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A HUGE CULTURAL AND HISTORICAL HERITAGE AT RISK: THE UNDERGROUND SETTLEMENTS OF SOUTHERN ITALY

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Abstract
The artificial cavities, excavated by man in different epochs and for many different purposes and functions in southern Italy, are increasingly suffering from problems of instabilities, which upward propagation may reach the ground surface and cause sinkholes. In addition to the main towns, as Naples and Palermo, where thousands of cavities of different sizes mark the urban and peri-urban territories, all the historical parts of towns and villages, and large rural sectors as well, are filled with man-made caves, that often pose nowadays serious risk to the built-up environment. As shown in many recent works, underground quarries are the type of artificial cavity that has caused the most severe problems in the last decades. In this paper, on the other hand, the hypogean civilian dwellings are taken into account: these are complexes of tens or hundreds of caves, that as a whole represented old villages, with civil dwellings, religious sites, and hydraulic works to guarantee the availability of the water resource to inhabitants, even during the hot dry season. In southern Italy, and in particular in the eastern regions (Basilicata, Apulia), such settlements were realized along the rock cliffs of *gravine*, the term used to designate the typical valleys of fluvio-karst origin, excavated in the Pliocene-Pleistocene calcarenites. With time, abandonment of these cavities, combined to degradation of the sites (often used as unauthorized landfills) and to water infiltrations, resulted in frequent collapses, that locally may threaten the nearby infrastructures and buildings. The issue of collapses linked to artificial cavities has therefore become important even for civil protection, and has to be carefully evaluated, in order to guarantee the safety of people and structures. In this paper, through description of some recent case studies, this topic is dealt with, aimed at pointing out the need to avoid degradation of this precious heritage, for preserving its remarkable cultural importance, and for mitigating the risk to society related to likely collapses and failures as well.
Keywords: hazard, risk, cultural heritage, safeguard, civil protection, southern Italy.

Riassunto
Cavità di origine antropica, scavate dall'uomo in Italia meridionale in varie epoche e per scopi diversi, soffrono sempre più di problemi di instabilità, la cui propagazione verso l'alto può raggiungere la superficie e originare sprofondamenti. Oltre a grandi città come Napoli e Palermo, dove migliaia di cavità di dimensione varia caratterizzano il territorio urbano e peri-urbano, tutti i centri storici di cittadine e villaggi, e anche settori rurali, mostrano numerose cavità artificiali che di frequente pongono un serio rischio all'ambiente urbanizzato. La tipologia di cavità artificiale all'origine del maggior numero di problemi è rappresentata dalle cave sotterranee. In questo lavoro, invece, si prendono in esame gli insediamenti ipogei civili: questi sono in genere complessi costituiti da decine o centinaia di grotte, che nell'insieme costituivano veri e propri antichi villaggi, con abitazioni civili, siti religiosi, e opere idrauliche per garantire la disponibilità della risorsa idrica agli abitanti, anche nel corso delle stagioni secche. In Italia meridionale, e in particolare in Basilicata e Puglia, questi insediamenti erano realizzati lungo le pareti rocciose delle gravine, termine con cui si indicano le tipiche valli di origine fluvio-carsica, scavate nelle calcareniti del Pliocene-Pleistocene. Nel tempo, l'abbandono di tali cavità, combinato al degrado dei siti (spesso utilizzati come discariche abusive) e a infiltrazioni d'acqua, sono risultati in frequenti episodi di collasso, che localmente possono minacciare le vicine infrastrutture ed edifici. Il tema dei crolli di cavità artificiali è quindi divenuto importante anche per la protezione civile, e richiede una attenta valutazione, al fine di garantire la sicurezza di persone e strutture. In questo articolo, attraverso la descrizione di alcuni recenti casi di studio, viene trattato l'argomento, evidenziando la necessità di evitare i fenomeni di degrado di tale prezioso patrimonio, per preservarne l'eccezionale importanza storico-culturale, e per mitigare il rischio alla società derivante da probabili instabilità e collassi.
Parole chiave: *pericolosità, rischio, beni culturali, salvaguardia, protezione civile, Italia meridionale.*

Introduction

Southern Italy, for a number of historical and geological reasons, presents a huge amount of artificial cavities, excavated by man in different epochs and for many different purposes and functions, practically covering all the categories of the typological classification developed by the Commission on Artificial Cavities of the Italian Speleological Society (Parise et al., 2013b). In addition to the main towns, as Naples and Palermo, where thousands of cavities of different sizes mark the urban and peri-urban territories, all the historical parts of towns and villages, as well as large sectors in the rural areas, are filled with man-made caves, that often pose nowadays serious risk to the built-up environment (Fig. 1).

