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AN UNDERGROUND HISTORICAL QUARRY IN THE HANBURY BOTANICAL GARDENS OF VENTIMIGLIA (ITALY)

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Abstract
This paper concerns with the original survey of an ancient underground quarry located in the internationally known Hanbury botanical gardens, located on the Mortola promontory, 2 kilometers from the Italy - France boundary. The gardens were established from 1867 by Sir Thomas Hanbury with the aim of acclimatizing several rare botanical species coming from all the temperate climate regions of the world. Many restoration works have been executed, and to this end an extended sandy layer located on the upper portion of the property was used as building material: it was extracted from weakly cemented yellowish sands probably belonging to the top of the Pliocene Ortovero clay formation. The artificial cave opens up to about 90 m a.s.l. and has a total length of 133 m and a maximum difference in level of 8 m; the total volume extracted is on the order of 1,500 m^3 and the internal stability seems guaranteed by some stone pillars. The NE portion of the underground quarry has not been surveyed yet because of the cavity infilling: some testimonies from inhabitants report a possible continuation under the village of Mortola Inferiore. The sand quarry of the Hanbury Botanical Gardens is therefore a cultural heritage with a high tourist potential, even if the site requires further analyses about the geotechnical features of the material aimed at assessing the stability of the underground volumes.
Keywords: artificial cave, quarry, yellowish sands, Hanbury Botanical Gardens, Capo Mortola, Ventimiglia.

Riassunto
Il lavoro riguarda il rilievo originale della cava sotterranea dei Giardini Botanici Hanbury di Ventimiglia (provincia di Imperia, Liguria), ubicati sul promontorio della Mortola, a pochi chilometri dal confine francese. I Giardini furono realizzati a partire dal 1867 da Sir Thomas Hanbury con l'intento di acclimatare specie botaniche rare provenienti dalle regioni temperate calde di tutto il mondo. Il banco sabbioso presente nella porzione superiore della proprietà è stato largamente utilizzato per ristrutturazione edilizia del Palazzo e di altri edifici limitrofi. Dal punto di vista geologico Capo Mortola è rappresentato da una sinforme di calcareniti e marne. Al di sopra, ma non affioranti in loco, vi sono delle siltiti ed arenarie fini giallastre debolmente cementate, ascrivibili probabilmente al top delle Argille plioceniche di Ortovero, che rappresentano il materiale estratto. Le sabbie giallastre sono a loro volta sormontate da depositi detritici di spessore metrico. La cava si apre a circa 90 m s.l.m. e presenta uno sviluppo complessivo di 133 m con un dislivello di 8 m; si stima che il volume complessivo estratto possa essere dell'ordine complessivo di 1500 m^3. La stabilità interna della cava in sotterraneo sembra garantita da alcuni pilastri in conci lapidei, appositamente lasciati in corrispondenza degli ambienti di maggiore sviluppo spaziale. La porzione NE della cava sotterranea non è stata rilevata per impraticabilità del cunicolo: alcune testimonianze raccolte da residenti riferiscono di un possibile proseguimento in sotterraneo verso il nucleo abitato di Mortola Inferiore. La cava di sabbia dei Giardini Botanici Hanbury rappresenta un bene culturale che potrebbe trovare una valorizzazione turistica, anche se il sito necessita di ulteriori studi sulle caratteristiche geotecniche del materiale finalizzati alla definizione della stabilità del vuoto sotterraneo.
***Parole chiave**: cavità artificiale, cava, sabbie giallastre, Giardini Botanici Hanbury, Capo Mortola, Ventimiglia.*

Introduction

The management of a complex and ancient territory like Italy is extremely difficult because most of the settlements are characterized by an overlap of different building structures: numerous underground cavities (aqueducts, reservoirs, canals, underground quarries, places of worship, etc.) have been realized during different building periods.

These underground elements are of historic, cultural, scientific and anthropological interest and could be seen as a resource under a socio-economic point of view, but also represen unknown features inside a urban environment: because of it, their knowledge is indispensable for a geological hazard assessment of the area.

Artificial caves offer a double reading in terms of risk: they both could be seen as vulnerable element under building activities or as a potential risk for settlements or collapses regarding the overlying infrastructure and buildings (Faccini et al., 2011).

