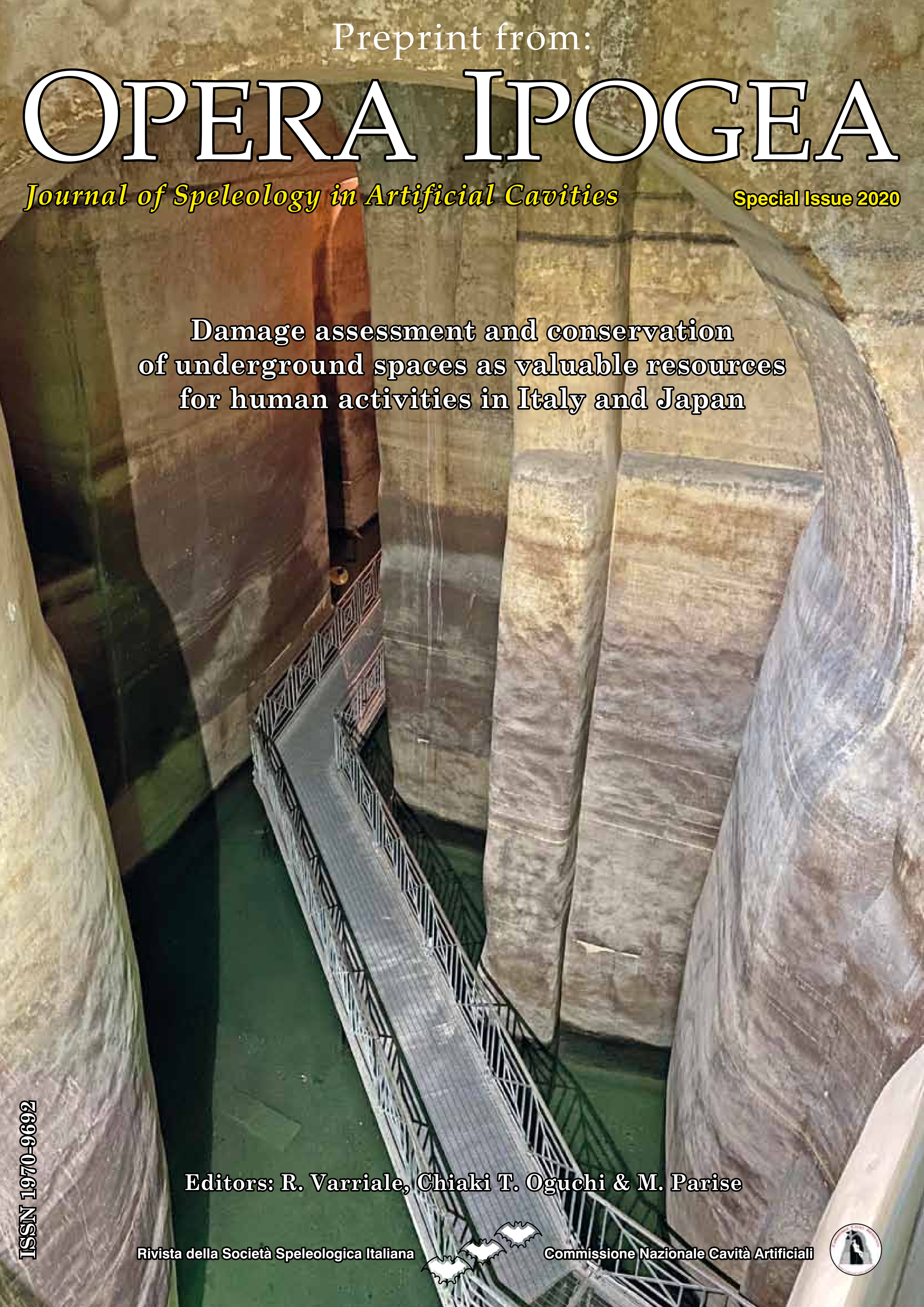
Preprint from:

# OPERA IPOGEA

*Journal of Speleology in Artificial Cavities*

**Special Issue 2020**

## Damage assessment and conservation of underground spaces as valuable resources for human activities in Italy and Japan



Editors: R. Varriale, Chiaki T. Oguchi & M. Parise

ISSN 1970-9692

Rivista della Società Speleologica Italiana

Commissione Nazionale Cavità Artificiali

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# OPERA IPOGEA

*Memorie della Commissione Nazionale Cavità Artificiali*
*www.operaipogea.it*

**Semestrale della Società Speleologica Italiana**
***Semi-annual of the Italian Speleological Society***

**Anno / *Year 22* – Numero Speciale / *Special Issue 2020***
Autorizzazione del Tribunale di Bologna n. 7702 dell'11 ottobre 2006
*Authorization of the Court of Bologna n. 7702 of 11th October 2006*

**Proprietario / *Owner***
Società Speleologica Italiana

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**Sede della Redazione / *Editorial office***
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**Composizione e impaginazione / *Composition and layout***
Fausto Bianchi, Enrico Maria Sacchi

**Copertina / *Cover***
Cisterna il Palombaro Lungo a Matera, Basilicata, Italia (foto: Archivio Antros – Matera)
*Palombaro Lungo water tank in Matera, Basilicata, Italy (photo: Antros Archive – Matera)*

