from the photos of the last 10 years and from recent cracks in the parking lot above. On the upper part of the slope there is also locally visible evidence of soil creep.

In the south slope of the saddle several stabilization works were made between 2013 and 2014:

- in the lower part of the slope two bored pile walls to prevent deep movements (with overlying gabions against superficial movements);
- along the slope a drainage network with naturalistic engineering works, severely damaged by rainfalls just after installation;
- in the upper part a reinforced anti-erosion mat and quincunx bored piles (12 meters-deep?) connected by a concrete capping beam, on which the parking lot wall rests. On both sides the parking lot paving has fractures attributable to crown cracks or simply to underground deformation.

At present the slope ground surface is widely subject to deformation and erosion closely related to the rainfall regime, with active widespread solifluction and mudflows (with crowns in fast retrogradation) (Fig. 12).

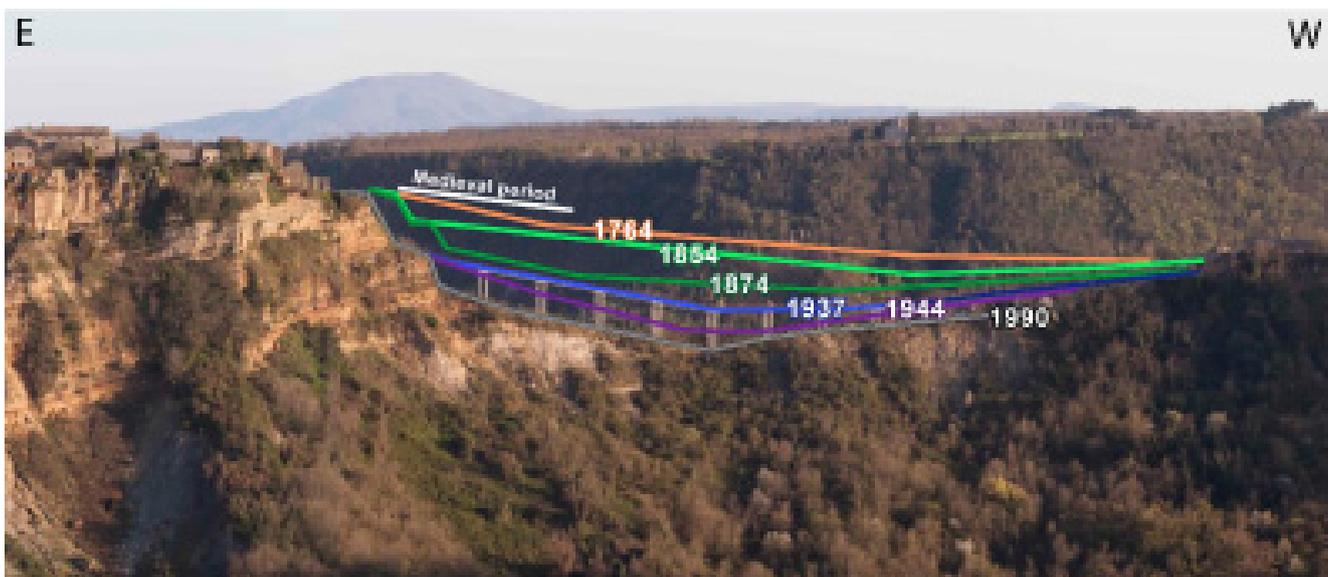


Fig. 9 - Evolution of the saddle between Bagnoregio and Civita (from MARGOTTINI, 1990; redrawn)

North-west side of the hill

In this area it seems that wide instability movements are cyclically reactivated (probably several decades), as evidenced by some photos dating back to the 1950s and the presence of low-trunk vegetation until 2014. As a matter of fact, in November 2014 there were several rock falls from the escarpment, and in March 03, 2015 the rock debris was involved in a large landslide (probably a mudflow rich in debris), followed on its right side by a smaller translational slide (Fig. 13). The debris avalanche was probably induced by the weight of the rock debris and the heavy rains of the previous months. In the following years the instability phenomena have continued with sheet erosion on the surface of rupture and several small mudflows. The deformation of the marine clay-silt deposits has led to the fractures' propagation along the escarpment with the dislocation of heterogeneous prisms (Fig. 14).