The presence of man-made cavities below the historical parts of towns is a common feature in large portions of Italy. Different typologies of anthropogenic cavities have been excavated in different epochs for many purposes, including temporary or long-lasting civil

Fig. 1: view of Gravina in Puglia, showing the present town buildings and roads above ancient caves.
Fig. 1: veduta di Gravina in Puglia, con edifici e strade della città moderna ubicati al di sopra di antiche cavità artificiali.

settlements, research and collection of potable water, establishment of underground working sites for olive oil production, worship sites, underground quarries, etc. Originally located at the outskirts of towns, many of these cavities are increasingly found in built-up areas due to urban expansion that has characterized the last century. Realization and excavation of the cavities had necessarily to take into account the main physical properties of the rock mass, and a number of geological constraints (Fig. 2) had to be considered at the time of construction to guarantee the stability of the cave.

As shown in many recent works, underground quarries are the type of artificial cavity that has caused the most severe problems in the last decades (Barnaba et al., 2010; Formicola et al., 2010; Parise, 2010, 2012; Del Prete et al., 2011; Fiore & Parise, 2013). The most significant sites at this regard, beside the town of Canosa di Puglia

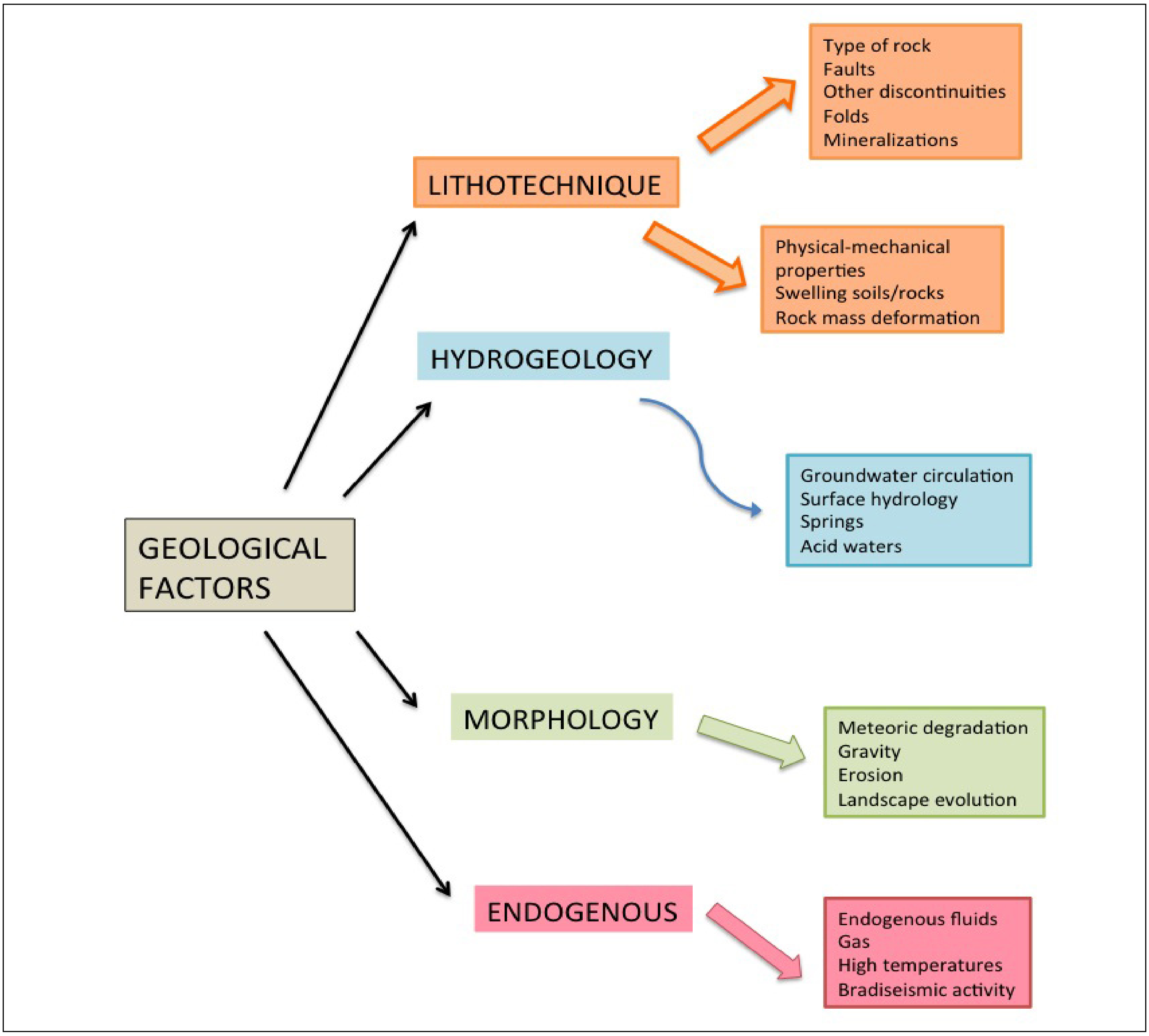

Fig. 2: flow chart summarizing the main geological factors constraining the realization of artificial cavities (modified after Del Prete & Parise, 2013).
Fig. 2: diagramma di flusso sintetico dei principali fattori geologici condizionanti la realizzazione di cavità artificiale (modificato da Del Prete & Parise, 2013).

