The Corviano Cliff Natural Monument (VT): an interdisciplinary approach aimed at its valorisation

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Short Note

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ABSTRACT

LiDAR technology, utilising UAV-mounted sensors or mobile devices such as the iPhone Pro, represents the most precise method for documenting archaeological heritage and enhancing data analysis and GIS-based management in conjunction with geological, geomorphological, and geostructural surveys. A multidisciplinary approach was applied to the Corviano Natural Monument (Viterbo Province), a plateau formed by pyroclastic deposits from the Cimino-Vicano volcanic district. The site, defensible due to its geomorphological features, has been inhabited since ancient times. The area includes a castle, church, necropolis, and rock-cut cavities, many modified over time. Erosional processes have undermined the volcanic deposits, leading to collapses and toppling landslides that have shaped steep tuffaceous cliffs. These cliffs are characterised by a dense network of joints, where exogenous processes and plant root systems have further widened the gaps. Structural surveys focus on these features, and ongoing collapses jeopardise the stability of the cliffs and anthropogenic cavities.

KEYWORD: UAV Lidar, Iphone Lidar, Corviano (VT), underground cavities, archeological heritage.

INTRODUCTION

The Corviano Natural Monument (Figs. 1A, B) lies on a section of the extensive plateau formed by the emplacement of pyroclastic deposits from the Cimino-Vicano volcanic district. The study area spans approximately 72 hectares and falls within the municipality of Soriano Nel Cimino (VT). The Corviano cliff, on which the eponymous necropolis is located, has been the site of human settlements since prehistoric times, likely due to its natural defensibility, as it is protected on three sides by steep walls shaped by the fluvial incision processes, which offered strategic advantages and natural barriers against potential attackers. During the Roman era, the area was traversed via publica Ferentiensis, a branch via Cassia that facilitated trade with the Tiber Valley. The cliff is bordered to the west by the Cannarecchi Stream, to the northwest by the Vezza River, and to the east by the Martelluzzo Stream. Corviano was located on the border between Byzantine and Lombard territories in the early Middle Ages, so its natural defences on the southern side were further enhanced by a double defensive wall and a moat that protected the medieval castle. The castle was abandoned in the late 13th or early 14th century following the conflicts between the Municipality of Viterbo and the Orsini family (Romagnoli, 2006). Beneath the castle, however, the remains of Etruscan walls and segments of megalithic walls visible in the Paraccia area attest to even earlier defensive structures. Over the millennia, human activity has contributed, to varying degrees, to the shaping of the cliff's topography, mainly through excavating anthropogenic cavities along the cliff walls. These cavities, which are the focus of this study due to their instability issues, are accessible via small stairways or short inclined planes. They sometimes extend into two or three spacious chambers, receiving air and light through large openings carved into the steep exterior wall. Archaeological analyses are currently underway at the site, conducted by a research group from the

University of Tuscia. These have been integrated with a Unmanned Aerial Vehicle (UAV) LiDAR survey of the entire plateau. The study is further complemented by detailed geological, geomorphological, and structural mapping, UAV photogrammetric surveys, and a topographic survey of the hypogean cavities using an iPhone Lidar system. Understanding the ongoing instability processes affecting both the edges of the cliff and the anthropogenic cavities located along its margins is essential for informing and guiding future interventions aimed at stabilising the Corviano cliff. This short note presents an interdisciplinary synthesis aimed at providing an integrated overview of both the archaeological significance of the site and the current instability issues affecting it. While not intended as an exhaustive treatment of each aspect, the study serves as a framework for understanding the complex interplay between cultural heritage and geotechnical risk. Specific technical aspects related to structural instability and conservation will be addressed in dedicated, more specialised contributions.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTINGS

The steep walls of the cliff (Figs. 1A, B) are composed of a pyroclastic flow deposit with a trachytic composition erupted by the Cimino Volcano District (CVD), referred to as Ignimbrite Cimina Auctt. (WBA), Ashy fine-grained deposit, generally massive and lithoid, light-grey or pinky in colour, with a structure of black flames (“pipernoide”) made of vitric stretched slivers. The massive banks often show prismatic jointing and pseudo-stratifications. It corresponds to the “Peperino Tipico” by Sabatini (1912). ^{40}Ar-^{39}Ar age comprised between 1,307 and 1,304 ky. (Nappi et al., 2022). This unit lies on a substratum made up of the Chiani-Tevere Formation (CNH), composed of prevailing clayey-sandy sediments of marine and saltish environment, and subordinately of gravelly deposits (Gelasian P.P- Santerían - Nappi et al., 2022) and was overlain by alkali-potassic volcanic rocks from the Vico Volcano District (VVD), the “Tufo Rosso a Scorie Nere Vicano” (WIC - Nappi et al., 2022), a pyroclastic sequence made up of a basal fall-out deposit of phonolithic pumices, followed to the top by several pyroclastic flow deposits rich of black scorias, lithic fragments, pumices, scorias and lavic fragments with an ashy matrix (Ignimbrite C, Locardi,1965). K/Ar ages: 150±7 ka (Sollevanti, 1983); ^{40}Ar-^{39}Ar 150±4 ka (Laurenzi & Villa, 1987). The pyroclastic deposits of Vico Volcano District (VVD) and the underlying Ignimbrite Cimina pyroclastic flow units formed an extensive volcanic plateau deeply incised by water activity. Over time, erosive processes have undercut the volcanic deposits at their base, causing collapse and toppling landslides (Fig. 1B) that have shaped the steep tuffaceous walls. These walls are characterised by a dense joints system, formed mainly due to contraction during the cooling of pyroclastic deposits and subsequently widened by exogenous processes and the wedging action of plant roots. Subsequent collapses caused the cliff faces to retreat. They produced a mosaic of large lithic blocks, locally called “erratic boulders,” which accumulated at the base of the cliffs over underlying marine sedimentary deposits (predominantly clay-based). This process has resulted in a highly distinctive landscape. The geomorphological features of this site (Fig. 1A) ensured its natural defensibility, while its geological characteristics (Fig. 1B) facilitated the excavation of cavities and the extraction of materials for construction.