**Quarta di copertina / *Back cover***
Chiesa K4c a Göreme, Cappadocia, Turchia (foto: Archivio Centro Studi Sotterranei – Genova)
*K4c church in Göreme, Cappadocia, Turkey (photo: Centre for Underground Study Archive – Genoa)*

**Prezzo di copertina / *Cover price***
Euro 25,00

**Tipografia / *Print***
A.G.E. s.r.l. – Via della Stazione, 41 - 61029 Urbino (PU) - Italia - Tel. +39 0722 328756

# Instability issues in underground cultural heritage sites

## Instabilità in siti sotterranei di interesse storico-culturale

*Mario Parise*[1, 2]

**Abstract**

Many sites of cultural heritage present part, or all, of their development underground. In some cases, it is precisely the underground sector to host the features of greater cultural and historical interest, thus being the most remarkable section of the site for visitors and scholars. However, entering underground sites, especially after paying a fee for access, requires these are safe and do not present any element potentially harming workers and visitors. To ascertain such requirements, prevention studies and researches are needed, aimed at identifying the possible instability features within the cave system and at their surroundings as well, in order to preliminary evaluate the possibility of failures in the rock mass. This article summarizes the main activities to carry out at this goal, which should represent the first step for any attempt of opening underground sites of cultural and historical heritage to the public. After discussing the main characters of cultural heritage sites with underground development, and their importance in different parts of the world and for many past civilizations, the article examines the main features observed at Taya Cave, in Japan, in one of the case studies considered within the framework of the bilateral project JSPS/CNR “Damage assessment and conservation of underground space as valuable resources for human activities use in Italy and Japan” (2018/2019). Taya Cave, a religious site excavated by Buddhist monks as a meditation place, consists of several corridors and meditation chambers, distributed over three different levels, and partly affected by instability signs.

*Keywords: artificial cavity, stability, cultural and historical heritage, safeguard.*

**Riassunto**

Molti beni culturali e storici presentano parte del proprio sviluppo, o sono interamente contenuti, nel sottosuolo. In numerosi casi, è proprio la parte sotterranea che costituisce il settore di maggiore interesse dal punto di vista storico, culturale, archeologico o antropologico, e quindi quello più oggetto di attenzione da parte di visitatori o studiosi. Entrare in un sito sotterraneo, specialmente se ciò avviene a seguito del pagamento di un biglietto, richiede comunque che il sito sia sicuro e non presenti pericoli di alcun tipo, che possano mettere a repentaglio la salvaguardia dei visitatori e di coloro che vi lavorano (gestori, guide, ec.). Al fine di raggiungere tale livello di salvaguardia, è necessario procedere in maniera preventiva (vale a dire, prima della fruizione pubblica) alla esecuzione di studi e monitoraggi che consentano di raggiungere una adeguata conoscenza sugli elementi fondamentali che caratterizzano l’instabilità dei luoghi, per potere valutare la suscettibilità a crolli o a collassi dell’ammasso roccioso che costituisce la struttura ipogea, oltre che per valutare le generali condizioni dell’ammasso roccioso all’ingresso della cavità e nei suoi immediati dintorni. In questo articolo si passano in rassegna le principali attività da mettere in pratica a tale fine, che dovrebbero costituire sempre la fase iniziale dei lavori indirizzati all’apertura al pubblico ed alla fruizione di siti sotterranei di interesse culturale e storico. Dopo una descrizione dei caratteri da prendere in esame, e dell’importanza che siti ipogei rivestono in varie parti del mondo e hanno avuto per molte civiltà del passato, il lavoro rivolge specificamente la sua attenzione nei confronti di uno dei casi comparativi trattati fra Italia e Giappone nell’ambito delle attività del progetto bilaterale JSPS/CNR “Monitoraggio del rischio e conservazione del sottosuolo antropico come risorse per le attività umane in Italia e Giappone” (2018/2020). Si tratta del caso della Grotta Taya, nei dintorni di Kamakura: è una cavità artificiale luogo di culto, realizzata da monaci Buddisti e che si sviluppa su tre diversi livelli, per una lunghezza totale di poco più di 1,5 km. Nonostante la facilità di accesso, e anche di percorso, all’interno del sistema sotterraneo vi sono alcune evidenze locali di problematiche di instabilità: dalla fuoriuscita di apparati radicali della sovrastante vegetazione lungo le pareti dei corridoi ipogei, che determinano degrado nell’ammasso roccioso ed esfoliazione e distacco di porzioni pellicolari dello stesso, a veri e propri depositi di crollo o derivanti da caduta di porzioni lastriformi dalla volta, sino a fratture con apertura variabile, da capillare a aperte, che talora intaccano anche i bassorilievi di carattere religioso e naturalistico all’interno del sistema ipogeo.