Actually the disastrous events related to anthropogenic cavities represent an underrated phenomenon in terms of risk in Italy, especially when compared with floods and landslides, but equally able to cause heavy damages and economic loss (Corazza et al., 2002; Corazza, 2004); in fact there have been several cases of underground cavities collapsed over the past twenty years, especially in Central and Southern Italy, in the regions of Basilicata, Calabria, Campania, Latium and Apulia (Catenacci, 1992; Pellegrino, 2002; Parise et al., 2013).

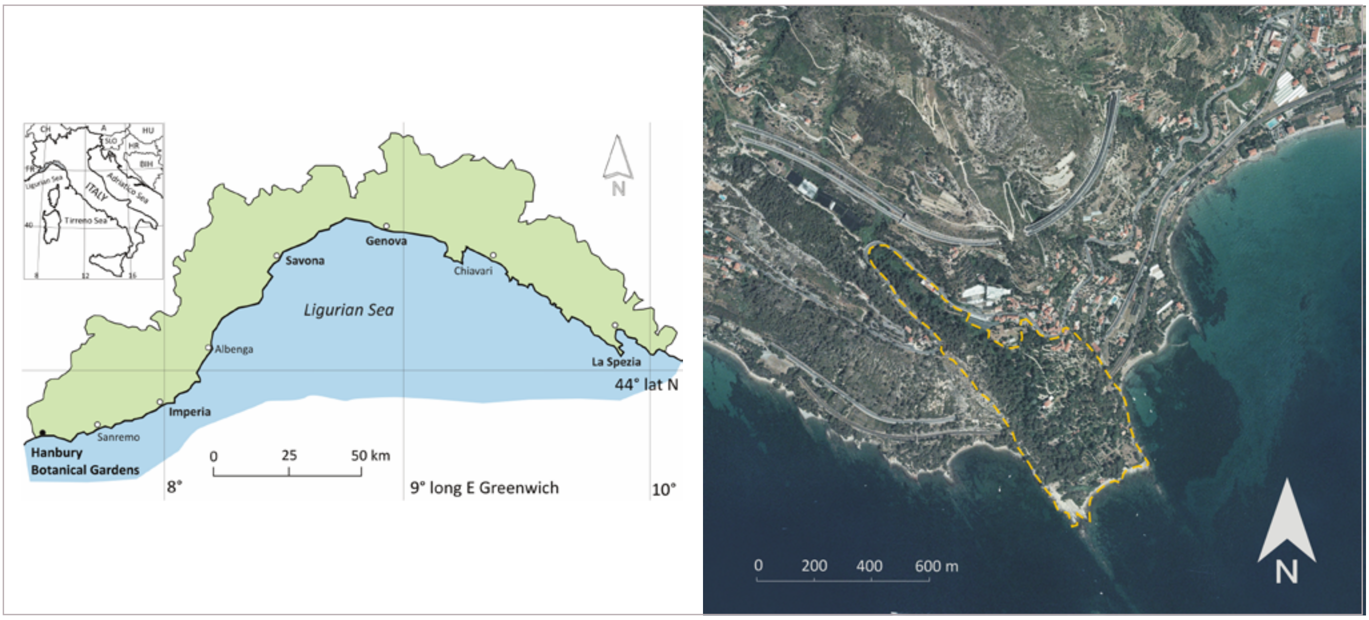

Fig. 1: geographic sketch map of Liguria (left) and aerial image of Capo Mortola, showing the boundaries of the Hanbury Gardens protected area (right).
Fig. 1: schema geografico della Liguria (sinistra) e foto aerea di Capo Mortola con indicazione dei limiti dell'area protetta "Giardini Botanici Hanbury" (destra).

Liguria Region presents several underground voids: based upon the outcomes of the work carried out by the Italian Speleological Society - Artificial Cavities Committee, nearly 400 artificial cavities have been registered so far, mainly in urban or suburban areas, and more than a half in the city of Genoa. More than 100 cavities have been detected inside the Imperia province, ten of which are located between the boundaries of the town of Ventimiglia, the area in which Hanbury Botanical Gardens are located.
One of these cavities is a sand quarry located in the beautiful and internationally known Hanbury Botanical Gardens and represent the main object of this work (Fig. 1); it was opened in the second half of the XIX century because of the request of building material for the realization of the Botanic Gardens, according to the will of the English merchant Sir Thomas Hanbury, which radically transformed the properties all around the older Palazzo Orengo.
Several construction activities such as the realization of pedestrian routes, the building restoration and the gardens adornment were carried out after the extraction of material from a sandy bank, mainly made of yellowish and weakly cemented siltstone and sandstone, belonging to the "Ortovero Clays" and "Monte Villa Conglomerates", of Pliocene age, outcropping in the upper portion of the property.
The sand quarry of the Hanbury Botanical Gardens is therefore a cultural heritage of scientific and tourist interest, even if the site requires further studies under a geotechnical point of view, aiming at assessing a careful stability analysis of the underground void.