MATERIALS AND METHODS

The University of Tuscia launched a research programme in 2024 to explore the site’s archaeological potential including test pits. It was preceded and accompanied by a series of diagnostic investigations. The main purpose of the LiDAR scan (Bennett et al., 2012; Devereux et al., 2008; Kokalj et al., 2011; Kolalj & Hesse, 2017) was to obtain better knowledge about the topography of the site, with particular relation to the inventory of the traces of hypogea, some of which are hidden by vegetation (Fig. 2). The scanning was carried out by a DJI M300 RTK UAV with a DJI ZENMUSE L1 scanner with the following parameters: number of laser beam reflections - 3; scan density - 460 points/m2; flight altitude - 70 m above sea level; overlays - 50 %. From the obtained point cloud, it was possible to generate a digital elevation model (DEM) with surface feature (Digital Surface Model - DSM) and without cover (Digital Terrain Model - DTM) and topographic map with contour lines. The Airborne Laser Scanning (ALS) data were analysed and visualised through different GIS models.

Before conducting field surveys, the area was contextualised within the regional stratigraphic and structural framework and from a hydrogeological perspective. The geological and geomorphological survey was conducted at a 1:5,000 scale, using the Regional Technical Map of Lazio (CTR) as a topographic base. The units identified in the geological map (Fig. 1A) correspond to those defined within the CARG project, specifically those of Sheet 345 “Viterbo” of the Geological Map of Italy at a 1:50,000 scale, along with the accompanying explanatory notes (Servizio Geologico d’Italia, 2022; Nappi et al., 2022). However, a more informal symbology was adopted for the geomorphological map (Fig. 1b) in order to better accommodate the needs of a more detailed analysis, as compared to the standardised CARG guidelines (Campobasso et al., 2021).

Regarding structural aspects, the investigation involved the survey and analysis of the main joint systems affecting the cliff face, isolated rock blocks and selected cavities and sclerometric measurements. Measurement of joint surface roughness profiles was supplemented with geophysical surveys - seismic refraction survey of compressional (P) and shear (S) waves, and Multi-Channel Analysis of Surface Waves (MASW) method, to define the parameters to be included in stability analyses.

The photogrammetric survey was prepared by setting up ground markers whose centres were measured using GNSS stations. The photogrammetric survey was carried out using the DJI Mavic Pro UAV model armed with a 12-megapixel on-board camera in automatic mode at an altitude of approximately 30m from ground level, speed of 2.5 m/s and with a photographic overlap of 75%. The photographic dataset was supplemented with manually acquired images taken along the walls at intervals of approximately 25 meters, with a walking speed of 2.5 m/s and a photographic overlap ranging from 70% to 75%. The photogrammetric survey