*Parole chiave: cavità artificiali, stabilità, patrimonio storico-culturale, salvaguardia.*

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## Introduction

When dealing with possible fruition to the public of underground sites, we must be sure of the stability conditions of subterranean spaces, before allowing people to access the cavities. This requires necessarily a careful and detailed study that must take into account all those factors playing a role in the present condition within the cave system. The issue of opening underground historical and cultural sites to the public is of high value for many areas worldwide: presence of man, and of his social, cultural, religious activities in caves was recorded in thousands of underground sites, practically during all the past civilizations. This is a huge cultural heritage that we need to keep and carefully exploit, with the twofold goal of preserving the memory of the past and, at the same time, providing the opportunity to local communities to develop socio-economic activities related to management of these sites (fig. 1). Nevertheless, the risk of instability, at both the entrance and within the cavities, cannot be disregarded (fig. 2). It might be sufficient only one sad or unfortunate event (i.e., a rockfall hitting a tourist, causing injuries or death) to literally destroy the work of years for those involved in opening the site to public and managing it through visits.

This paper illustrates the actions that are considered necessary to carry out before opening a cultural heritage site to public, in order to safeguard the lives of visitors, as well as of the operators working therein (managers, guides, etc.). It derives from many years of research about stability of natural and artificial underground caves, and includes part of the activities carried out within the framework of the bilateral project between Japan (JSPS) and Italy (CNR), entitled “Damage assessment and conservation of underground space as valuable resources for human activities use in Italy and Japan” (2018/2019). Following some general considerations about importance of underground cultural heritage sites, and the need to perform stability analyses before opening them to public, some features for one of the case studies dealt with in the aforementioned bilateral project (Taya Cave, in Japan) are described and evaluated.

Fig. 1 – View of the Rivolta village, at the outskirts of the historical centre of Ginosa di Puglia. Notwithstanding the richness of cavities in the town, this is the only sector where they were object of works aimed at offering them to tourists, with free visits to have a glimpse on the rupestrian culture (photo: M. Parise).

*Fig. 1 – Il villaggio di Rivolta, alla periferia del centro abitato di Ginosa in Puglia. Nonostante la grande ricchezza di cavità nell’abitato, è questo l’unico settore ove lavori di sistemazione hanno consentito di offrire ai turisti l’opportunità di affacciarsi al mondo della civiltà rupestre (foto: M. Parise).*

Fig. 2 – Farmacia del Mago Greguro *(Wizard Greguro Chemist's)*, a well-known artificial cavity excavated along the flank of a karst valley at Massafra (Apulia, Italy): above, general view of the site; below, release tension cracks extending from pavement and walls to the vault in the outer part of the cave (photos: M. Parise).

*Fig. 2 – Farmacia del Mago Greguro, nota cavità artificiale scavata lungo il fianco di una valle carsica a Massafra (Puglia, Italia): in alto, vista complessiva del sito; in basso, fratture da rilascio tensionale che si estendono da pavimento e pareti sino in volta, lungo la porzione esterna della cavità (foto: M. Parise).*

## Stability of cultural heritage sites: why it is a crucial issue

Cultural heritage sites are distributed all over the world, and many of them have, at least partly, an underground development. The underground has always played an important role in culture, civilizations and religions: it represents typically the entrance to the below, signifiying the passage to the after-life. In prehistoric times, it was the main shelter for humans, the home where to protect themselves from animals, harsh weather, different types of hazards, enemies. This means that caves, both natural, and later on man-made, definitely had a primary role in the history of humankind.
The most significant sites, considered of high importance to humans, are those enlisted in the World Heritage List of the United Nations Educational, Scientific and Cultural Organization (UNESCO). This organization aims at encouraging the identification, protection and preservation of cultural and natural heritage around the world, considered to be of outstanding value to humanity. This is embodied in an international treaty called the Convention concerning the Protection of the World Cultural and Natural Heritage, adopted by Unesco in 1972. Since then, 1121 sites have been included in the Unesco World Heritage List (https://whc.unesco.org/). Out of this, more than 150 sites have been established for values directly related, or somewhat linked, to underground features. They are distributed over 73 state parties, in all the continents, and in 7 cases are transboundary, that is they involve two or three countries. The majority of the sites, corresponding to 52 %, belong to the list of cultural sites; 37% have been defined for natural criteria, and 11% are mixed (including both cultural and natural criteria). Among the natural sites, the link with the underground environment is generally due to presence of karst landscape and landforms, and/or of caves, in many cases of remarkable importance for prehistoric art on their walls, testifying some of the most ancient pictorial representation of humankind (Lawson, 2012). The most remarkable of the sites showing mixed criteria, enlisted by Unesco, is probably the *Goreme National Park and the rock sites of Cappadocia*, in Turkey (fig. 3), where a

Fig. 3 – Typical view of Cappadocia (Turkey), showing the beautiful combination of natural landscape and artificial cavities (photo: M. Parise).

*Fig. 3 – Tipico panorama della Cappadocia (Turchia), con la magnifica integrazione di bellezze naturali del paesaggio e diffusa presenza di cavità artificiali (foto: M. Parise).*

wonderful combination of beauty of the natural landscape and history and ability in realizing underground structures, and making them an essential part of the cultural and social life, is witnessed (Triolet & Triolet, 1993; Bixio *et al.*, 2002; Gilli *et al.*, 2014).