Cavon Grande (north-west side of the hill)

This area has undergone a quick evolution in the last decades, as evidenced by the succession of photos in Fig. 15: in 1967 it looked like a 'calanco', but later the retrogradation of the slope movements in the marine clay-silt deposits led to the involvement of the cliff with several rock collapses between the 1990s and 2000 and with following debris flows and avalanches. Near the crown of the rockfalls area a stabilization system was made around 2000, consisting of passive and active anchors (nails and bolts) connected to 7 structural wells dug in the ignimbrite for a depth of about 16 meters, behind a long fracture in the cliff that in a few years led to the collapse of a part of so-called Greco house (Fig. 16). At present, rockfalls in the lower part of the scarp, mudflows and debris flows and avalanches are active.

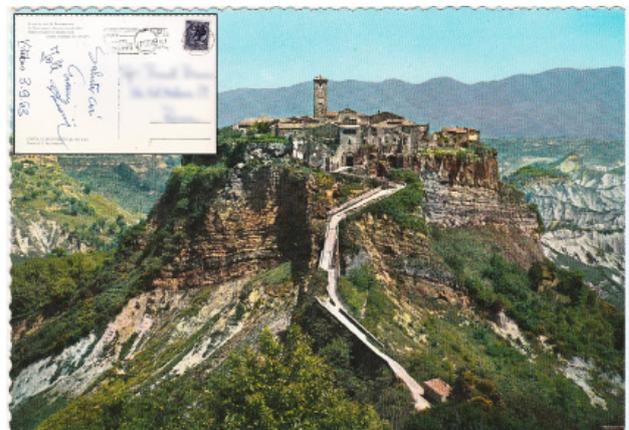


Fig. 10 - Color photo of the first bridge and also a precious personal memento of the first bridge to Civita: a postcard sent to my aunt on September 3, 1963 by my father together with his mother and his maternal grandfather

North-east side of the hill

In the upper part of the north-east side of Civita di Bagnoregio a wide chestnut grove lay on a layer of debris at the base of the escarpment, ensuring better stability of this area than the neighbouring ones. The pyroclastic debris is highly heterometric, deriving from rock falls, topples and detachment of fragments and blocks over time. In the OBI unit, from the north end of the tunnel to the structural wells area of Greco house, rock anchorages were made a few years ago. The rest of the escarpment to the east is intensely fractured. Recently, a restoration and extension of the path from the valley floor to the Civita di Bagnoregio tunnel has been carried out as follows:

- a rain water drainage system has been made from the path side to the Lubriano/Rigo ditch downstream of the ford;

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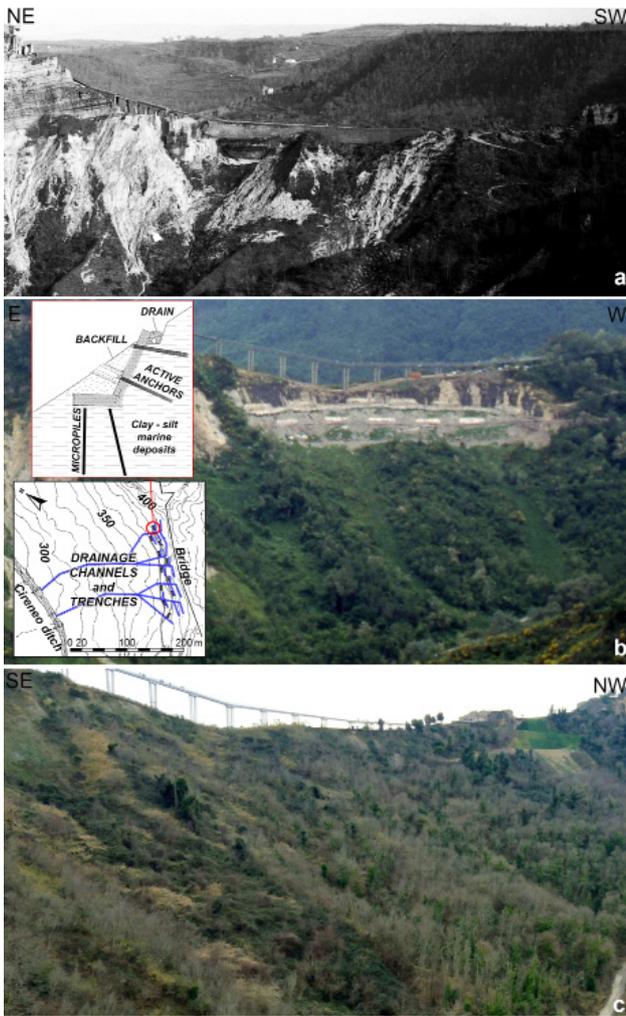