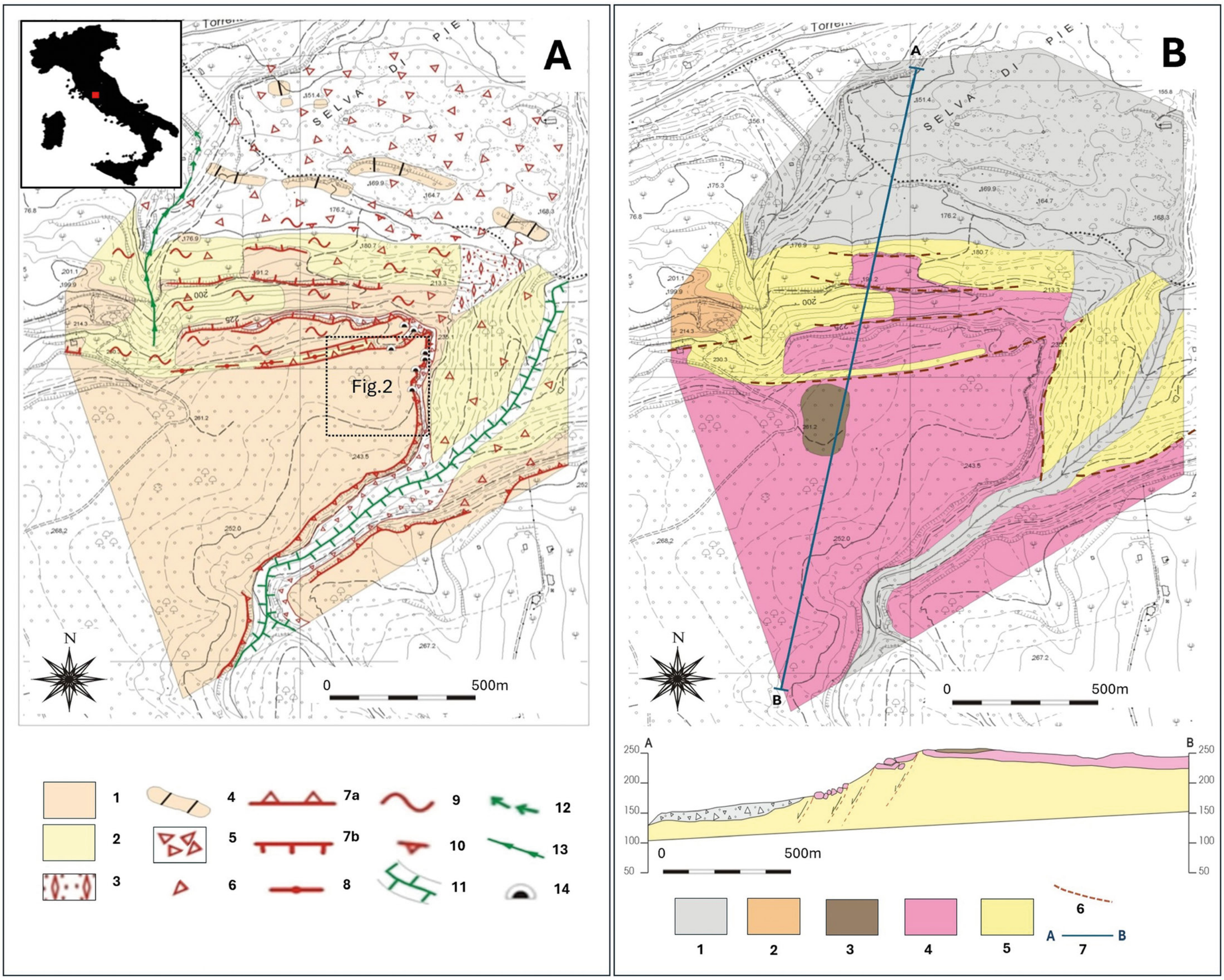

Fig. 1 - A) Geomorphological map, location of the study area and the lidar survey (fig.2): 1) pyroclastic rocks; 2) clayey-sandy sediments; 3) talus fed by rockfalls, topplin-falls and tumble; 4) large isolated blocks; 5) fall/topplin landslide body; 6) isolated fallen/toppled block; 7) rock wall affected by fall/ toppling: a) >10m high, b) 5-10m; 8) lateral spreading trench; 9) deep-seated gravitational slope deformations; 10) counterslope; 11) step and pool channel reach; 12) incising channel 13) gully/barranco; 14) anthropogenic cavity entrance. B) Geological map: 1) landslide body with large blocks, Holocene; 2) Tufo Rosso a Scorie Nere Vicano (WIC) Middle Pleistocene p.p. 3); Tufi Stratificati Varicolori Vicani (XFP) Middle Pleistocene p.p.; 4) Ignimbrite Cimina (WBA) Lower Pleistocene); 5) Chiani-Tevere Formation (CNH), Lower Pleistocene; 6) gravity induced shear plain: 7) trace of the geological section. The acronyms of the units are from the CARG project (Nappi et al., 2022). Topographic base: Regional Technical Map (CTR) of Lazio, scale 1:5.000.

was processed using Agisoft Metashape software (Agisoft, 2020), and scaled with ground points acquired through a GNSS station. This station, composed of a GS08 Plus rover and a CS10 controller, was used to measure the centres of ground markers, which served as Ground Control Points (GCP) and Check Points (CP) during data processing.

The 3D survey focused on selected cavities, which had previously been subject to traditional topographic surveys and was conducted using an iPhone 15 Pro, which mounts a Sony IMX591 ToF-type SPAD LiDAR sensor (Tavani et al., 2022; Luetzenburg et al., 2021). The survey involved the acquisition of surface portions around the cavities where the markers detected in the orthophotos obtained from the UAV flight were also present. The cavities were surveyed in a single acquisition aligned to the surface portion, given the small size. The survey mode involved the manual use of the iPhone while maintaining a distance of between 1.5 and 3m from the walls. Given the good natural lighting of the cavities, LED supporting lights of limited power were used. The UAV and the iPhone LiDAR surveys were merged using the open-source software Cloud Compare version 2.1 (Cloud Compare Team, 2024), using the specific Alings Two Clouds tool, which involves aligning one cloud or 3D model to another cloud or 3D model by selecting four homologous points. The presence of markers common to the two surveys allowed this, aligning the LiDAR survey to the UAV survey.

A structural survey was carried out to assess the stability conditions of the cliff face and the underlying cavities, with particular attention to the orientation and characteristics of the joint systems. This analysis provided the basis for evaluating potential failure mechanisms and guiding any necessary mitigation strategies. To define the stability conditions, the joints were plotted on an equal-

