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ORIGINAL ARTICLE

Underground Geosites and Caving Speleotourism: Some Considerations, From a Case Study in Southern Italy

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Abstract
Small-size karst landforms may potentially provide very useful information to fully understand the behavior of karst systems and their dynamics. "Inghiottitoio della Masseria Rotolo," located in a remarkable karst area of southeastern Italy, was originally a very small swallow hole, able to collect huge amount of water during rainstorms. After works of excavations, and the later caving explorations, it has become the deepest cave in Apulia, reaching the water table at depth of −264 m, with further exploration underwater that brought the depth to 324 m below the ground surface, for a total development of the system greater than 1800 m. This cave is described in the context of the possibility to define underground geosites and to promote speleotourism, with the main goal to spread among the great public information about karst processes and landscape evolution in Apulia. At this aim, the main historical and morphological features of the area where the cave is located (the Canale di Pirro polje) are also described. The karst system of the "Inghiottitoio della Masseria Rotolo" is being studied through a scientific project funded by the regional authority, and a great number of data is being collected, which could be extremely useful to reconstruct the different phases of cave development and to put this cave within the overall context of karst evolution in this sector of central Apulia. Transferring the scientific outcomes to the high number of tourists and visitors would be essential to spreading the main information about karst and to improve the level of knowledge on this remarkable karst system.

Keywords Cave · Speleotourism · Karst · Apulia

Geosites and Underground Geotourism

Geomorphology has a cultural part ("cultural geomorphology," according to Panizza and Piacente 2003) that allows to consider the landscape as a component of the heritage of a territory. In this sense, the relationships between certain cultural components (historical monuments, archaeological sites, etc.) and the geomorphological context within which they developed, too, should be taken into account. Thus, cultural geomorphology can be defined as the study of the geological and morphological components of a territory, either as cultural elements of a landscape or in interaction with other objects, belonging to fields such as archaeology, history, architecture, etc. (Panizza and Piacente 2003, 2005, 2008). Together with these issues, there is also the concept of cultural landscape, that is, a landscape "fashioned out of a natural landscape by a culture group" (Sauer 1925).

Geotourism is a form of natural area tourism specifically focused on geology and landscape. It promotes tourism to geosites and the conservation of geodiversity and an understanding of earth sciences through appreciation and learning (Dowling 2008, 2011). This is achieved through independent visits to geological features, use of geo-trails and viewpoints, guided tours, geoactivities, and patronage of geosite visitor centers (Dowling and Newsome 2006; Newsome and Dowling 2010).

The primary focus of geotourism is sustainable tourism, to experience the earth's geological features in a way that could ideally foster environmental and cultural understanding, appreciation and conservation, and be locally beneficial (Panizza

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2001, 2009; Pralong 2005; Dowling 2011). In this sense, it has many links with ecotourism, cultural tourism, and adventure tourism; at the same time, since geology is directly included in the above definition, geotourism implies learning from, appreciating, and engaging in geosites. In other words, every kind of speleotourism should allow visitors to reach an understanding of the processes at the origin of a specific landform or feature. The educative part is therefore crucial to tourists and should be prepared in a simple but exhaustive way and addressed to adults as well as to young tourists.

According to Grant (2010), the main goals of sustainable geotourism development are essentially:

- to develop greater awareness and understanding of the significant contributions that geotourism can make to the environment, the local communities, and the economy
- to promote equity in geo-development
- to improve the quality of life to the host community
- to provide a high quality of the geological experience for the visitor
- to maintain the quality of the geoheritage on which the foregoing objectives depend

To this list, another goal has to be added, that is, to help research to obtain the necessary funding in order to improve the environmental and scientific knowledge of the geosites.

Among the many different landscapes on the Earth surface, karst is definitely one of the most peculiar and fragile, for a number of reasons. Karst terrains are highly vulnerable natural systems that may suffer degradation in consequence of many human actions (Parise and Pascali 2003; Corvea et al. 2014; Artugyan 2017). In such settings, even tourists and recreational activities have to be taken into account, if carried out without the proper care (Van Beynen and Townsend 2005; North et al. 2009).