during the 1980s and 90s, is Altamura, where in the last decades many problems have been encountered, due to expansion of the urban areas in sectors where a complex network of underground quarries is present (Pepe et al., 2013). Many sinkholes were registered, with the latest in December 2013 (Fig. 3), and the whole area was involved in detailed cave mapping that represented the base for building a susceptibility map to sinkholes (Fig. 4).

In this paper, on the other hand, the hypogean civilian dwellings are taken into account: these are complexes of tens or hundreds of caves, that as a whole represented old villages, with dwellings, religious sites, and hydraulic works to guarantee the availability of the water resource to inhabitants, even during the hot dry season (Fonseca, 1980; Laureano, 1993, 2001). In southern Italy, and in particular in the eastern regions (Basilicata, Apulia), such settlements were realized along the rock cliffs of *gravine*, the term used to designate the typical valleys of fluvio-karst origin, excavated in the Pliocene-Pleistocene calcarenites (Parise et al., 2003).

With time, abandonment of these cavities, combined to degradation of the sites (often used as unauthorized landfills) and to water infiltrations, resulted in frequent collapses, that locally may threaten the nearby infrastructures and buildings. The issue of collapses linked to artificial cavities has therefore become important even for civil protection issues, and has to be carefully evaluated, in order to guarantee the safety of people and structures.

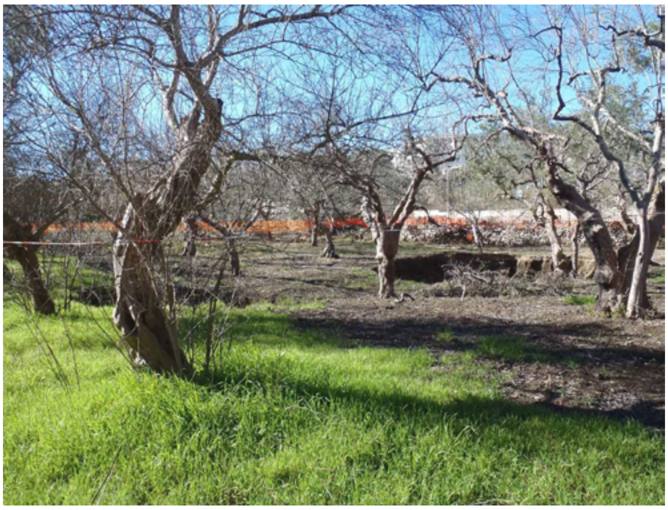

Fig. 3: the most recent sinkholes at Altamura, occurred in December 2013.

Fig. 3: i più recenti sprofondamenti ad Altamura, avvenuti nel Dicembre 2013.