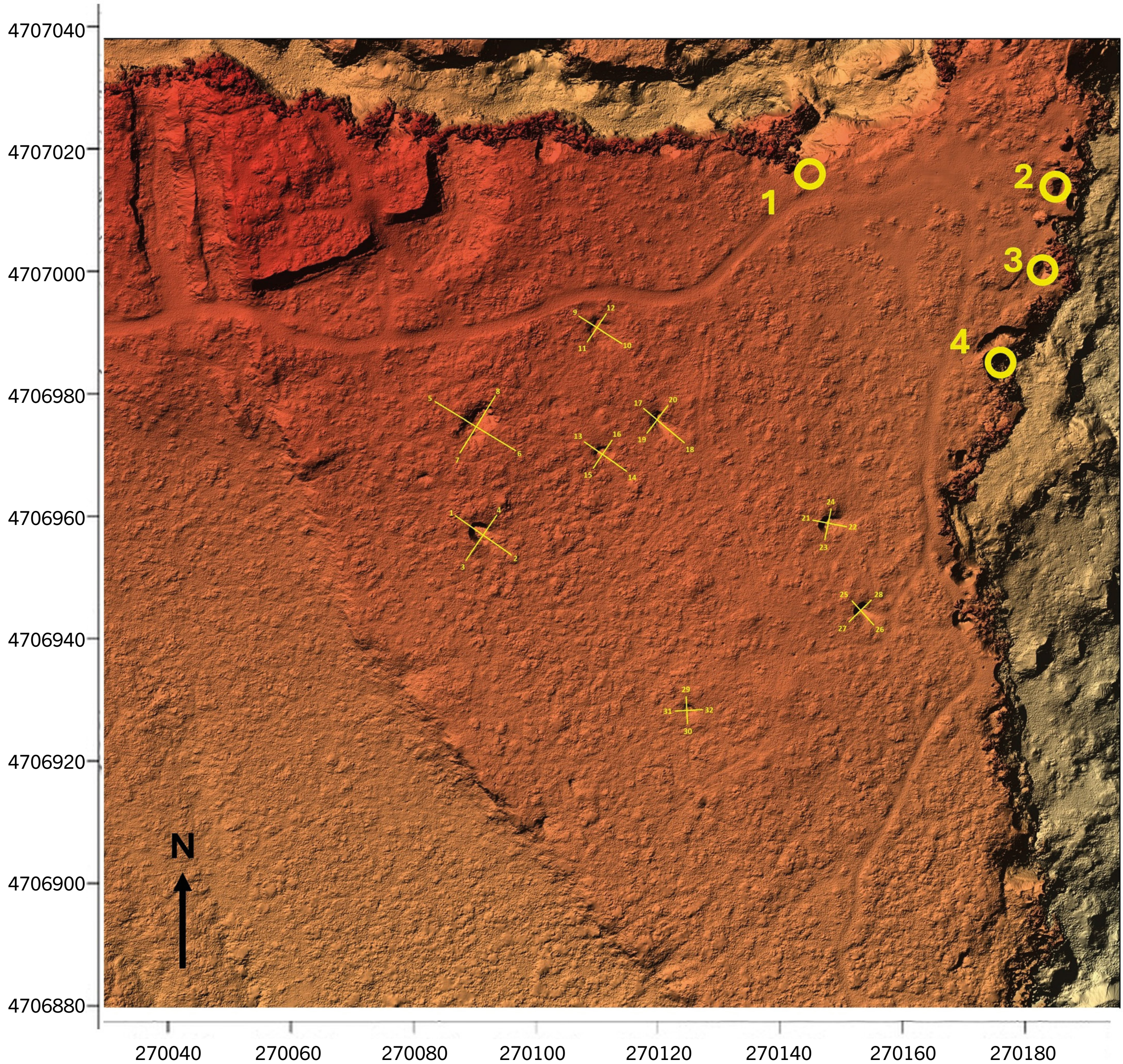

Fig. 2 - Corviano, Lidar survey through which it is possible to detect the entrances of investigated cavities (yellow circle) but also of other hypogean environments (yellow crosses), masked by dense vegetation present on the platform of the plateau. All spatial data were referenced using the WGS84 UTM Zone 33N coordinate system (processing M. Piotrowski, P. Piotrowska).

area Schmidt net in the lower hemisphere using great-circle and pole projections. Great-circle projections are particularly useful for highlighting the relationships between joints, while pole projections enable statistical analysis. Fig. 3A illustrates the locations of the geostructural measurements, displaying all the surveyed joints.

Numerical and empirical methods of vault stability assessment. Barton's Q method was used to classify the rock mass (Barton et al., 1974; Barton, 1987), and it was accompanied by the survey of joints in the rock mass and cavities (Figs. 3A, B).

The following equation gives the Q parameter:

$$Q = \left(\frac{RQD}{Jn}\right) \times \left(\frac{Jr}{Ja}\right) \times \left(\frac{Jw}{SRF}\right)$$

RQD= (Rock Quality Designation) considers the rock mass's subdivision.

Jn= (Joint Set Number), which depends on the number of joint families in the rock mass.

Jr (Joint Roughness Number), which depends on the roughness of the most unfavourable family.

Ja= (Joint Alteration Number), which depends on the degree of joint alteration, thickness and nature of the fill, and which is also determined by the most unfavourable family

Jw= (Joint Water Number), which depends on hydrogeological conditions.

SRF= (Stress Reduction Factor), which is a function of the stress state in massive rocks or tectonic disturbance