Caves characterize karst landscapes, representing the direct link between the surface and the underground, and in a variety of different cultures worldwide, they have always represented the “dark side of the planet,” often seen as the way to enter into unknown spaces. Underground exploration needs special equipment and techniques; nevertheless, the attraction of unusual and mysterious subterranean places is since a long time the main impulse for people to partake in underground geotourism. Historically, the earliest forms of this category of geotourism can be traced in the visits of caves and mines (Hose 2008; Garofano and Govoni 2012). Their exploration and access is not easy, and to guarantee their use by tourists, paths need to be equipped, for example, with lights, lifts, and stairways (Toomey 2009; Debevec et al. 2018; Stepišnik and Trenchovska 2018). Underground visits also require the support of trained staff (Hose 2005; Novas et al. 2017) in order to assure the security of the visitors and to offer valuable cultural contents and explanations about the cave.

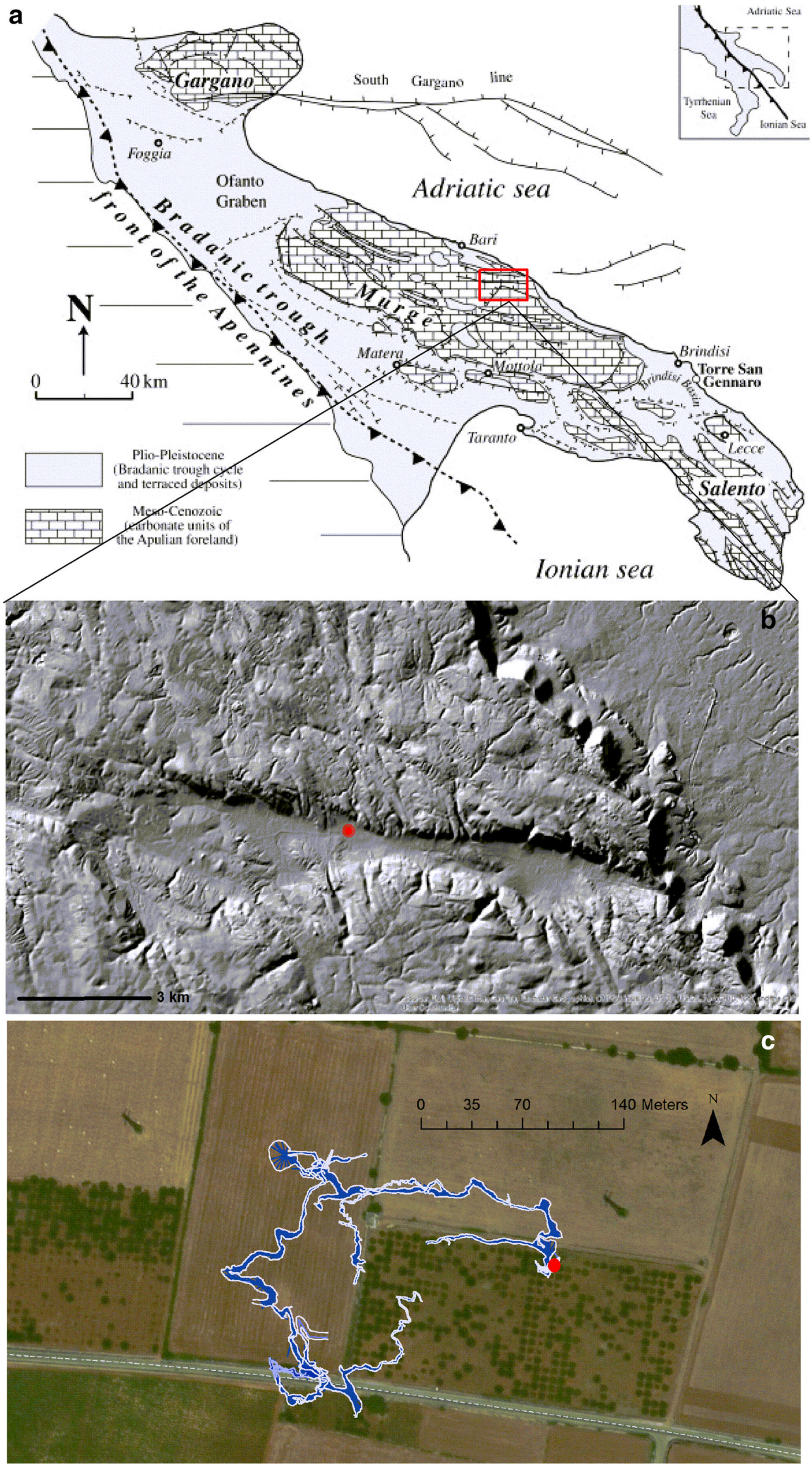
Nowadays, more than 800 show caves are operating worldwide (Zhang and Jin 1996; Gillieson 2011). Tourist exploitation of caves may have a positive impact from an economic perspective for the local communities. However, it should always be preceded by detailed and multi-year studies and monitoring to assess the impact that visitors might have on the cave ecosystem. Open access to caves raises, in fact, the risk of degradation of the underground environment due to poor regulation of the visits, lack of maintenance, or excessive numbers of visitors (Cigna 1993, 2019; Huppert et al. 1993; Buecher 1999; Despain et al. 2016). The first step needed to start the process of transformation of a natural cave into a show cave is to recognize its value. This step requires not only the understanding of both aesthetic and scientific aspects but also to reach an awareness of the sustainability related to the fragile karst environment (De Waele et al. 2003, 2011; Calò and Parise 2006; Parise et al. 2015; Stevanović 2015). At the same time, it must be considered that not all caves can be transformed into show caves, and in many cases, the only option remaining is to promote visits exclusively by trained and expert cavers. In this latter case, another type of geotourism can be considered: speleotourism (Tičar et al. 2018; Tomić et al. 2018). This includes visits to underground caves and similar geomorphological features. An important aspect of the attractiveness of caves lies in the subjective experience of every individual. When dealing with experts, such as is the case for cavers, this means that the experience is affected by a variety of factors, covering aspects such as expertise of the caver and difficulty in the progression of the cave (long pits, difficult technical passages, narrow passages, flooded or partly flooded passages, etc.).