Fig. 11 - North side of the bridge. a) Morphological situation between 1945 and the early 1960s (ICCD - Archivio Gabinetto Fotografico Nazionale / Fondo Raffaelli, Armoni e Moretti / Ditta Raffaelli, Armoni e Moretti / inv. n. E087839; <https://fotografia.cultura.gov.it/iccd/item/E087839>). b) Stabilization works (March 1991; courtesy of prof. Quintilio Napoleoni), with the plan of the interventions and the section of the typical wall (NAPOLEONI, 1991; redrawn). c) The current appearance (2024)

- works of natural engineering have been performed in areas with active landslide, partly deformed or damaged by slope movements and runoff erosion.

The most inclined part of the slope is the lower one (below the chestnut grove); here the active phenomena (soil creep, solifluction, mudflows) seem they could have an evolution in widening and retrogradation (Fig. 17).

South-east side of the hill

A large part of the southeastern sector of Civita di Bagnoregio (Contrada Carcere) collapsed during the strong earthquake of 1695 (<https://storing.ingv.it/cfti/cfti4/quakes/01199.html#>).



Fig. 12 - Active solifluction and mudflows in the bridge area. a) South and north and slopes, 2015. b) South slope, 2024: undermining of anti-erosion mat is evident



Fig. 13 - Landslides on the north-west side of the hill: a) November 2014, rock fall; b) March 03, 2015, wide mudflow with a smaller translational slide (evolved in a mudflow) on its right side

At present in the mass rock there are several families of discontinuities: the fractures are mainly vertical, very persistent and open, with a slight undulation, defining heterometric rock prisms potentially subject to falling/toppling and detachment of single blocks (MARGOTTINI, 2017; FRANCONI *et alii*, 2024) (Fig. 18). Such phenomena have also occurred recently, leading in 2012 and 2023 to the interruption of the pathway. The presence of hypogea at different heights in the scarp has probably a negative effect on the stability of mass rock. The eastern end of the cliff is very thin and intensely fractured.

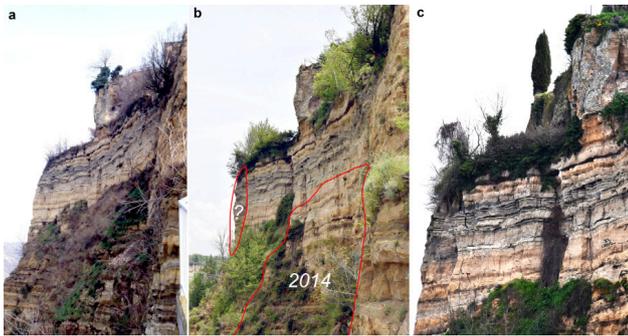


Fig. 14 - Evolution of the escarpment on the north-west side of the hill. a) 1991 (courtesy of prof. Quintilio Napoleoni). b) 2019: in red the areas of detachment of recent rockfalls. c) 2024. From 1991 to 2024 the increase in the mass rock fracturing and the growth of vegetation are evident