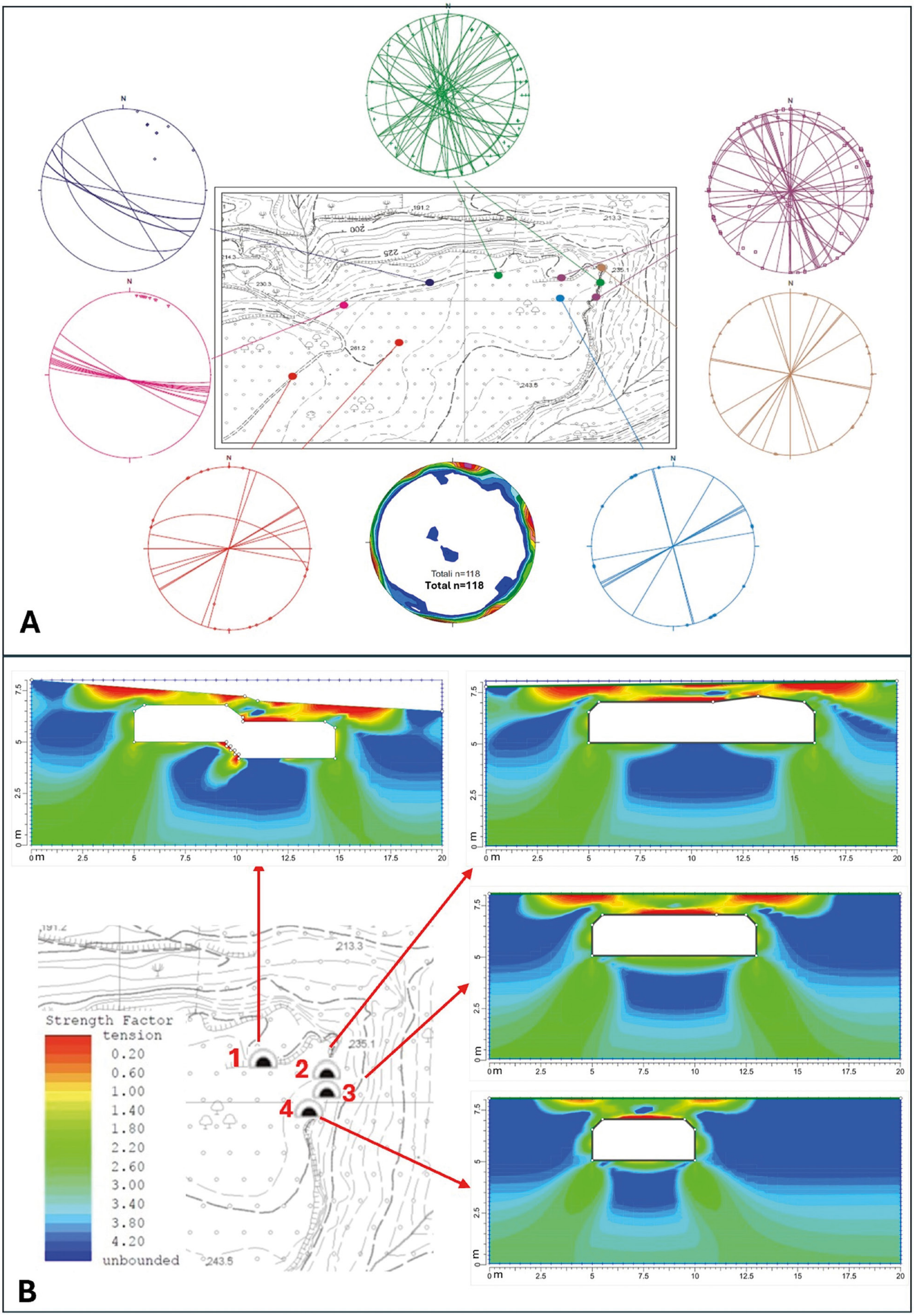

Fig. 3 - A) locations of the geostructural measurements and stereograms with surveyed joints and pole densities. B) Vault stresses in cavities 1, 2, 3, 4. Topographic base: Regional Technical Map (CTR) of Lazio, scale 1:5.000 (the distance between contour lines is 5 meters). See also Fig. 2 for a more precise location of the cavities.)

The classification of Q allowed the application of the Critical Scaled Crow Span method (Carter, 1992), according to which vault instability is probable if the scaled span Cs is greater than the critical span Sc. Cs and Sc can be calculated with the following equations:

$$Cs = \sqrt{(\gamma}/T(1+\frac{S}{L})(1-0.4cos\theta))$$

$$Sc = 3.3Q^{0.43}(senh^{0.0016}(Q))$$

S= clear span of the vault in metres
L= length of the vault in metres
T= thickness of the vault in metres
γ= specific gravity of the rock mass (2.05 t/m3)
θ = deep direction of the stratification

The caves' numerical stability was verified using the Rock-Science Examine 2D programme, using the Hoek-Brown criterion (Hoek & Brow, 1980). The numerical simulation data were obtained using MASW (Multichannel Analysis Surface Waves).

RESULTS

Detailed geological and geomorphological maps at a 1:5,000 scale were produced (Fig. 1A, B). In particular, the surveys identified the presence of a lateral spreading trench associated with deep gravitational deformation phenomena and a series of gravity-induced shear planes displacing the northern slope of the cliff. The upper part of the deformed slope (pyroclastic rocks -WBA) exhibits high-angle extensional shear planes, often resulting in trenches and uphill-facing scarps, while the lower part (clayey-sandy sediments - CNH) displays compressive features such as bulges and low-angle shear planes. Towards the Vezza River, the landslide body consists of disarticulated "Peperino" (WBA) slabs, which transition further downslope into a chaotic accumulation of large blocks resting on the "slowly moving" pelitic substrate (CNH).

More generally, along the entire edge of the cliff, particularly on the eastern and southern sides, a landslide scarp (a rock wall affected by fall/toppling) is actively evolving, with a chaotic accumulation of large blocks at its base.

The area of the medieval settlement (about 4 hectares) is defined on the western side by the remains of an imposing boundary wall, probably dating from the early medieval period. At the northwestern corner of this wall, at a slight elevation, the enclosure of the fortified residence (rocca), built in several phases between the 11th and the end of the 13th century, can be identified.

Along the southern edge of the plateau is located a church, identified and excavated by J. Raspi Serra in 1975 (Raspi Serra, 1976): a single-nave apsidal building (about m 5.30 x 9.50), dated between the 8th and 9th centuries AD, surrounded by a vast cemetery comprising 32 "anthropoid" tombs (sarcophagi and graves). This burial type, also known as "logette", characterised by a rectangular or trapezoidal shape and the presence of a hollow at the head, was particularly widespread along the Lombard-Byzantine *limes* of Tuscia. The chronology of known examples does not seem to go beyond the 8th century (Pastura, 2020).

Along the walls that define the medieval settlement, there are twenty artificial cavities, mostly overlooking the Vezza valley. The caves present an irregular plan characterised by curvilinear and rectilinear stretches; the only distinguishing feature is the type of access, parietal in most cases and utilising a stairway cut into the tuffaceous boulder. However, even though the type of access seems to be the only element of distinction among the cavities present, the hypothesis seems plausible that the access with stairs from the top of the plateau is an emergency solution implemented following the collapse of the cliff (Di Calisto, 2003).