In this article, through description of an important cave system in Apulia (southeastern Italy), and of its relevance in the Apulian karst, we discuss the possibility to define underground geosites, their importance, as well as their limits, and highlight the need of careful and detailed studies aimed at including karst caves in the inventory and list of geosites, notwithstanding the limited access they could pose.

Canale di Pirro: Geological and Morphological Features

The study area is located in central Apulia (SE Italy), within one of the main surface karst landforms of the region, the polje of *Canale di Pirro* (Fig. 1). Polje, a Slavic word literally meaning “field,” indicates in karst geomorphology a

Fig. 1 (A) Geological sketch of Apulia (after Pieri et al. 1997), showing location of the study area (red rectangle); (B) digital elevation model of the Canale di Pirro polje, with the red dot marking the entrance of Inghiottitoio di Masseria Rotolo; (C) plan view (on Google Earth) of the cave survey


a
Gargano
South Gargano line
Foggia
Ofanto
Graben
Adriatic sea
Bari
Bradanic trough
front of the Apennines
Murge
N
0
40 km
Matera
Mottola
Brindisi
Torre San
Gennaro
Brindisi Basin
Taranto
Lecce
Salento
Ionian sea
Plio-Pleistocene
(Bradanic trough cycle
and terraced deposits)
Meso-Cenozoic
(carbonate units of
the Apulian foreland)
Adriatic Sea
Tyrrhenian
Sea
Ionian Sea
b
3 km
c
0
35
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140 Meters
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depression, typically with a flat floor, developed along main structural lineations, or bounded by these on its flanks (Gams 1978, 2005; Pavičić et al. 2002; Dogan 2003; Nicod 2003; Bonacci 2004; Breg 2007). Due to flat topography, and the common presence of residual deposits, poljes are often flooded in the aftermath of rainfall events; depending upon local situations, and the presence of swallow holes, the water can be absorbed underground in a matter of hours, or days. In many polje worldwide, presence of temporary lakes is common (Šusterčič and Šusterčič 2003; Lopez et al. 2009; Parise 2009; Gracia et al. 2014).

The *Canale di Pirro* polje develops in direction about W-E, with an overall length of some 12 km (Anelli 1957; Parise 2006); it is a very elongated landform, bounded on both the sides by tectonically controlled ridges. At its easternmost side, it reaches a NW-SE tectonic line separating inland Murge from the Adriatic coastline (Di Geronimo 1970; Sauro 1991; Bruno et al. 1995; Parise 2011). Geologically, the backbone in the study area is represented by a several thousands of meters-thick sequence of Cretaceous limestones, affected by high angle, mainly NNW-SSE, W-E, and NW-SE normal faults (Neboit 1975; Ciaranfi et al. 1988; Funiciello et al. 1991; Doglioni et al. 1994; Pieri et al. 1997). The above fault systems locally result in the development of a karst landscape consisting of morpho-structural ridges bounding elongated depressions, as also morphologically expressed further south (Tozzi 1993; Bosellini and Parente 1994; Gambini and Tozzi 1996; Gil et al. 2013; Pepe and Parise 2014).

Canale di Pirro is among the 440 geosites recently appointed in Apulia (Mastronuzzi et al. 2015), following the Regional Law emanated in 2009 about "protection and safeguard of sites of geological and speleological interest". Due to the wide outcrops of soluble rocks, and the intense development of karst processes in the region (Parise and Pascali 2003; Iurilli et al. 2009; Parise 2011; Simone and Fiore 2014), a high number of identified geosites include surface and subsurface karst landforms.

History of *Canale di Pirro* is strictly linked to water. Many ancient maps of the area, starting with the first cartographic document dating back to the sixteenth century (Gastaldi 1561), show the presence of a water course, named *Cana*, within the polje, even though there is no consistent documentation throughout the history (Trisciuzzi 1989; Sisto 2006). Part of *Canale di Pirro* was used at the turn of the fifteenth century as stud to breed horses and stallions for the *"Repubblica Serenissima"* of Venice. As a testimony on the occurrence of flood problems in the area, documentation was found about an event which occurred in 1506, when the breeding farm was destroyed after a summer rainstorm caused the formation of a huge lake, killing about all the animals (only four stallions and nine foals survived; Notarnicola 1933).

Within such a setting, it is expected to find many swallow holes in the *Canale di Pirro* polje. Actually, only a few of them are still existing, as effect of the human activities and in particular of agricultural practices. In the polje, all the fields have been intensively cultivated, especially for vineyards, wheat, cherry trees, and olive trees. Becoming a significant part of the local economy, agriculture has received more and more attention by locals. However, in many cases, due to lack of knowledge of the karst environment, and of the importance of swallow holes as sites of natural recharge of groundwaters, many of the original caves and swallow holes have been destroyed or clogged by farmers.