The situation is more variegated when looking at the man-made underground features that characterize the Unesco cultural sites. About this issue, a variety of cavities excavated or realized by man with many different purposes appear. Using the typological tree of classification (Galeazzi, 2013; Parise *et al.*, 2013) they belong mostly to three categories: E (mining works, with prevalence of E3, metal mines, but presence also of E2, salt mines), C (religious works, as both C1, place of worship, and C2, burial places), and A (hydraulic works, including all the works realized for water systems, from collection, transport and distribution). Nevertheless, all other categories are also represented, as permanent dwellings (B1), transit tunnels (F2), defensive works (D1), etc. Of particular importance are the underground water systems in many different settings, especially characterizing semi-arid lands, where the availability of the water resource was more limited, and man had to find sustainable ways to keep and use it during the dry season: called in different ways according to the different languages (*qanat, falaj, aflaj*, *karez*), these systems are absolutely remarkable, and show the high level of hydraulic engineering technique that was reached by past civilizations (Laureano, 2001; Mays, 2007; Al-Taiee, 2012; Semsar Yazdi & Labbaf Khaneiki, 2010, 2012).

In all the Unesco sites where access to the underground elements is allowed, so that visitors could enjoy the beauty of the subterranean world and of the works therein realized by man in past epochs, the main issue to be considered is stability of the site, related to a variety of natural hazards (Ghosh, 1990; Yan *et al.*, 2001; Sassa *et al.*, 2002; Margottini & Spizzichino, 2014).

In addition to the Unesco sites, presenting peculiar and remarkable elements that guided to their inclusion in the World Heritage List, many other sites do exist sharing similar cultural, historical and archaeological features. These are typically managed at the national, regional, or (this being the most common situation) at the local level. Whatever the management, an assessment of the stability conditions should be required in these cases too, in order to ensure safety for workers and visitors.

A preliminary count of rupestrian settlements in the Mediterranean Basin resulted in about 2,000 sites (Bixio *et al.*, 2012; Polimeni *et al.*, 2019), each one of them in turn consisting of tens or hundreds of individual cavities, bringing the overall count of cavities to an incredible number. Many of these show remarkable value as regards the cultural and historical heritage, testifying past civilizations and different ways of living, often in difficult environmental situations (Golany, 1989). Technical capability in construction and maintenance of the sites, and a careful sustainable use of the natural resources, derived from a thorough knowledge of the natural environment and a deep respect of wilderness, are astonishing if we think to time of realization of the most ancient settlements.

Differently from what initially thought during the 1800s, the development of a “rupestrian culture” in many areas of the world appeared to be not limited only to the dimension of a religious and meditation purpose, as hermits or monks, but rather it became actually a way of living in caves (Fonseca, 1970; Raspi Serra, 1976; Laureano, 1993; Lionetti *et al.*, 2015). In other words, man tried to adapt his needs taking advantage of what was offered by the local landscape, and worked to realize underground facilities. Even in adverse and difficult climatic conditions, in response to collective needs the landscape was therefore transformed to find architectural solutions that could allow the communities to establish a way of settling in the natural environment, adapted to its main characteristics. This was obtained by digging and carving the rock mass, in order to produce dwellings and shelters, at the same time learning to take from the natural ecosystems (plants, animals) food and other resources.

From a technical standpoint, in terms of possibility to create underground dwellings, the rock mass had to satisfy some fundamental constraints: first of all, it had to be easy to work, at the same time providing good mechanical properties to sustain the excavation and to guarantee stable conditions. Morphology of the site is among the main controlling factor in the development of the rupestrian culture (Del Prete & Parise, 2013): it offered, for instance, a safe place from enemy attacks in case of steep to vertical rock walls. At the same time, vertical or overhanging walls are typically the sectors mostly affected by slope failures and instability. Especially when the settlements consisted of multi-story dwellings, the many rooms excavated in the rock mass, with a variety of interconnecting passages, could result in an overall decrease in the mechanical properties of the outer portion of the rock mass (Pecorella *et al.*, 2004; Aydan *et al.*, 2005; Waltham & Lu, 2007; Fraldi & Guarracino, 2009). This latter is the most susceptible sector to instabilities, since it is interested by development of release tensional cracks, at the origin of frequent rock falls and failures from vertical walls (figs. 4 and 5).

Typology of the artificial cavity has also to be taken into account: for instance, in contrast to usual dwelling, generally showing simple plan and limited extension, rock-cut churches and worship sites cover a wide range of planimetric shapes, from a single room to highly complex structures, with a variety of architectural elements (apse, niches, etc.) (Dell’Aquila & Messina, 1998), also distributed in multiple stories, up to hermitages and monasteries, often decorated with rupestrian paintings, that were dug into the tuff and limestone rock masses.