The structural data collected from both the rock slope and the underground cavities were analyzed to characterize the principal sets of discontinuities and evaluate their potential impact on the stability of both the slope and the cavities. The pronounced dispersion of measurements along the great circle (Fig. 3A) indicates the presence of multiple joint families with distinct orientations. Most joints display sub-vertical attitudes, leading to the representation of each plane by symmetrically opposed poles along the great circle. Discontinuity sets were defined by plotting the poles of the joint planes on an equal-area Schmidt net and delineating clusters through isodensity contouring. The rock mass quality and the stability of isolated blocks bounded by the joint systems affecting the rock slope were classified. Furthermore, global stability analyses of the slope and specific stability assessments of selected cavities were performed. Rock Mass Quality and stability assessments of isolated rock blocks detached by the joint systems affecting the cliff faces were classified. Additionally, global stability assessments of the cliff face and stability evaluations of selected cavities were conducted.

The photogrammetric survey was characterised by small errors, estimated by the Metashape software as 3.8 cm on GCP and 5.3 cm on CP. The products obtained were the point cloud, the textured 3D model (Fig. 4B) and the orthomosaic (Fig. 4A), used as an orthophoto in the GIS environment.

The point clouds and textured 3D models obtained from the iPhone LiDAR survey of the investigated cavities have been aligned with the UAV survey. (Figs. 4C and D).

As reported in Table 1, the models' alignment was associated with minimal errors. CloudCompare automatically calculated the alignment error as the root mean square (RMS) value. The resulting model (Fig. 4E) was then used to extract a set of geometric parameters relevant to assessing the vault's stability.

Table 2 shows Barton's Q values determined in the cavities and the Cs and Sc values for each individual hall that makes up the surveyed cavities, considering their entire extension. (Fig. 3B) shows the results of stability simulations.

Table 1 - Alignment errors of the cavity survey to the UAV survey.

CAVITY	RMS (m)	SCALE FACTOR
1	0.024	0.991
2	0.034	0.986
3	0.027	0.989

Table 2 - Results of Carter method.

Cavity	Part	γ	S	T	L	cosθ	CS	Sc	Q
2	Room 1	2.05	4.74	3.02	6.15	0.98	3.76	3.79	1.38
2	Room 2	2.05	5.57	1.69	4.01	0.98	5.09	3.79	1.38
2	Total	2.05	5.07	2.35	10.88	0.98	5.01	3.79	1.38
3	Room 1	2.05	3.07	2.05	3.15	0.98	2.43	4.14	1.70
3	Room 2	2.05	7.17	1.68	5.61	0.98	5.94	4.14	1.70
3	Room 3	2.05	6.01	1.76	2.67	0.98	4.21	4.14	1.70
3	Total	2.05	6.28	2.16	8.23	0.98	5.05	4.14	1.70
4	Total	2.00	4.56	1.85	6.58	0.98	4.02	4.14	1.70

DISCUSSIONS

Culturally significant heritage sites, such as the rock-cut cavities of Corviano, which are threatened by hydrogeological instability, require an integrated approach combining historical-archaeological data with geological and geomorphological information for their preservation. LiDAR technology mounted on UAVs is an excellent help for detecting the openings of underground cavities or identifying sinkholes related to their collapse in densely vegetated areas. In particular, the effectiveness of LiDAR technology integrated into low-cost devices such as iPhones is now well-established in producing reliable models of surveyed environments (Monsalve et al., 2023; King et al., 2023). The limitations of such instrumentation are well known and are inherent to the low numerosity of the point cloud they generate and the limited acquisition port.

However, the low cloud numerosity is still sufficient to describe underground environments' geometry and produce a 3D model suitable for further processing. The low acquisition range (between 4 and 5m maximum) in cavities, especially artificial ones, is not a limitation precisely because of the narrowness of the environments, where the iPhone's small size allows for agile surveys. Another limitation of the iPhone is the absence of a rigorous reference system associated with the surveys produced. This limitation can be addressed by using special markers, GNSS stations, or other high-precision GPS systems, such as RTK devices that integrate directly with an iPhone, for accurate georeferencing. These surveys can be aligned with models and point clouds generated through photogrammetry to study iterations between cavities and the surface and detect vital measurements of cavity dimensions and distances to the surface (Madonna et al., 2024). In this work, special markers, as suggested in recent publications (Gentili et al., 2024), greatly facilitated the alignment of the LiDAR survey with the UAV survey, with errors at the centimetre scale and in line with data found in the literature. The model obtained made it possible to get essential measurements of the cavity geometries. Combined with the geomechanical survey using well-established procedures, this made it possible to apply empirical methods of vault stability. This is very important because having an estimate of the susceptibility to the collapse of the vault of a cavity, especially if it is superficial, means intransigently assessing the susceptibility to sinkholes in a given area. At the Corviano cliff, three out of five known cavities were studied and surveyed. Based on the Critical Scaled Crown Span method, indications of instability—or conditions close to it—were observed in all the investigated cavities. Only one of the three, cavity n.3, appears to present a relatively stable condition, albeit within an overall highly unstable setting. Given that numerical simulations were also available for the same cavities, allowing stress quantification on the vaults, a comparison was carried out between empirical and numerical approaches. While both methods generally suggest a marked tendency toward instability, some divergence was noted at the scale of individual chambers and the system as a whole. In particular, cavity n.4 showed a slight discrepancy, with the empirical method pointing to a marginally more stable condition, potentially reflecting a borderline case.

Due to space limitations inherent to the short note format, this contribution does not aim to develop in detail specifical aspects addressed, but rather to emphasise the importance of an interdisciplinary approach that employs archaeological, geological, geomorphological, and geostructural conventional field methods and technologies, such as LiDAR photogrammetry, UAV survey and numerical modelling for underground stability. Such integration is essential for a more holistic understanding and effective management of complex sites such as Corviano.