Instability related to artificial cavities

Failures in underground caves do not occur without warning, and the effects produced by the processes active in deforming the rock mass can be generally observed before major displacement occurs (Parise,

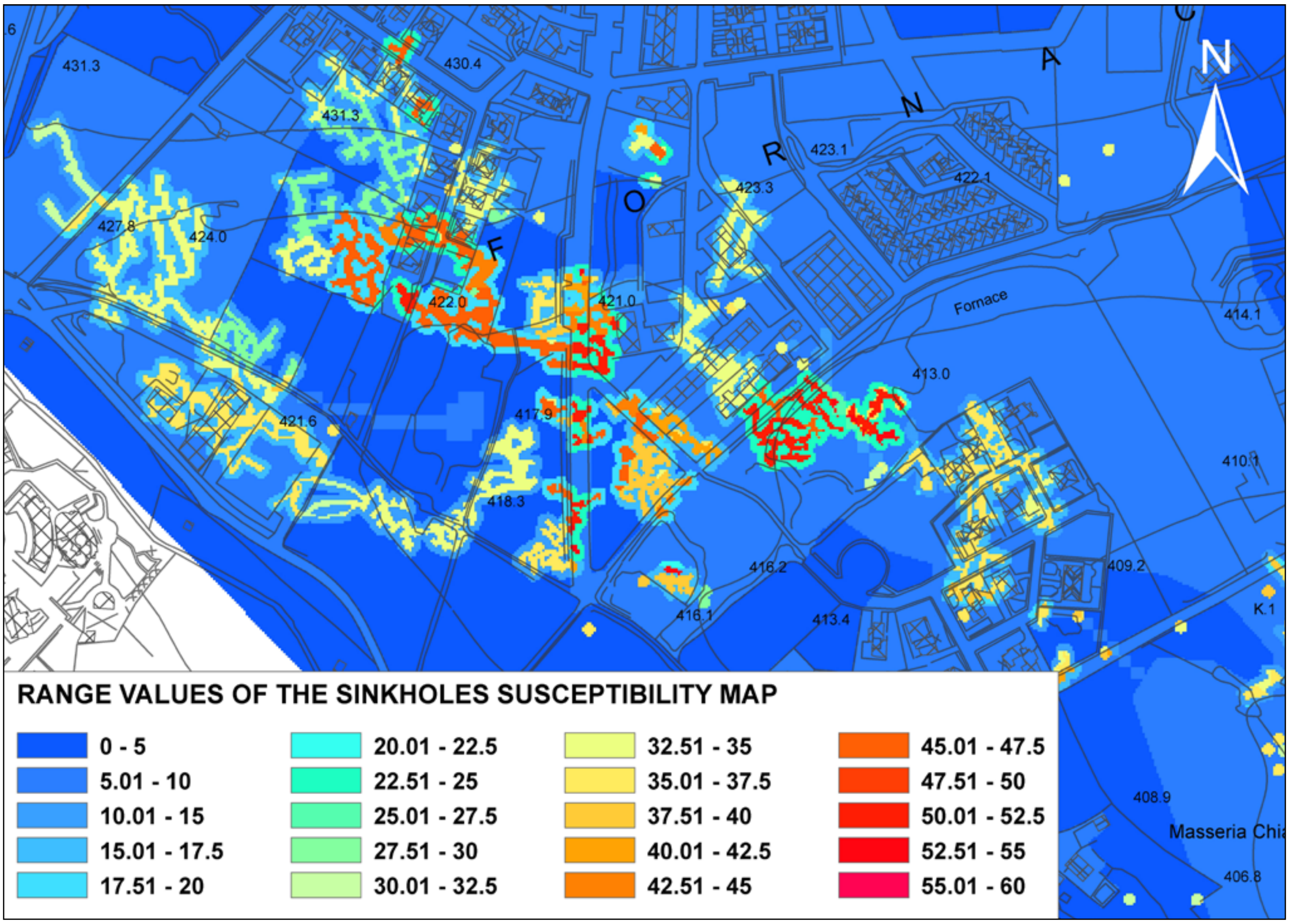

Fig. 4: sinkhole susceptibility map at Altamura (after Pepe et al., 2013).

Fig. 4: carta della suscettibilità agli sprofondamenti ad Altamura (da Pepe et al., 2013).

Fig. 5: incised thalweg of the gravina at Ginosa, as an effect of the flooding events of October and December 2013.
Fig. 5: incisione nel fondovalle della gravina di Ginosa, in conseguenza degli eventi alluvionali di Ottobre e Dicembre 2013.