At present, two main sites are the most important swallow holes in the polje: the main one is Gravaglione (cadastral number PU 354 in the regional Cadastre of natural caves of Apulia). The name comes from the latin *grava*, typically associated to very deep features of karst (see Parise et al. 2003): located in the central sector of the polje, it consists of an elongated depression which collects most of the surface runoff from the head of the catchment. The other swallow hole is *Inghiottitoio di Masseria Rotolo* (PU 355). Importance of this latter cave, and its rediscovery, has been recently described by Parise and Benedetto (2018). Here, we would like only to highlight the remarkable fact that the original swallow hole (not a real cave, but rather a small depression in the ground, where water is used to infiltrate underground during and after heavy rainfall), was included in the Register of Natural Caves of Apulia in 1969 because of the appreciation of the importance of the site from a karst standpoint. In 2012, after some months of digging at the site, cavers were able to find a narrow passage leading underground to what, with later explorations, has become the deepest cave in Apulia region, reaching the water table at a depth of 264 m below the surface. Further, speleo-diving explorations brought the final depth to 324 m (Parise and Benedetto 2018).

Flood Problems in the Canale di Pirro Polje

Linking the karst features of the landscape to history of the site and presence of different civilizations is particularly important in a land as Apulia, where this connection was always very strong. Living in karst, especially in arid and semi-arid lands, requires a very good knowledge of the geological and hydrogeological properties of the terrains, aimed at understanding where water could be present and in what time of the year (Parise and Sammarco 2015). Presence of water has always been the first basic element for establishing human settlements. In this sense, also the name *Canale di Pirro* has relationships with the presence of water, as documented by

Fig. 2 (A) Dry stone wall surrounding the cave entrance; (B) cement rings located at the entrance of Inghiottitoio di Masseria Rotolo, in order to reinforce it and protect the access of speleologists

Parise and Benedetto (2018), quoting a variety of historical sources.

`tpIn karst, water courses are typically interested by flow only during the rainy season, or soon after the main rainstorms. This means that at the surface, a very limited amount of water is present, and there is lack of permanent rivers and torrents, since water rapidly infiltrates underground through the network of fissures and conduits in the soluble rock mass (White 1988; Ford & Williams 2007; Parise and Gunn 2007; Gutierrez et al. 2014; Parise et al. 2018a). Karst landscape is

Fig. 3 The vertical pits in the first part of the karst system: Pozzo Santi Medici and Pozzo GASP (photo courtesy Umberto Spinelli)

Fig. 4 The sector of the cave called "Grotte di Castellana," with spectacular speleothems (photo courtesy Umberto Spinelli)

also characterized by changing features, in the forms of infiltration sites that might be present at different locations from year to year, as a consequence of changes, both of natural and anthropogenetic origin (White 2002).

Fig. 5 Calcite-crystals deposits founded in La Gola di Caronte and La Saletta degli Angeli (photo courtesy Umberto Spinelli and Rodrigo Torres)

Fig. 6 Deposits hanging over the present pavement of the cave, testifying ancient stages of filling of the karst system (photo courtesy Umberto Spinelli)

Many karst areas of Apulia are frequently affected by flash floods, typically occurring in response to clustered intense rainfall. This was the case for recent events in Bari (Mossa 2007; Andriani and Walsh 2009; Cotecchia and Scuro 2010), as well as for those repeatedly affecting the territory surrounding the Gulf of Taranto (Parise 2015), the Salento peninsula (Delle Rose and Parise 2010; Forte 2018), and the Gargano Promontory (Martinotti et al. 2017; Parise et al. 2018b). Effects of the floods are often exacerbated by land mismanagement actions, carried out without having a proper knowledge of the karst landforms and their hydrological functioning (Calò & Parise, 2006; Parise & Gunn 2007; DeWaele et al., 2011). Among these actions, clogging of natural swallow holes and expansion of urbanized areas often resulted in obstructing the natural drainage and the surface runoff, thus producing significant consequent losses to society (Šusterčič and Šusterčič 2003; Breg 2007; Gutierrez et al. 2014).