General settings of the Hanbury Botanical Gardens

The Hanbury Botanical Gardens in Ventimiglia, internationally known for its collections of exotic plant species, are located on the Mortola promontory, on the W Coast of Liguria, a few kilometers from the French border (Gastaldo, Profumo, 1995).
They are located inside a Protected Area of about 20 hectares extended between the coastline and 200 m a.s.l.; this area was set up in 2001 and it is currently managed by the University of Genova.

Fig. 2: historical map of Capo Mortola (end of XVIII century, from archive of Italian Military Geographic Institute).
Fig. 2: carta storica di Capo Mortola (fine del 1700 circa, dagli archivi dell'Istituto Geografico Militare Italiano).

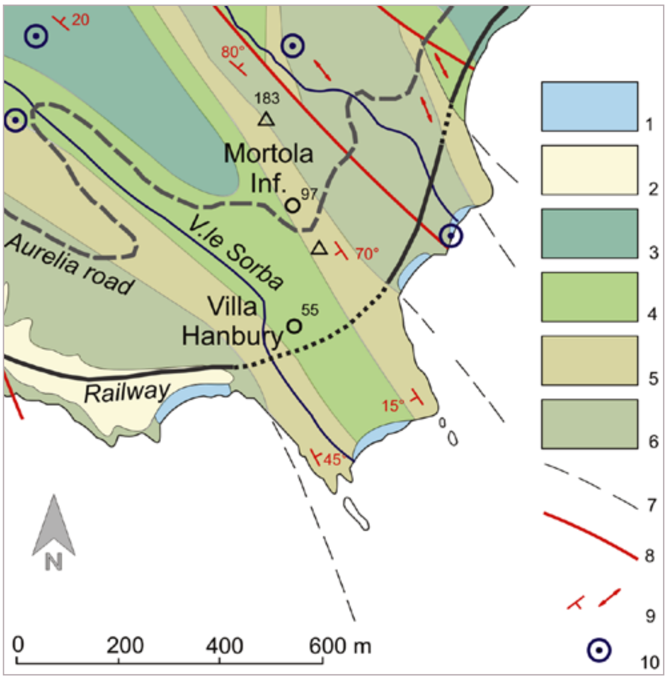

Fig. 3: geologic sketch map of Capo Mortola (modified after CALVINO, STEFANON, 1963). Legend: 1) gravelly beach deposit; 2) weakly cemented scree slope; 3) sandstone, shale and siltstone; 4) grey-blue marl; 5) bioclastic limestone; 6) marl and marly limestone; 7) underwater geologic contact; 8) fault and thrust; 9) strata attitude; 10) spring.

Fig. 3: schema geologico di Capo Mortola (modificato da CALVINO, STEFANON, 1963). Legenda: deposito ghiaioso-ciottoloso di spiaggia; 2) falda detritica debolmente cementata; 3) arenaria, argillite e siltite; 4) marna grigio-azzurra; 5) calcare bioclastico; 6) marna e calcare marnoso; 7) contatto geologico subacqueo; 8) faglia e sovrascorrimento; 9) giacitura degli strati; 10) sorgente.

The Hanbury Botanical Gardens were built starting from 1867 under the supervision of Sir THOMAS HANBURY, who bought the building and the surrounding areas formerly owned by the Marquis ORENGO from Ventimiglia (Fig. 2), with the goal to acclimate rare species of plants of high pharmacological interest coming from warm-temperate regions all over the world (MOORE, 2004). Among the building works carried out in time, there are also the accommodation of footpaths, the restoration of the palace and other buildings on the property, as well as architectural ornamentation of the gardens.

In fact the Ventimiglia climate is classified as an hot-summer Mediterranean climate (Csa), according to the KOPPEN Climate classification (MCKNIGHT, HESS, 2000), with an average annual temperature of almost 16° C and an average annual rainfall of about 800 mm/year. The driest month is July with 18 mm of rain per month, while November is the rainiest month, with an average of 121 mm/month; the average temperature in the hottest month of the year, July, is 23.3° C while the average temperature during the coldest month, January, is 9.2° C.