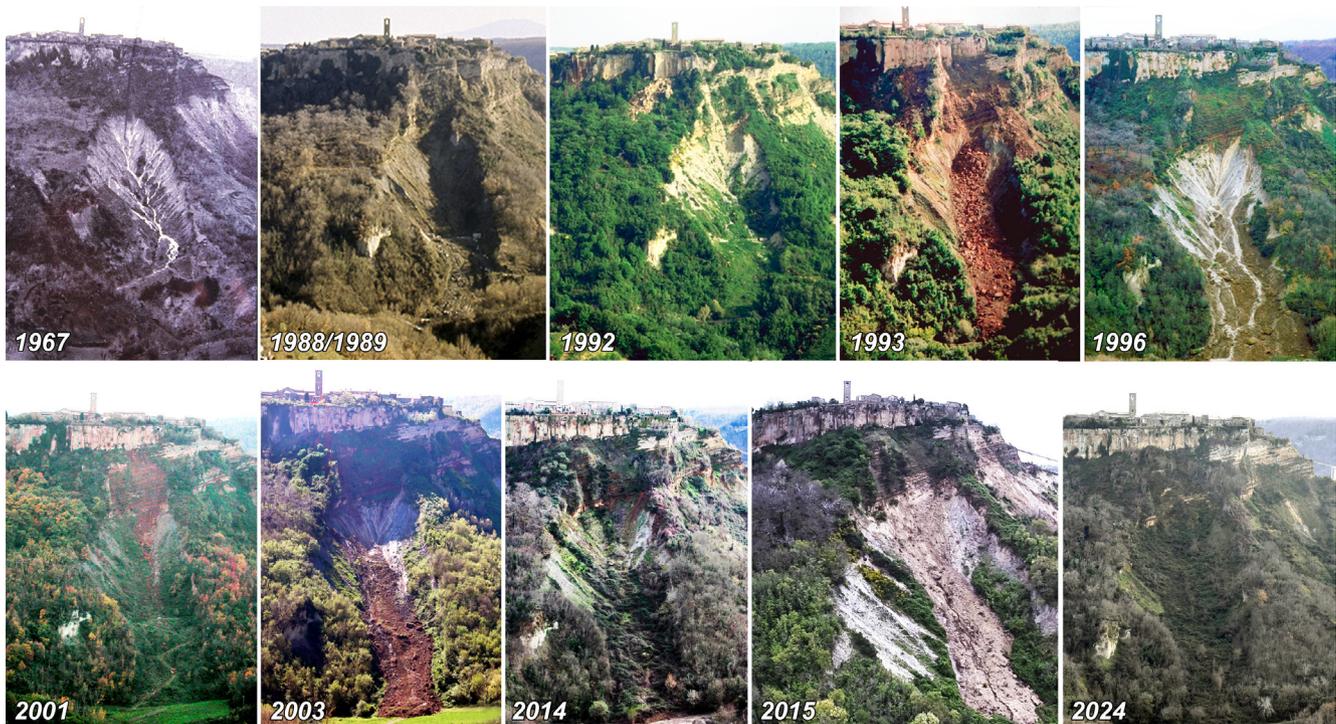


Fig. 15 - Evolution of the "cavon grande" form from 1967 to 2024 (MARGOTTINI & DI BUDUO, 2017; modified)

At the southeastern base some mudflows and debris flows are active with frequency dependent on the rainfall regime.

Tunnel (east side of the hill)

According to local verbal reports the tunnel crossing the cliff in a north-south direction was made about a hundred years ago by widening an ancient (probably Etruscan or Roman) underground water conduit that channelled rainwater to the south side of the town. The straight sign of the ancient vault and two small side conduits are still visible. The tunnel is dug into the top of the stratified pyroclastic deposits fairly compact and stable (except the end parts of the tunnel on the slopes).

Site of St. Bonaventura native house remains (south side of the hill)

St. Bonaventura is the most illustrious and famous person born in Civita (1217/1221 – Lyons, France, 1274, 15 July): he was a philosopher, theologian, Franciscan Order minister, bishop and the most important biographer of St. Francis of Assisi. Dante Alighieri meets St. Bonaventura (together with St. Tommaso D'Aquino) in the 12th Canto of Paradiso among the wise spirits of the 4th Cielo. About three hundred years after his birth, part of the house was transformed into a church dedicated to him, of which little is known. Since the strong earthquake of 1695 the native house of St. Bonaventura was damaged several times by rockfalls until it was abandoned in ruins in 1826: currently there are few stones in the northeast corner of the building and a part of the basement.