CONCLUSIONS

The Corviano Cliff is a site of extraordinary interest due to its remarkable historical, archaeological, natural and geological significance. However, the area's accessibility for tourism purposes is limited by geological hazards, which must be considered to mitigate associated risks. Ongoing surveys, particularly the census and 3D mapping of cavities integrated with surface LiDAR and UAV surveys of the cliff area, can be instrumental in better understanding the stability conditions of the cavities and the entire cliff. This heritage must be preserved and maintained for sustainable and responsible tourism. The availability of 3D models of hypogean environments integrated with detailed geological, structural, and geotechnical data can significantly enhance stability studies and stability assessments in numerical simulation models like Rocscience RS3 Finite Element Analysis Software (RocScience, 2025). These models provide precise geometric and structural data, allowing a more accurate representation of discontinuities, stress distribution, and material properties in simulations (e.g.,

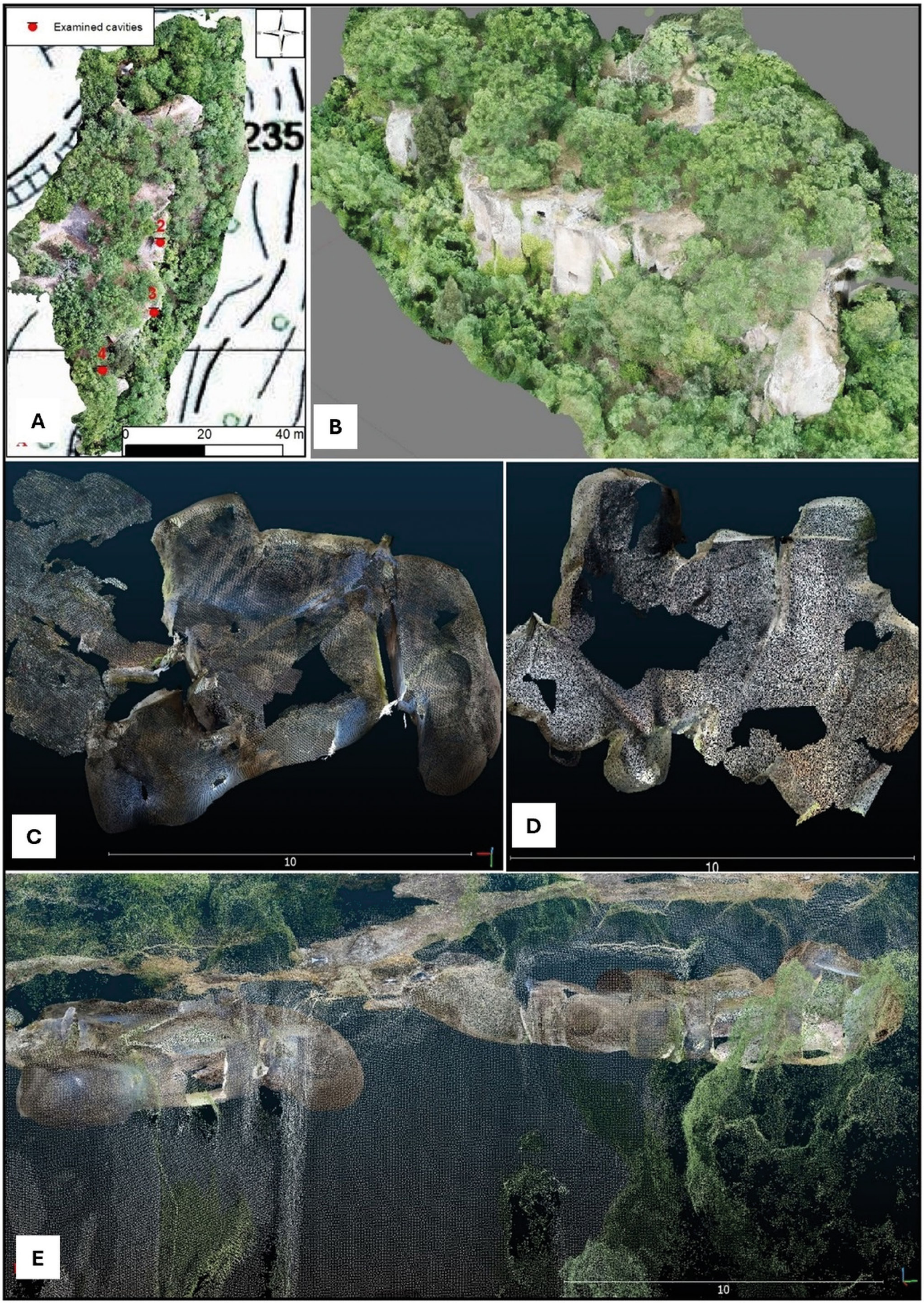

Fig. 4 - A) survey orthophoto, based on CTR Lazio 1:5000, with the location of the cavities examined (n.2, 3, 4 . See also Figs. 2,3); B). Textured 3D model from UAV survey; C-D) examples of Lidar survey of the cavities; E) clouds of the cavities aligned to the UAV survey.

Hoek-Brown criteria, Hoek et al., 2002). Such integration improves the reliability of stability analyses and facilitates the identification of potential failure zones, aiding in developing targeted preservation strategies. The geothematic mapping produced proves to be of significant value, particularly from an archaeological perspective. The documented instability processes reveal an ongoing morphological evolution that has profoundly altered the original morphology of the anthropogenic cavities, causing collapses that have exposed, along the cliff faces, cavities which were likely once entirely subterranean.

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REFERENCES

Agisoft (2020) - Agisoft Metashape software (Version 1.6.3). Available online: https://www.agisoft.com accessed on 16 July 2021.

Barton N. (1987) - Rock mass classification, tunnel reinforcement selection using the Q-system. In Rock Classification Systems for Engineering Purposes; ASTM International: West Conshohocken, PA, USA.