The "Palazzo" is approximately located in the center of the Gardens, currently owned by the Italian State and granted in perpetuity to the University of Genova; the whole protected area has passed through several

Fig. 4: a specimen of Chiroptera on the underground quarry ceiling.

Fig. 4: un esemplare di Chiroptera sul soffitto della cava sotterranea.

changes over the last centuries; in the lower portion of the area it is still possible to see a portion of the original Roman road, Via Julia Augusta.

The superficial hydrographical network is represented by the Vallone della Sorba stream; its spring is located in the vicinity of Mt. Bellenda (540 m a.s.l.), then it flows following an average NW-SE direction towards the Hanbury Botanical Gardens: the mouth is in proximity of the E sector of Capo Mortola (Fig. 3).

This last promontory is considered the S end of a narrow syncline showing an approximate N-S strike, called the Mortola syncline, one of the structures developing on the W side of the Grammondo anticline (CALVINO, STEFANON, 1963). The outcropping formations are part of the coverage belonging to the Argentera Massif (CARBONE et al., 1980). In the Capo Mortola area the two sides of the syncline are very well exposed: it shows bioclastic limestones (Capo Mortola Calcarenites) on both sides, while in the core the grey-blue marls (Olivetta S. Michele Silty Marls) have almost completely been obliterated, due to creation of several terraces along the slopes of the Hanbury gardens.

Along the N side of the gardens some weakly cemented yellowish sands are detected: those outcrops represent the extracted material inside the quarry which is the main feature of the present study. This bench could be ascribed to the top of the Pliocene clays of Ortovero or to the bottom of the Pliocene conglomerates of Monte Villa (GIAMMARINO et al., 1984, 2010; MARINI, 2001).

Material and methods

The topographic survey of the cave has been carried out through different "speleologic" techniques: the wide use of electronic instrumentation has been precious for a precise morphometric restitution of the analyzed volume.

The data collected through a laser distance-meter show high accuracy values standing on length measures (lower than a few centimeters) and angle measures (lower than 0.5 degrees of azimuth inclination). Is it also possible to measure different transects inside the cavity with the aim of defining the real dimension of the underground void.

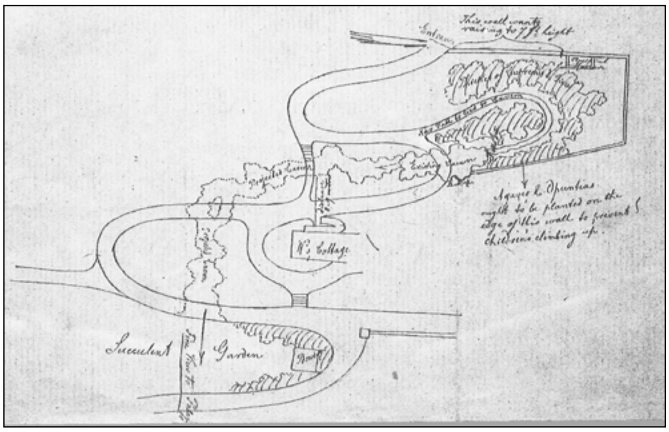

Fig. 5: Winter's plan for the top of the Gardens (from Muratorio, Kiernan, 1995). In dotted line note the "existing cave" and the "projected cave".
Fig. 5: progetto di Winter per la parte superiore dei Giardini (da Muratorio, Kiernan, 1995). Si noti con il tratteggio la "existing cave" (cavità esistente) e la "projected cave" (cavità in progetto).

The data are directly downloaded on an electronic device inside the cave through the bluetooth technology; a software suddenly validates the data received by the electronic device and it is also possible to link pictures or notes to the single detected measures (Fig. 4).
Consequently a careful elaboration of the dataset has been carried out through the use of specific softwares with the aim of defining the cartographic superimposition, the volumetric estimation and to obtain a 3D restitution.

The historical underground quarry
Historical documentation of the underground quarry is testified by the sketches of Ludwig Winter, the botanist and designer of the Botanical Gardens (Muratorio, Kiernam, 1995): in its rough plan of the upper part of the Gardens it is possible to observe an "existing cave" and a "projected cave" (Fig. 5). As concerns the latter, there is only the entry at lower altitude, although we cannot exclude that it has been continued and later abandoned. Winter had probably intention to realize an underground system developed under the Botanical Gardens, perhaps even to connect at the notch located near to the place now called Dragon fountain.