Recently there's been a further small rockfall probably due to the action of tree roots (Fig. 19).

'Ponticelli' (east of the town)

'Ponticelli' is a very thin, really high and unusual clay ridge, on which the Civita di Bagnoregio inhabitants used to walk on until the 1960s, using it as a shortcut to reach some areas in the Rio Torbido valley, before erosion prevented definitively the passage (Fig. 20). This uncommon place shows in an enchanting and dramatic way the quick geomorphological dynamic of this area.

Its unique morphology could have anthropogenic and/or

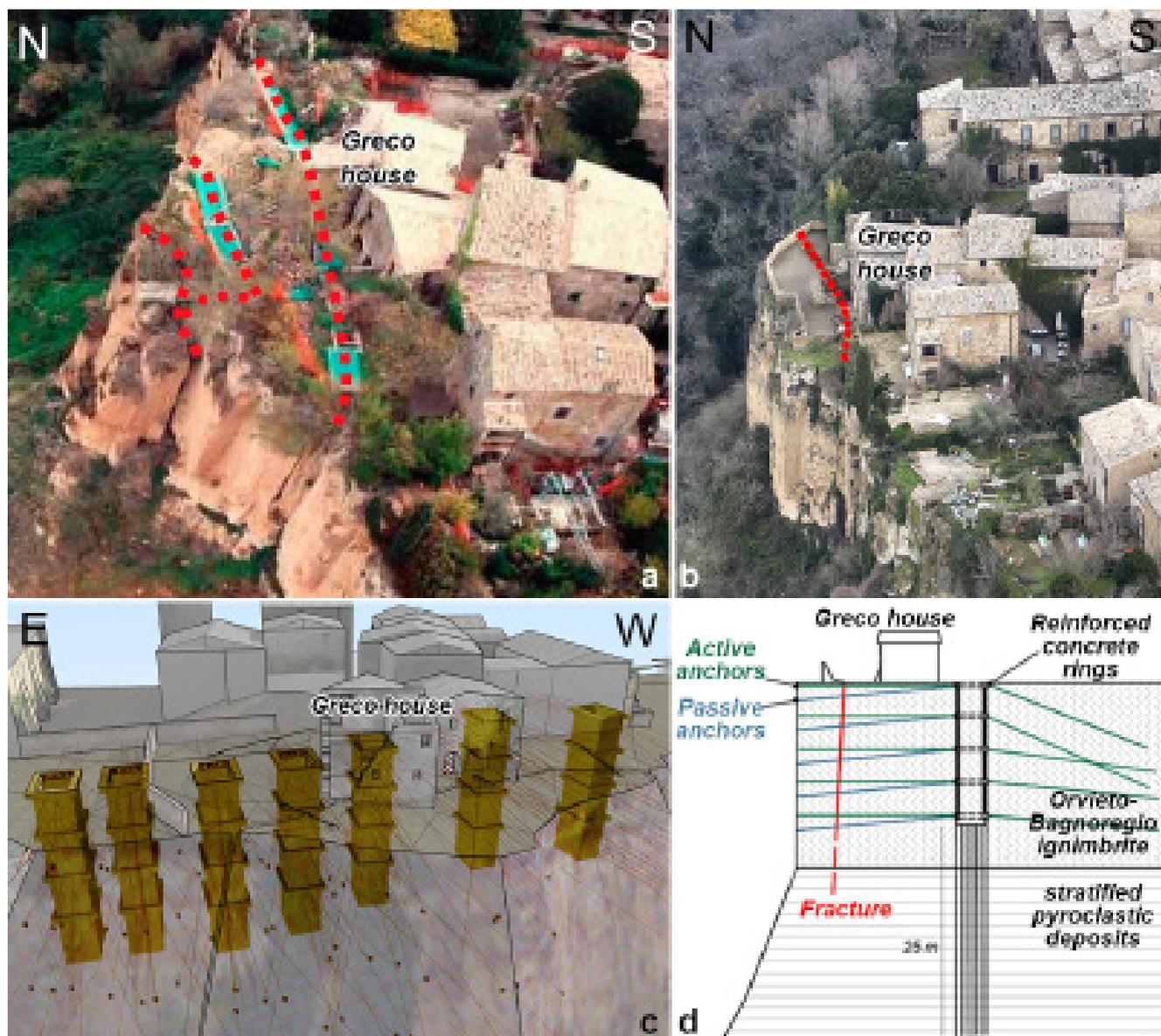


Fig. 16 - Stabilization work made around 2000 in the north side of the hill. a) Fractures in the “cavon grande” crown area, a few before the structural wells were built (DELMONACO et alii, 2008). b) Present situation (some blocks of rock were scaled during the works). c) Perspective view of the 7 structural wells (Museo Geologico e delle Frane, Civita di Bagnoregio). d) Schematic section of the structural well of Casa Greco (from DELMONACO et alii, 2004; redrawn and modified)

structural origins. Two hypotheses in fact could be formulated to explain its peculiar characteristics:

- the protection provided for a long (undefined) time by rigid structures on the path (wooden poles);
- the presence of a fault, along which waters rich in calcium carbonate (derived from the calcareous pre-Pliocene substrate) mixed with the pelitic deposits, may have created a thin rigid structure.

Further historical, structural, and compositional investigations should be carried out to understand the ‘Ponticelli’ origin.

CONCLUSIONS

The present study has led to the definition of the current geomorphological situation of the Civita di Bagnoregio area. A key problem that affected the study was the abundance of vegetation, which hindered the execution of the landforms survey. Anyway, it is evident - and well known - that on the clayey slopes spontaneous vegetation offers a good protection against surface erosion, making the surface part of clay-silt deposits less unstable. When vegetation and soil are removed (naturally or artificially), the pelitic deposits are exposed to weathering and the softening



Fig. 17 - Landslide occurred in 2013 on the north side of Civita (probably a translational slide evolved in a mudflow) (a: 2012; b: 2013)



Fig. 18 - Escarpment at the top of the south-east side of the hill: some families of vertical discontinuities and variously dislocated rock prisms are evident