The region of Cappadocia is extremely rich in rock-cut churches, counting to no less than 600 (De Jerphanion, 1925; Jolivet-Levy, 1997; Rodley, 2010). In detail, the provinces of Nevşehir, Kayseri, Kırşehir, Aksaray and Niğde show the highest concentration of underground sites in the volcanic tuffs of Anatolia, and have

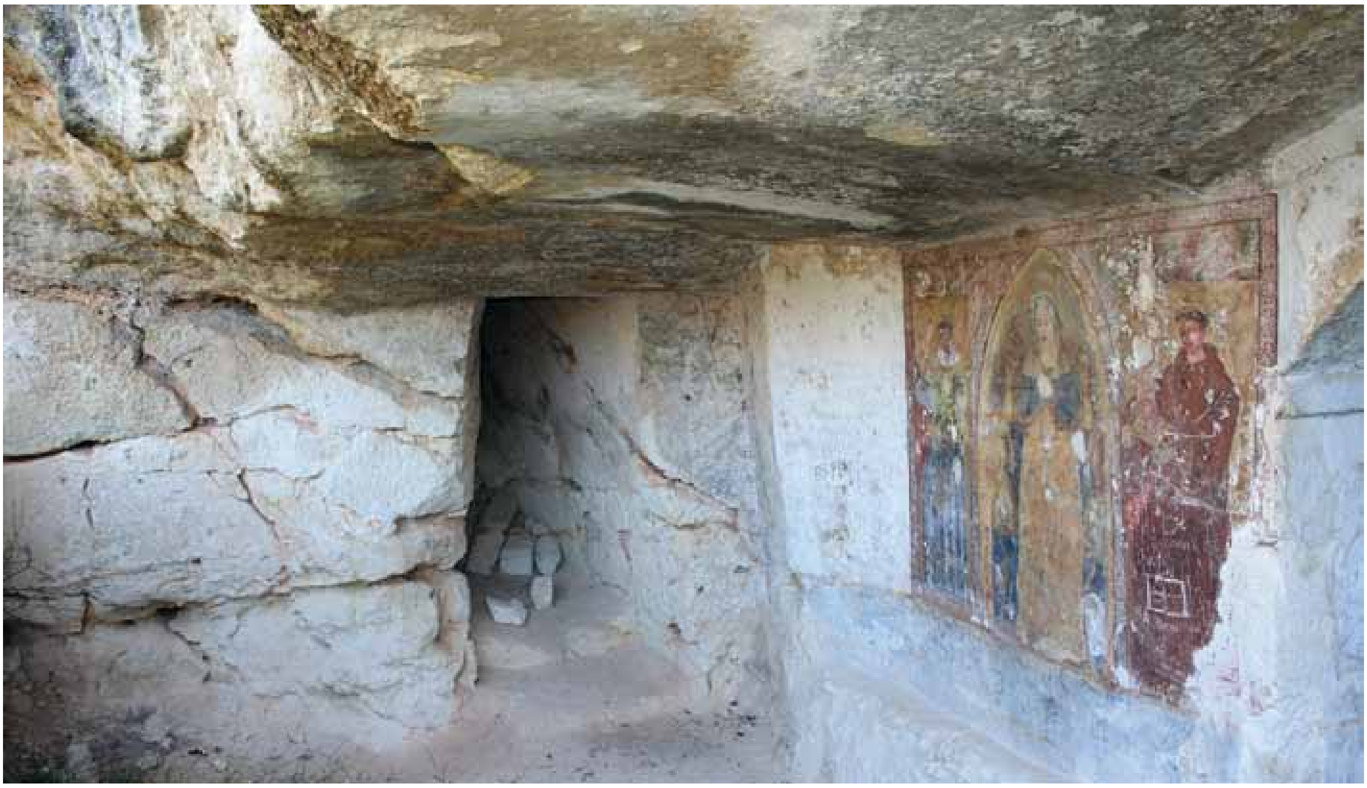

Fig. 4 – Severe cracks affecting a worship site (typology of artificial cavity C1 in the classification by Parise et al., 2013) (photo: M. Parise).

*Fig. 4 – Profondo sistema di lesioni che attraversano un sito di culto (tipologia di cavità artificiale C1 nella classificazione di Parise et al., 2013) (foto: M. Parise).*

Fig. 5 – Open cracks crossing the entrance of artificial cavities, threatening the overall stability of the sites: above, artificial cavities at Otranto; below, a cavity in the Fasano area (photos: M. Parise).

*Fig. 5 – Fratture aperte che interessano l'ingresso di cavità artificiali, a minacciare la stabilità dei siti: in alto, cavità artificiali a Otranto; in basso, una cavità nella zona di Fasano (foto: M. Parise).*

historically represented a cultural bridge linking the East and the West, with remarkable evidence of architectural and artistic remains. Cappadocia includes thousands of sites of religious importance (churches, monasteries, tombs), as well as civil settlements and other types of artificial cavities, also comprising very ingenious water systems to guarantee the possibility to collect, transport and use the precious water resource (Castellani, 2001; Bixio *et al.*, 2002, 2017; Hu *et al.*, 2012; Parise & Sammarco, 2015). Water resources were provided through complex networks of surface channels, excavated to collect and transport the rainfall, and to feed with water the underground cisterns and tanks, following techniques that have widely been found also in other parte of the world (Laureano, 2001; Parise *et al.*, 2013).