Fig. 6: the underground quarry entry, at 90 m a.s.l.
Fig. 6: l'entrata della cava sotterranea a 90 m s.l.m.

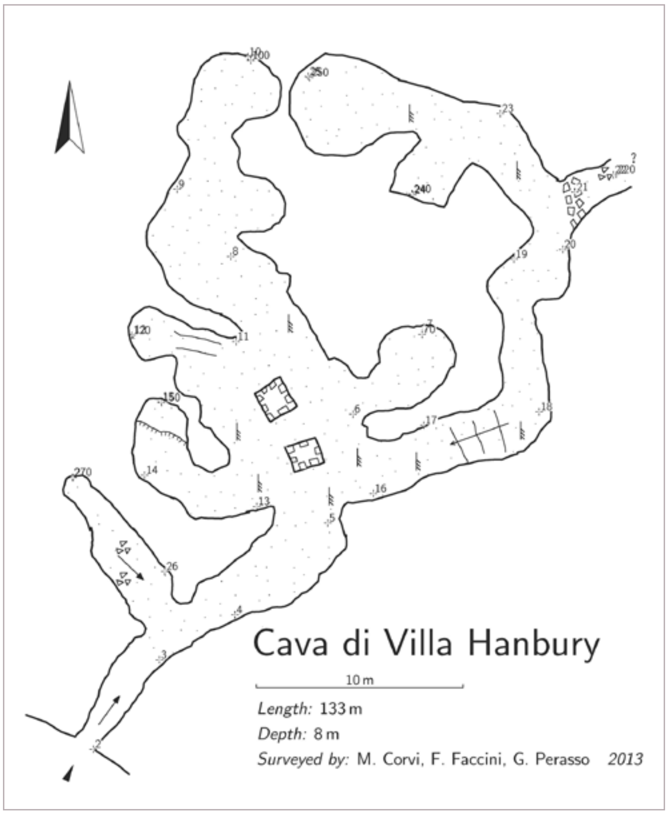

Fig. 7: underground historical quarry plan.
Fig. 7: planimetria della cava storica sotterranea.

The artificial cave opening is located at 90 m a.s.l. showing a total length of about 133 meters with a difference in height of about 8 m (Fig. 6); the approximate volume is around 1,500 m^3.
Its planar asset shows a main corridor starting from the entrance and going deeper underground inside the slope following an approximate NE-SW direction (Fig. 7); after some meters there is a bifurcation and the NNW corridor stops at the end of a gentle and narrowing uphill path, filled with debris and quarry material (Fig. 8).
The main corridor leads to the wide central volume of the cave: it is approximately 50 to 60 m^2 wide and the top of the cavity (reaching 4 m in height) is sustained by two massive pillars made by cemented rocky blocks, 1.5 m wide (Fig. 9).
Several extraction tunnels start from the main chamber with a short development in length (not more than a few meters) except for two of them which are longer: the first one keeps deepening northward following a N-S direction for 12 m, and in the left corner of the room it continues for a dozen meters; in the right corner of the room, while the second one has a circular development over the cavity, turning counter-clockwise until it reaches the first tunnel. On the right side in the middle of the second gallery there is a branch almost completely blocked by landfill; standing on local depositions, it leads right under the historical centre of the not so far village of Mortola Inferiore.
The presence of numerous roots showing a few