2013). The main problem lies in the possibility to observe and recognize such phenomena.
Documentation by cavers, in particular, is extremely important, since it provides local authorities and land use planners the indispensable material (maps, photographs, videos) to take their decisions. This is true especially for artificial cavities, frequently located below or in the proximities of inhabited areas or infrastructures. As a consequence, any problem occurring within the underground setting may have direct, sometimes catastrophic, consequences, on the built-up areas above (Waltham & Swift, 2004; Parise & Gunn, 2007; De Waele et al., 2011; Parise, 2012).
Some of the most common processes of cave evolution derive from progressive failures in the rock mass constituting the roof of the cave, until reaching the ground surface, and thus originating collapse sinkholes (Tharp, 1995; Klimchouk & Andrejchuk, 2002; Canakci, 2007; Waltham & Lu, 2007; Parise, 2008). Observing and documenting features related to such processes is of crucial importance, for the likely consequences this may have in terms of risk as well.
Evolution of instability processes in underground caves is generally dependant upon internal factors, such as the low mechanical strength of soft rocks, or external natural and/or anthropogenic factors that can modify the boundary conditions, the loading, or the physical and mechanical properties of involved materials. Changes in loading can be, for instance, caused by construction of buildings or infrastructures above the ground surface, that can modify the stress state around the cave, the destruction of pillars within underground rooms with consequent increase in the cave span, as well as seismic loading conditions or man-made vibrations due to traffic, construction works, etc. Changes in the boundary conditions may be represented by the variation of the wetting conditions within the cave due to all those processes promoting weathering of the rock mass, thus leading to a gradual reduction of the corresponding mechanical strength (Fookes & Hawkins, 1998; Zupan Hajna, 2003; Calcaterra & Parise, 2010, and references therein).
Lack of maintenance of ancient cavities, nowadays included in the urban development, or located nearby built-up areas, is at the origin of many problems. For instance, the closure of cave entrances may induce changes in the microclimate environment within the subterranean spaces, and cause deterioration of the outer portions of the rock mass. Given that most of the man-made caves in southern Italy have been dug into the so-defined "soft rocks", that is calcarenites and volcanic rocks, such processes may easily result in degradation of the physical properties of rocks, favoring instabilities. Geotechnical analyses, based upon data deriving from topographic surveys of the caves, detailed geo-structural surveys, and the characterization of the rock mass properties, need to be implemented to verify the stability conditions of the subterranean spaces (Parise & Lollino, 2011; Lollino et al., 2013; Lollino & Parise, 2014), and to identify the most suitable engineering works aimed at mitigating the related risk.
The historical center of Ginosa (Taranto province, western Apulia) is located on a hill bounded by the development of a *gravina*, that created a deep meander around the historical sector of the town. Most of the built-up areas show several levels of underground caves; some of them are kept in good state of conservation, and still used nowadays, or have been re-structured and adapted as bed&breakfast or hotels. Others, however, have been abandoned, and used as sites to discharge illegally solid and liquid wastes. These activities inevitably caused problems of instabilities. When the instabilities affected the lower levels of caves, a situation of danger arises for all the structures above.
In October 2013, and in December 2013, the Ginosa area was struck by two heavy rainstorms that caused serious flooding problems: the *gravina* thalweg was incised for a maximum of some 2 m (Fig. 5), and many caves located at its lower flanks were inundated by water and mud. Beside the direct damages caused by the floods, indirect effects had to be registered on the underground settings: in fact, in late December some

Fig. 6: partial view of the January 21, 2014, collapse at Ginosa.
Fig. 6: vista parziale del crollo di Ginosa del 21 Gennaio 2014.