## Opening a cultural heritage site to the public

A crucial point in the valorization of cultural heritage sites is the possibility to allow its fruition to the public. Whether this might be organized through payment of a fee for visitors, or through free access, or limited to scholars and experts, the first action to be taken is an evaluation of the stability at the site. Without this step, it is not possible to have people entering the site. The stability assessment has necessarily to include analysis of the outer part of the cavity: that is, its entrance area, but more in general the hill or ridge where it has been excavated. This is important to be sure that no possibility exists for failures from higher sectors, that could eventually reach the cave access and produce damage or threaten the visitors. Then, it should move to examine the cavity itself, by taking into account a variety of features that might indicate instability. By using as base map a topographic survey of the cave systems, obtained through classical or innovative (laser scanner) methods or by means of speleological approaches (Day, 2002), several geological and geo-structural elements can be mapped to have a preliminary indication about the stability condition at the site (Parise, 2015): among these, presence and pervasiveness of discontinuities, and understanding of their origin (primary, as bedding planes; tectonic, as joints and faults; or gravitational, as release tension cracks in the proximity of the outer slopes). Typically, the zones of highest weakness are represented by areas where more discontinuity systems are present. Aperture of the cracks, and passage of water through them, is also of crucial importance, since it indicates the possibility of water infiltration, eventually resulting in degradation of the rock mass (Ulusay & Hudson, 2007), and, in cases of friable and soft materials, in the possibility to easily enlarge the joints, predisposing the site to failures (fig. 6).

Any other feature that might play a role in favouring instabilities has also to be observed: for instance, the effects of vegetation from outside, since the roots could enter the cracks in the rock mass, also acting to widen them. If the root systems are able to reach the underground spaces, some effects on the rocks can be seen, in form of exfoliation and crumbled rock material along the walls. This effect is of course linked to the action of water within the discontinuity system, and needs to be carefully checked, especially during, or soon after, heavy rainstorms.

Presence of breakdown deposits, derived from occurrence of past events of failures, is particularly significant to be mapped because they provide the essential proof that some sites have been affected in the past by instability. The possibility of new failures is generally higher when these have already occurred previously, so the mechanisms of failures must be identified, and an assessment of the residual risk (possibility of further failures) carried out. In the most critical situations, some parts of the cave system could be closed to visitors, if their present conditions are too dangerous.

All the informations above represent the basis on which to design a monitoring system, aimed at controlling the evolution of the critical sites through installation of specific equipments such as fessurimeters. Further, physical parameters (temperature, air humidity) in the cave system should also be monitored. This activity is important before opening the cave to public, and should be carried out for at least one or two years, in order to understand the physics of the underground environment during the seasons, and on the occasions of the most significant rainstorms as well. As defined for show caves, in natural karst underground environment, these data are essential for the definition of the visitor capacity of the cave: this is defined as "that flow of visitors into a defined cave that confines the changes in its main environmental parameters within the natural ranges of their fluctuation" (Cigna, 1993). In practice, the visitor capacity establishes the maximum number of visitors that could enter the site in groups, in order not to produce any negative effects (in terms of damage, or disturbance) on the underground system (Cigna & Forti, 1988).

Eventually, the data above, including the monitoring data, might be useful for the design and realization of any stabilization works, wherever these are considered to be necessary to safeguard the site.

## Considerations on the Taya Cave, Japan

Taya Cave (fig. 7a) is an artificial cave at the outskirts of Kamakura, Japan, which origin is likely to go back to the 13$^{th}$ century (Kamakura period). The cave, excavated by Shingon Buddhist monks as a site for spiritual training, is the longest of this type in Japan, with an overall length of several hundreds of meters (Jeremiah, 2006, 2007). Time of excavation is not certain, with estimate ranging from the year 1200 to 1700. The result is a underground maze of tunnels and passages, distributed over three interconnected levels. From a geological standpoint, the subterraneans spaces have been excavated in Quaternary marine sediments, consisting of silts and sandstones (Oguchi *et al.*, 2020). The cave consists of corridors leading to meditation chambers which

Fig. 6 – Frescoes of the pre-iconoclast period in the Agacalti Kilisesi (Daniel Pantonassa Church) in the Ilhara Valley (Cappadocia, Turkey), heavily interested by open cracks (photo: M. Parise).

*Fig. 6 – Affreschi del periodo pre-iconoclasta nella Chiesa Agacalti nella Valle Ilhara in Cappadocia (Turchia), fortemente interessate da fratture beanti (foto: M. Parise).*


Fig. 7 – Taya Cave, Japan: a) entrance of the cave; b) cracks crossing some reliefs on the walls of one of the meditation chambers; c) evidence of slab detachments from the vault; d) fall deposits of variable size partly closing a sector of the cave; e) roots entering the wall cave, causing exfoliation processes in the outer portions of the rock mass (photos: M. Parise).

*Fig. 7 – Grotta Taya, in Giappone: a) ingresso della grotta; b) lesioni in parete, che attraversano bassorilievi all'interno di una degli ambienti di meditazione; c) distacchi di lastre di roccia dalla volta; d) depositi di crolli, che occludono parzialmente uno dei passaggi nel sistema ipogeo; e) radici che attraversano le pareti della cavità, determinando la esfoliazione delle parti esterne dell'ammasso roccioso (foto: M. Parise).*

walls and ceilings have been carved with Buddhist images; there is also a spring room, with relief of a great turtle and birds on the walls. Several inscriptions and mantras (sacred words), carved in kanji and sanskritic languages, decorate the upper walls (Jeremiah, 2007).