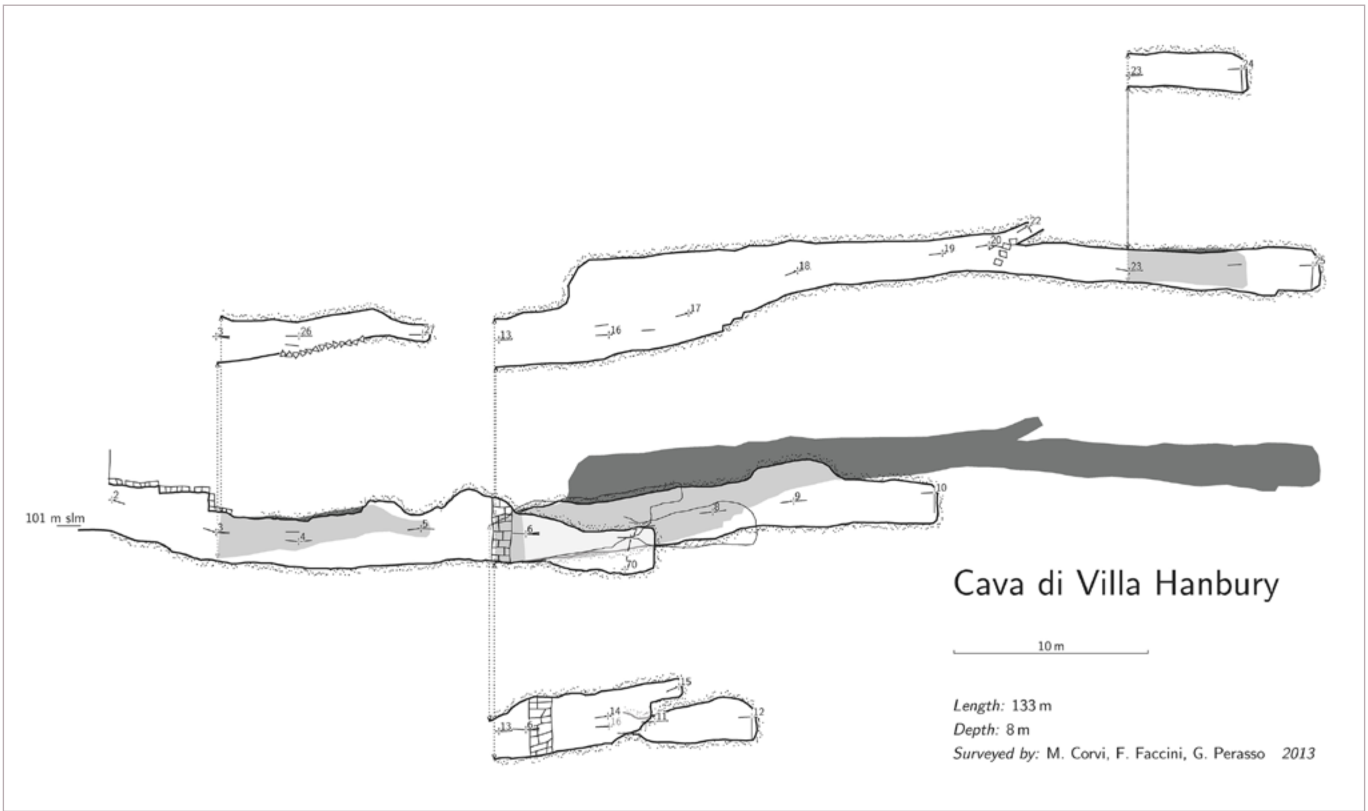

Fig. 8: underground historical cave sections.
Fig. 8: sezioni della cava storica sotterranea.

centimeters diameter is also frequent, giving witness of the proximity of the ground surface above which is between 6 and 8 m far from the cavity ceiling.
The material extracted from the quarry is mainly yellowish sand of good quality: for this reason it has been widely used as inert material in mortars for construction use (Fig. 10).
On the basis of the scientific literature the weakly cemented sand could be attributed to the Pliocene deposits referable to the top of the Ortovero clays, typically represented by yellowish siltstones and fine sandstones, although the proximity with the Conglomerates of Monte Villa (facies CMV_C - Giammarino et al., 2010) makes uncertain the attribution.
The extraction of the material has been easily carried out, even through the use of simple tools such as picks, chisels and bribes, some of which have been abandoned in several points of the underground quarry (Fig. 11).
The poorly cemented sands were effortlessly excavated along the cavity walls. Locally, hard calcareous levels could be found: they were attributable to the result of the passage of water rich in carbonates with consequent deposition through soil volumes showing higher permeability values.
Overall, the geo-material once extracted in this underground cave could be classified as a weakly cemented sand, with shear strength and deformation values comprised between those of a coarse, overconsolidated sand and a poorly diagenized sandstone (Hoek et al., 2005); the presence of the pillars positioned in the center of the main room highlights the needing of preventing the subsidence on the upper ground levels, artificially made unstable by the cultivation process.