and swelling processes go deeper, with a consequent decrease in shear strength. For this reason, the first important step in preventing erosion on the clayey-silty part of the slopes is to preserve soil integrity and vegetation cover. The other factors, besides gravity,



Fig. 19 - East side of the native house of St. Bonaventure remains: a small rockfall probably due to the action of tree roots. a) 2015, July 13. b) 2015, July 27



Fig. 20 - The ' Ponticelli' clay ridge east of Civita, with the last wooden planks of the ancient path

that clearly appear to play a primary role as predisposing factors and triggering causes of instability are runoff on slopes and deformation of pelitic deposits at the base of escarpments.

At a general level, in order to find long-term solutions to instability processes, the measures to be taken must be properly calibrated with the intense and complex dynamics of the slopes. Basically, it would be reasonable to program interventions considering the different situations on the whole slope and preventing landslides in addition to stabilize them, thus optimizing the financial commitment. This would only be possible with the complete and constant geomorphological analysis and instrumental monitoring of the area where this is necessary. The instrumental monitoring should involve at the same time all the main elements of the 'slope-system', each with different characteristics and stress-strain behaviour:

- surface part of the clay slope subject to softening, erosion and faster deformation;

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- clay deposits subject to swelling down to a certain depth;
- stratified pyroclastic deposits on the escarpments;
- human structures (buildings, roads, walls, etc.).

A committee of experts should plan geotechnical investigations and monitoring, analyse the instruments data, and constantly update the geomorphological map, in order to identify and quantify the slopes dynamics for an appropriate program of technical actions to be taken over time (a dynamic study and intervention strategy for a geomorphological dynamic area). It would be also very useful to create an accessible database with analyses, studies, surveys and monitoring carried out in the past.

In essence, the interventions that appear to be most important are:

- preserve soil integrity and spontaneous vegetation cover;
- a proper regulation of rainwater (and wastewater) in order to avoid the infiltration in the mass rock and the flowing on the clayey slopes (the places in the rivers where water is channelled must be properly identified and stabilized);
- prevent as much as possible the deformation of the silty clay deposits at the base of the scarps.

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