The complex development of the underground passages, distributed at different levels, testifies the engineering ability of the workers at its time of realization. Traces of the excavations, and remains of the chisel and of the other tools used, can be seen at many sites within the cave system. Many Buddhist reliefs have been added to the cave during different phases of renovations in the late 19$^{th}$ century.

Taya-cave is since 1990 a historic site registered as cultural property of Yokohama City. The cavity is within the area of the Josenji Temple. Due to several evidence of degradation at the site, in 2017 the Taya-cave preservation execution committee was established.

The artificial cavity is located below Mt. Taya, in the area of a*"satoyama"*, that is an area at the foothill of a ridge or small mountain, characterized by different types of plants and trees, and generally managed by

Fig. 8 – General view of an underground oil mill affected by serious fracturing, and details of a fractured pillar, from which detachment of small parts of rock has already occurred, due to excessive overload (photos: M. Parise).

*Fig. 8 – Vista complessiva di un frantoio ipogeo interessato da severe lesioni, e dettagli di un pilastro fratturato, dal quale distacchi di materiali rocciosi sono già avvenuti a causa del sovraccarico esistente (foto: M. Parise).*

the local community. Presence of a thick vegetative cover at the ground may also play a negative role with regard to instability, due to the underground development of the tree roots: these may be observed at several locations within the cave (fig. 7e), showing their capability to cross the overburden and reach the underground void, thus causing degradation of the rock mass, development of weathering processes, and eventually detachment of slabs of rocks (fig. 7b, c).

As correctly stated by Tamura *et al.* (2020), in order to develop conservation plans for Taya Cave it is therefore necessary to consider also the rural regional town planning and design, taking into account management and planning of the *satoyama*, beside that of the cavity itself. The strong link between the cavity and the overlying terrains cannot be disregarded as regards any conservation activity that would be implemented at the site.

Strictly from a standpoint of stability within the cave, it has to be pointed out that degradation and weathering are affecting the bas-reliefs (fig. 7b), and locally they have a serious effect in small-scale failures, occurring through exfoliation and detachment of cm-wide pieces of walls, and in erosional features related to the passage of water rills. These latter may be observed also at the main entrance of the cave, where the runoff coming from the hill above works in producing rills and small gullies in the slope. As previously mentioned, detachment of slab walls is further favoured by the presence of vegetation roots, coming out along the cave walls and vault.

Tension cracks, from hair cracks to more enlarged, open joints, are visible at many locations in the cave. They often cross the bas-reliefs, and in several cases act as water ways, as highlighted by the dark color surrounding the cracks at thos points where the water comes at the surface. These features, even though generally not severe, represent in any case an indication of processes going on, and should be carefully monitored in order to ensure stability at the site, and to mitigate the risk to visitors.

The situation is, on the other hand, definitely more serious in other sectors of the cave, where breakdown deposits are present (fig. 7c, d), as well as evidence of slab failures from the walls. These are indications of past instability, that might proceed upward through progressive failures. At such sites, a careful survey should be carried out, to verify thickness and characters of the overburden, aimed at evaluating whether the possibility of upward stoping of the failures might be real or not. At this goal, several studies have shown the importance in evaluating the stability conditions in correspondence of the main places of support of the cave systems (fig. 8), such as pillars and arches (Carter, 1992; Diederichs & Kaiser, 1999; Swedzicki, 2001; Hutchinson *et al.*, 2002; Fraldi & Guarracino, 2009).

Overall, the historical and religious value of Taya Cave requires to put in practice actions to safeguard the site and to ensure safe visits to the place. A careful mapping of the instability features within the cave system might be the priority, in parallel to implementation of a monitoring system at the most critical sites of the cave. These actions should be pursued while also taking into exam the ground features above the cave, from type of vegetation, water infiltration, analysis of the water need of existing plants and trees, eventually taking into account the possibility to change the vegetative cover by putting in place plants with lesser development of root systems and/or with lower need of water. Surface drainage system could also be considered in order to reduce the infilitration of water underground. Even if the overall situation of Taya Cave seems not to be particularly severe, the measures indicated above are considered necessary to preserve the site, at the same time allowing small group of visitors to enjoy the cave and its religious atmosphere.