Research perspectives and conclusion

The study of the weakly cemented sand quarry inside the area of the Hanbury Botanical Gardens represents a further contribution to the urban planning in predominantly urban and peri-urban area (Bennet, Doyle, 1997) characterized by a significant environmental-geological complexity.
The comparison between the artificial cave and the surface topography is therefore necessary to determine the exact position and projection of tunnels and cavities and to analyze the environmental risk, susceptibility hazard, and to detect which measures could contribute to the preservation of the landscape from a social and environmental point of view (Fig. 12).
These underground structures may also be assessed in the light of a cultural and tourist exploitation, even if only a portion of the cave and related tunnels could be now usable for a tourist purpose, for example through guided speleological tours.
For this purpose it is mandatory to enhance other technical and scientific analysis and surveys in order to better estimate the potential development (since some portions of the underground cavities are still unexplored) and the structural and stability conditions related to a possible risk increase.
The lack of attention to the underground heritage by the side of politics and management authorities brings to a consequent degradation of many cavities and increasing the sinkhole risk for significant portions of territory (Beck, 1984; Newton, 1984, 1987; Sinclair, Stewart, 1985; Wilson, Shock, 1996; Parise, Lollino, 2011).
The comparison between the extension of underground

Fig. 9: the wide central volume of the underground quarry is sustained by two massive pillars made by cemented rocky blocks (see figg. 7 and 8 for location).
Fig. 9: l'ampio volume centrale della cava sotterranea è sorretto da due grossi pilastri realizzati con blocchi lapidei cementati (per l'ubicazione di questi si rimanda alle figg. 7 e 8).

Fig. 11: extraction tools abandoned in several points of the underground quarry.
Fig. 11: strumenti di coltivazione abbandonati in molti punti nella cava sotterranea.

cavities and the surface topography is therefore an essential action to undertake, taking into account that the future urban projects will inevitably involve areas close to these cavities. As a likely consequence, a very hazardous situation might be created, in which there would be the possibility to operate without knowing the geometry, the actual size and the environmental and geological conditions of the underground structures (Fig. 13).

Fig. 10: the yellowish sand extracted on the quarry: note the interlayered white calcareous crusts.
Fig. 10: le sabbie giallastre estratte nella cava: si notino i crostoni calcarei biancastri.

This aspect will also be an essential item regarding the development of the plans by the Basin Authority (that is, the body in charge of land management and planning), in analogy with what has already been achieved in other regions or in other Ligurian basins (rediscovery and restoration of tunnels for military purposes, aqueducts, places of worship, canals, etc.).
It is therefore mandatory the involvement of experienced and scientifically qualified speleologists and professionals to gather information and measurements of fundamental importance both for the subsidence hazard assessment and risk mitigation and for the cultural development of the artificial cavities.

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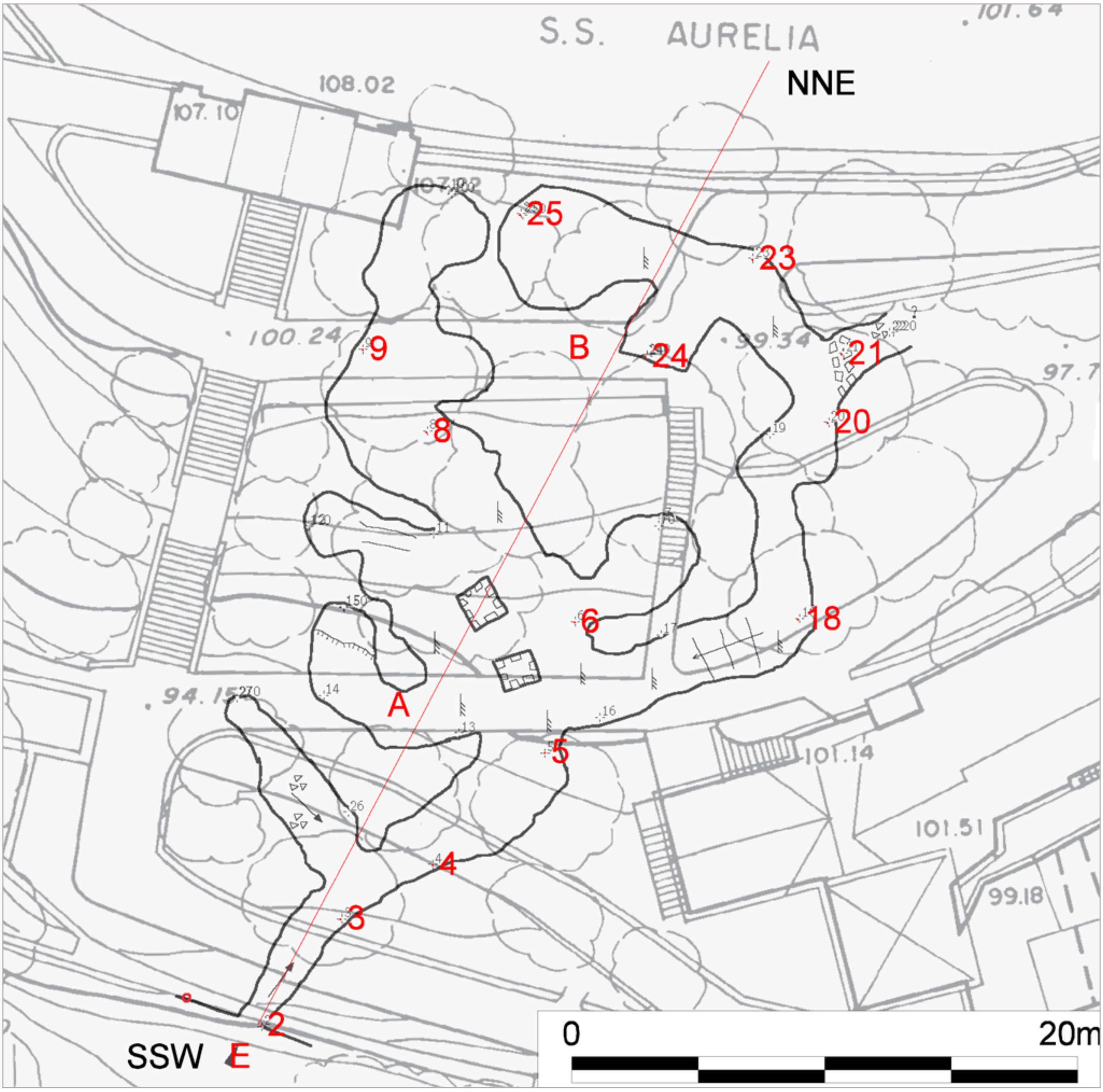