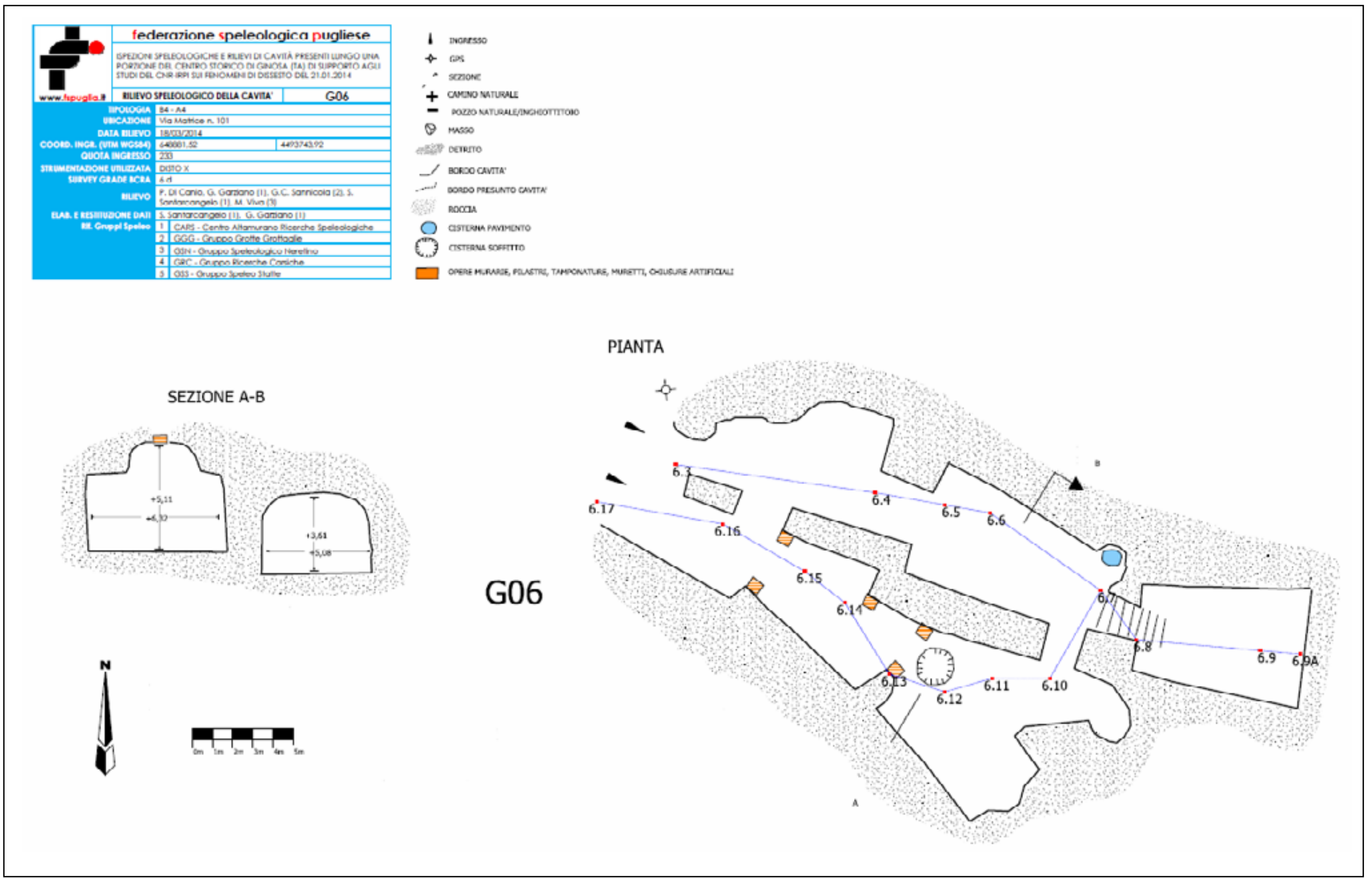

Fig. 7: example of a map (plan and cross sections) of a man-made cave at Ginosa (survey FSP and CNR-IRPI; drawing G. Garziano & S. Santarcangelo).

Fig. 7: esempio di un rilievo (pianta e sezioni) di una cavità artificiale a Ginosa (rilievo FSP e CNR-IRPI; elaborazione G. Garziano & S. Santarcangelo).

cracks were observed on several houses and man-made caves, that were declared dangerous and evacuated. This action of prevention resulted of extreme importance, since on January 21, 2014, a complex of caves situated below Via Matrice (one of the main street bordering the historical part of town) collapsed (Fig. 6). Luckily, no one was injured by the collapse, in consequence of which a large portion of the town centre was precautionally evacuated.

The 2014 event at Ginosa is only one of the many examples documented in a national chronological catalogue of (natural and anthropogenic) sinkholes in Italy, managed by the Institute for Geo-hydrological Protection of the National Research Council (CNR-IRPI; Parise & Vennari, 2013; Parise et al., 2013c).

A procedure to evaluate the susceptibility to sinkholes in artificial cavities

Based upon the experiences carried out in the last years in several areas of southern Italy, a procedure addressed to an evaluation of the susceptibility to sinkholes, related to presence of artificial cavities, is here briefly summarized. The procedure is intended to provide local authorities with a rapid tool to perform a preliminary assessment of the hazard conditions, especially in inhabited areas, and should ideally represent the base on which to define further detailed and site-specific researches, including geotechnical studies such as 3D slope stability analyses and/or modelling.