Barton N., Lien R. & Lunde J. (1974) - Engineering classification of rock masses for the design of tunnel support. Rock Mech., 6, 188-236.

Bennett R., Welham K., Hill R.A. & Ford A. (2012) - A Comparison of Visualisation Techniques for Models Created from Airborne Laser Scanned Data. Archaeological Prospection, 19, 41-48.

Campobasso C., Carton A., Chelli A., D'Orefice M., Dramis F., Graciotti R., Guida D., Pambianchi G., Peduto F. & Pellegrini L. (2021) - Carta Geomorfologica d'Italia alla scala 1:50.000 - Aggiornamento ed integrazioni delle linee guida della Carta Geomorfologica d'Italia alla scala 1:50.000 e Banca Dati Geomorfologica (Fascicolo I, Versione 2.0). Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA).

Carter T.G. (1992) - A new approach to surface-crown pillar design. In Proceedings of the 16th Canadian Rock Mechanics Symposium, Sudbury, ON, Canada, 75-83.

Cloud Compare (version 2.1) [GPL Software] (2024) - Available online: http://www.cloudcompare.org/ (accessed on 20 July 2024).

Devereux B.J. Amable G.S. & Crow P. (2008) - Visualisation of LiDAR terrain models for archaeological feature detection. Antiquity 82, 470-479.

Di Calisto S. (2003) - Corviano, in De Minicis E. (ed.), Insediamenti rupestri medievali nella Tuscia. I. Gli abitati, Roma, Kappa, 187-208.

Gentili F. & Madonna S. (2024) - Photogrammetry from UAV and Low-Cost Lidar for Sinkhole Hazard Mitigation in Urban Areas: Applications and Evaluations. Geographies,2024, 4, 343-362, https://doi.org/10.3390/geographies4020020.

Hoek E., Carranza-Torres C. & Corkum B. (2002) - Hoek-Brown Failure Criterion – 2002 Edition. Rocscience. Retrieved from

Hoek E. & Brown E.T. (1980) - Empirical strength criterion for rock masses. J. Geotech. Eng. Div., 106, 1013-1035.

King F., Kelly R. & Fletcher C.G. (2023) - New opportunities for low-cost LiDAR-derived snow depth estimates from a consumer drone-mounted smartphone. Cold Reg. Sci. Technol., 207, 103757.

Kokalj Ž., Zakšek K. & Oštir K. (2011) - Application of sky-view factor for the visualization of historic landscape features in lidar-derived relief models. Antiquity, 85, 263-273.

Kolalj Ž. & Hesse R. (2017) - Airborne laser scanning raster data visualisation: A guide to good practice. Ljubljana: Založba ZRC.

Laurenzi M.A. & Villa I.M. (1987) - 40Ar-39Ar chronostratigraphy of Vico ignimbrites. Per. Mineral., 56, 285-293.

Locardi E. (1965) - Tipi di ignimbriti di magmi mediterranei: le ignimbriti del vulcano di Vico. Atti Soc. Tosc. Sc. Nat., Mem., Serie A, 72, 55-173.

Luetzenburg G., Kroon A. & Bjørk A.A. (2021) - Evaluation of the Apple iPhone 12 Pro LiDAR for an Application in Geosciences. Sci. Rep., 11, 22221, https://doi.org/10.1038/s41598-021-01763-9.

Madonna S., Gentili F., Mattioli M., Scatolini A., Pendola V., Monaldi G.G. & Monaldi G. (2024) - Survey techniques integrating smartphone LiDAR and UAV photogrammetry: the example of the anthropic underground cavities of Montefiascone (Viterbo, Central Italy). Rend. Online Soc. Geol. It., 64, 26-34. https://doi.org/10.3301/ROL.2024.46.

Monsalve A., Yager E.M. & Tonina D. (2025) - Evaluating Apple iPhone LiDAR measurements of topography and roughness elements in coarse bedded streams. J. Ecohydraulics, 10(2), 181-191.

Nappi G., Antonelli F., Chiocchini U., Bonomo F., Madonna S., Mattioli M., Ricci A., Valentini L.A. & Vita L. (2022) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000, F. 345 Viterbo. 273 pp., ISPRA, Roma.

Pastura G. (2020) - Le sepolture a logette nell'Alto Lazio. Analisi sulla diffusione e l'orginire di uan tipologia funeraria. Rivista di Archeologia Cristiana, 96, 245-276.

Raspi Serra J. (1976) - Una necropoli altomedievale a Corviano (Bomarzo) ed il problema delle sepolture a "logette" lungo le sponde mediterranee. Boll. Arte, 61,144-157.

ROCSCIENCE – RS3 Finite Element Analysis Software. Rocscience https://www.rocscience.com/software/rs3 (consulted 03-01.2025)

Romagnoli G. (2006) - Ferento e la Teverina viterbese. Insediamenti e dinamiche del popolamento (secc. X-XIV), Viterbo, Università degli Studi della Tuscia.

Sabatini V. (1912) - I vulcani dell'Italia centrale e i loro prodotti: parte II. Vulcani Cimini. Mem. Descr. Carta Geol. d'It., 15: 1-636.

Servizio Geologico d'Italia (2022) - Carta Geologica d'Italia alla scala 1:50.0000, F. 345 Viterbo. ISPRA, Roma.

Sollevanti F. (1983) - Geologic, volcanologic and tectonic setting of the Vico-Cimini area, Italy. J. Volcanol. Geotherm. Res., 17, 203-217.

Tavani A., Billi A., Corradetti A., Mercuri M., Bosman A., Cuffaro M., Seers T. & Carminati E. (2022) - Smartphone assisted fieldwork: Towards the digital transition of geoscience fieldwork using LiDAR-equipped iPhones. Earth-Sci. Rev., 227, 103969.