Fig. 12: overlay map between topographic surface and artificial cave plan.
Fig. 12: sovrapposizione tra superficie topografica e planimetria della cavità artificiale.

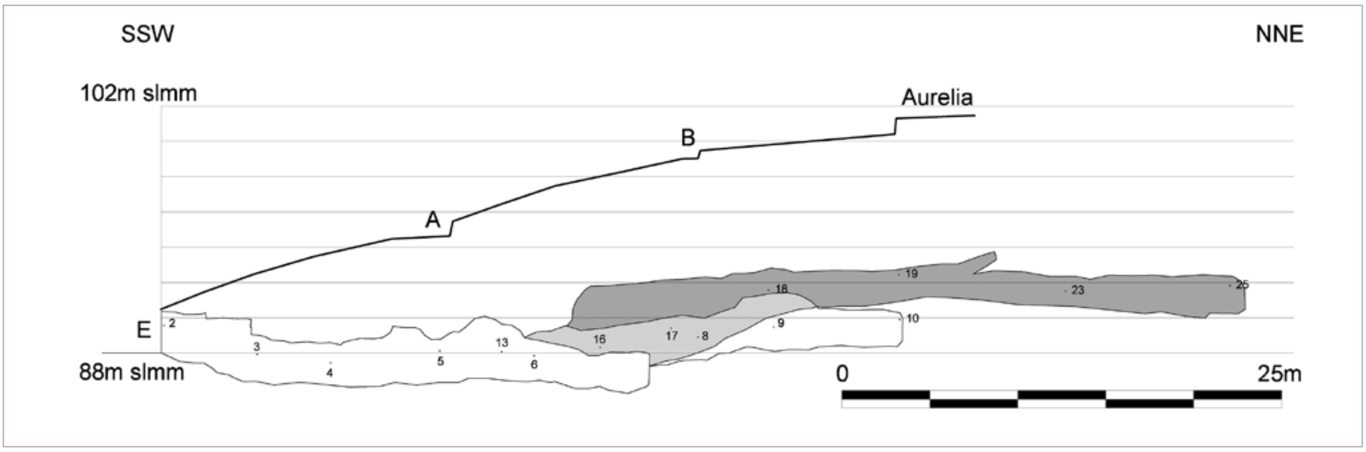

Fig. 13: cross section showing the relationship between the topographic surface and the underground historical quarry.
Fig. 13: sezione illustrativa dei rapporti tra la superficie topografica e la cava storica sotterranea.

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