The first action to be put in practice when dealing with the hazard posed by unstable underground voids is necessarily the knowledge of both development and depth of the cave; this requires to carry out a topographic survey (Fig. 7). Such an operation, nowadays easily standardized at the surface, presents several problems when performed underground. This is true not only as concerns the delicacy and sensitiveness (and, consequently, the reliability) of the instruments used, but especially for the capability of people to move underground, often in very narrow spaces, sometimes even partly interested by presence of water. As in speleological surveys, therefore, it is crucial to have the availability of expert cavers to explore and map the underground environment. In the last decades, cave mapping has greatly increased the level of precision and reliability, and surveys produced by means of modern technologies (including disto/compass/clinometer wireless connected with a PDA, and dedicated softwares) may be considered of high quality, if carried out according to specific standards (in particular, those established by the British Cave Research Association; see Day, 2002).

Once the survey is available, it must be portrayed on topographic maps at proper scale, and correctly located in terms of georeferentiation. This is extremely important, since the projection of the underground voids at the surface will display all the above man-made structures (buildings, roads, lifelines, etc.) that

may potentially interfere with the cavity, or be involved in instability problems deriving from the cavity itself.
For the above reasons, great care must be dedicated to positioning the cavity, and especially to its access points. In many cases, especially when working in densely inhabited areas, long and complex survey lines have to be realized in order to be sure about the precise location of the cave entrance(s).
The cave survey must consists of a plan map, integrated by cross sections; the latter have to be surveyed anywhere necessary, that is at all those locations within the cave where changes in the cave profile are observed, or where some particular aspect needs to be detailed. Further, the cave survey has to be integrated by a photographic documentation; at this aim, the common use of digital camera make possible nowadays to have a high number of pictures (and videos), useful to control, even at later times, the real conditions within the cave systems.
Once the cave survey is available, its simple boundaries (that is, the cave limits) may be used as a sort of "container" where to depict a number of additional informations, specifically addressed to a preliminary assessment of the stability conditions. These observations need to be done directly in the caves, and therefore requires direct surveys from the geologist or engineer experts (PARISE & LOLLINO, 2011). For instance, aspects that must be carefully observed and mapped are the following evidences of (possible or already occurred) instability:
- presence of hair cracks;
- presence of open cracks (aperture on the order of cm);
- several families of cracks;
- water infiltrations;
- voids of pseudo-karst origin;
- wall deformations;
- blocks in precarious equilibrium;
- fallen blocks;
- instability in man-made elements;
- stabilization works.

Then, the likely elements at risk must be considered, as buildings, isolated houses, roads, lifelines, other infrastructures. For all of these, the possibility of a direct or indirect involvement in the case of a likely collapse of the cavities must be taken into account.
Beside than in the single cavity, all the above evidences of instability must be analyzed also as regards those nearby, especially when there is a superimposition or a connection with other voids; that is, cavity systems at multiple storeys, or complex systems made of different, interconnected, rooms. In fact, collapse of a cave may involve other nearby structures, even though these do not show at the moment any instability problems. The possibility of a chain reaction must be carefully considered.
A particular attention should be given to boundary conditions such as the possibility of leakage from pipelines or sewage systems, since interactions between liquids and the rock mass generally decreases its physical properties, causing a degradation of the rock (ZUPAN HAJNA, 2003; CALCATERRA & PARISE, 2010). Other boundary conditions may be the vibrations deriving from heavy traffic, working operations and/or excavations in nearby areas, etc.
Taking into the due account all these informations, it is possible to qualitatively determine a degree of susceptibility to sinkholes (or, more in general, to instability processes), that may be expressed as low, medium, and high susceptibility. In case of medium to high susceptibility, more detailed analysis and site-specific studies will be requested to guarantee the stability of the system.
Further, a preliminary stability analysis may be done by taking into consideration the size and height of the cavity, and of the overburden as well, on some of the available charts where a general indication of