## Final considerations

Valorisation of the cultural heritage, especially when these are located in small villages and/or in rural areas, should be the priority for land managers and developers, and become a real possibility to develop local economies and involve people in social activities (Lapenna *et al.*, 2017). Nevertheless, any attempt in attracting tourists to visit underground cultural and historical sites must be accompanied by careful evaluation of the likely hazards, in order to design plans and implement actions aimed at the mitigation of the risks: as concerns underground cavities, the most common hazard is represented by sinkholes, generally of the collapse, or cover-collapse, types (Gutierrez *et al.*, 2014; Parise, 2019). In many areas of the world an high frequency of collapses linked with underground artificial cavities is being observed in the last decades (Canakci, 2007; Ferrero *et al.*, 2010; Sunwoo *et al.*, 2010; Parise, 2012, 2015; Parise & Vennari, 2013). This highlights the need of prevention works, before any exploitation and valorization plan could start, with the goal to understand the possible occurrence and evolution of failures (Hatzor *et al.*, 2002; Parise & Lollino, 2011; Lollino *et al.*, 2013). A complete geotechnical study should start from characterization of the main physico-mechanical properties of the rock mass (Boadu, 1997; Andriani & Walsh, 2006), and of their discontinuity networks, with a particular focus on the degradation of the material in function of the wetting and weathering processes (Zupan Hajna, 2003; Ghabezloo & Pouya, 2006; Calcaterra & Parise, 2010). Data and information deriving from these phases of study and analyses should then be integrated by others from indirect surveys, namely geophysical methods (Boadu, 1997; Cardarelli *et al.*, 2003; Pepe *et al.*, 2015), that become particularly important when logistics and accessibility of the site is difficult. For monitoring, and to reconstruct the historical evolution of the sites during a time span of years, even the use of satellite data could be useful (Abelson *et al.*, 2003; Castaneda *et al.*, 2009; Gutierrez *et al.*, 2011; Calò *et al.*, 2011). In this way designers might eventually have available all the necessary information to correctly decide the most feasible and suitable engineering works of stabilization, if needed (fig. 9), or to proceed with exploitation of the site.

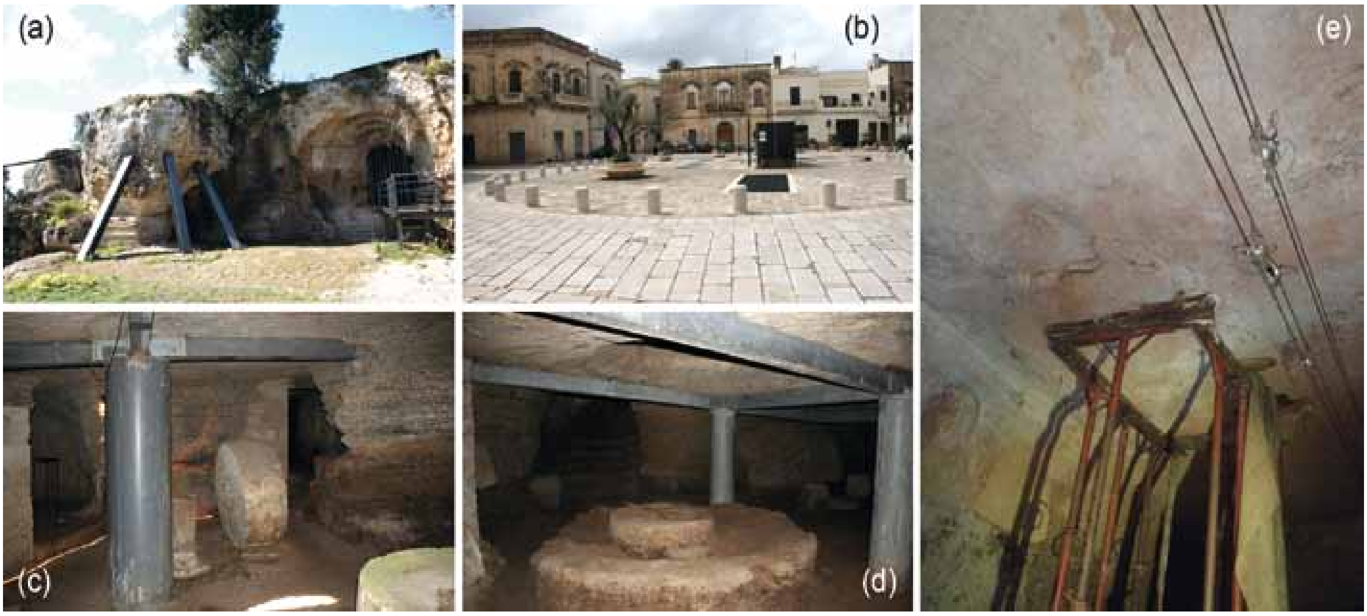


Fig. 9 – Stabilization works in artificial cavities of cultural heritage in Apulia: a) sustaining steel rods at Fasano; b) view of the main square in Presicce, showing the entrance to the system of underground oil mills; c, d) details of piles and beams for stabilizing the site, that is now open to public; e) temporary scaffolding to sustain the vault, showing open cracks, at Cantina Spagnola, the most famous artificial cavity of cultural interest at Laterza (photos: M. Parise).

*Fig. 9 – Lavori di stabilizzazione in cavità artificiali di interesse culturale in Puglia: a) colonne di acciaio di sostegno a Fasano; b) la piazza principale di Presicce, con l'accesso al sistema sotterraneo di frantoi ipogei; c, d) dettagli di pali e travi di sostegno nell'ambiente ipogeo di Presicce, al fine di stabilizzare il sito, attualmente aperto al pubblico; e) impalcature temporanee a sostegno della volta, interessata da lesioni aperte, nella Cartina Spagnola, la cavità artificiale di maggiore interesse culturale a Laterza (foto: M. Parise).*

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