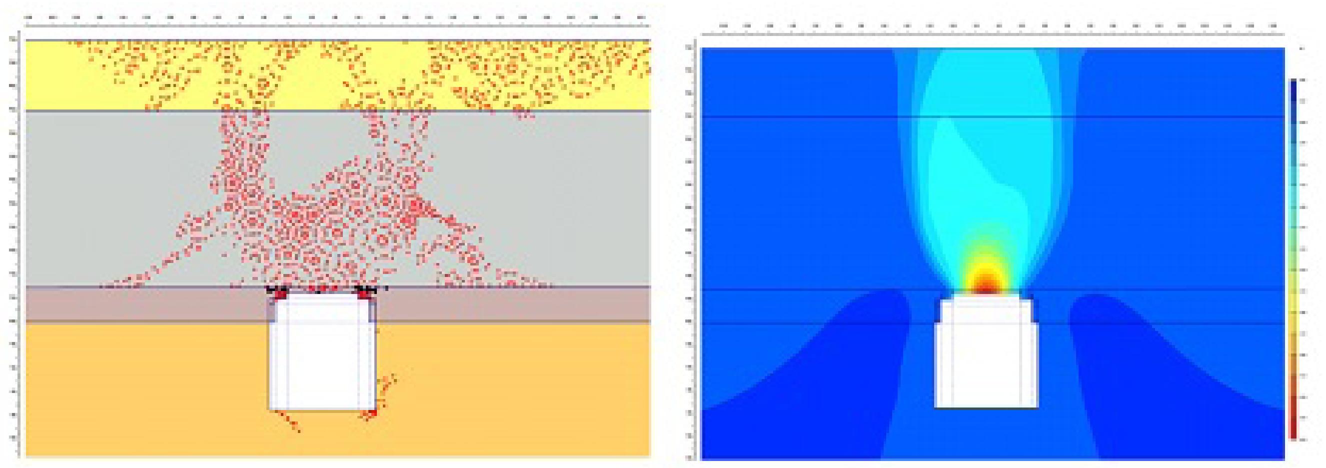

Fig. 8: finite element model applied to an underground cave in southern Italy, in the hypothesis of an increase in the cave size (after LOLLINO & PARISE, 2014): a) plastic zones; b) vertical movements.
Fig. 8: risultati modello FEM di Cutrofiano: a) zone plastiche calcolate nell'ipotesi di aumento delle dimensioni della cavità; b) isolinee degli spostamenti verticali nell'ipotesi di aumento delle dimensioni della cavità (da LOLLINO & PARISE, 2014).

the proximity or not to instability conditions may be obtained. Span of the void, crown pillar, or thickness of the overburden are typically the main geometrical factors used at this aim (Hutchinson et al., 2002; Gutierrez et al., 2014).

As further steps toward a complete evaluation of the sinkhole susceptibility, especially for those cases where the preliminary evaluation highlighted hazardous situations, site-specific analysis, with detailed geological-structural surveys, and implementation of numerical codes for the stability assessment need to be performed. In addition, the use of geophysical techniques (ground penetrating radar, electrical tomography, seismic techniques, etc.) may provide useful hints about the presence and development of presumed underground voids (Sammarco et al., 2010). This is particularly required when a decision needs to be taken as regard the evacuation of people from sectors considered at risk; in any case, the evaluation of the instability conditions should also be completed by general indications about the ways to solve the problems pointed out.

Remote sensing techniques, including analysis of satellite images and interferometric techniques, even though promising, does not show at the moment the possibility of real applications to civil protection issues (especially as indicators of possible premoniotry signs before collapse); their use, therefore, must be considered with care. Without any doubt, further research is still needed at this aim (see Parise et al., 2013a, and Gutierrez et al., 2014, and references therein).

Conclusions

Instability in underground artificial cavities, regardless of their typology, may represent a serious hazard to the built-up environment. This is especially true in urban areas, and where there is no knowledge of the presence of voids, due to loss of memory and closure of the accesses. Upward propagation of the failures may lead to formation of a sinkhole at the surface, with severe repercussions on human buildings and infrastructures.

Such eventualities are a serious problem for many historical centres in southern Italy, and deserve careful attention and study, aimed at a preliminary evaluation of the possibility of failures. The procedures summarized in this paper addresses this goal, aimed as it is at allowing local authorities and technicians to perform a first assessment of the instability conditions within underground voids, through direct surveys and observations. It is, however, important to stress that this is only the first step for a stability analysis; it is in fact necessary, when some evidences of instability have been detected, to proceed with further analyses, consisting of site-specific surveys and geotechnical modelling (Fig. 8), in order to precisely define the geometry and features of the specific cave, and evaluate its stability.

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