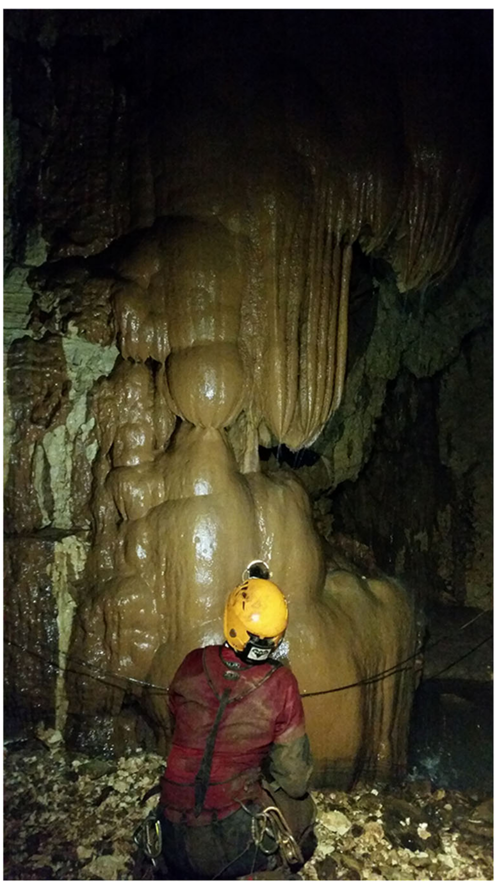

Fig. 7 Majestic carbonate flowstone deposit at the cave bottom, close to the water table (photo courtesy Umberto Spinelli)

As concerns *Canale di Pirro*, a local scholar, Martellotta (2006), citing Notarnicola (1933), describes nomadic swallow holes, which position keeps changing, according to the different rainstorms and the arrival of variable amounts of rainfall and runoff water from the polje flanks. This testifies the high dynamics of the karst systems within the polje and how they accommodate local clogging and closure of swallets.

Nowadays wide sectors of *Canale di Pirro* become lakes during and after heavy rainstorms, requiring several hours to days to be absorbed underground. This situation is not limited to the polje but interests nearby lands, where in the past repeated episodes of flooding had to be recorded: the town of Castellana-Grotte, at a distance of some 10 km, was affected at the turn between the nineteenth and twentieth centuries by at least ten severe flood events, the strongest one in 1893 claiming four casualties (Ce.Ri.Ca. 1996; Parise 2003). This response to rainfall was caused by many natural swallow holes being closed during the previous decades, due to urban expansion.

Cave Description

In karst, it is quite common that the known caves might host some unexplored spaces (Putiska et al., 2014; Zvab Rožič et al., 2015; Despain et al., 2016), hidden behind a pile of breakdown deposits, or concealed by calcite flowstones, or simply not accessible to man due to narrowing of passages. Especially when caves were originally explored decades ago, a re-visitation might be interesting nowadays, with the potential to open a new light to the knowledge so far acquired (Zhu et al., 2014; Fabri et al., 2015).

The karst system of *Inghiottitoio di Masseria Rotolo* is a remarkable cave of Apulia region, for many different reasons, from the impressive beauty of underground karst environments to peculiar morphological aspects, including its depth (the cave is nowadays the deepest in Apulia); last but not least, the presence in the lower part of the system of the water table allows scientists and researchers to study groundwater in a direct way, offering about a unique opportunity to the science of karst hydrogeology in the region. Following the discovery of the passage leading to the underground system, the cave entrance was made safe by positioning cement rings to reinforce it and constructing a dry stone wall around it (Fig. 2).

The cement rings mark the first meters of descent underground and are followed by a passage wide enough to allow entrance by man, leading cavers to a series of vertical shafts, named *Pozzo GASP!* and *Pozzo Santi Medici*, through which a depth of about 100 m below the ground surface is reached (Fig. 3).

From here, a sub-horizontal level develops for a few hundred meters, before becoming a meandering canyon-like feature. Starting from this level, a series of lateral branches are encountered. Through small jumps and some shafts, the cave system then deepens, until reaching what is, without any doubt, the most impressive feature: the so-called *Pozzo dei Veneti*, a 20 m large and over 100 m deep circular pit, leading down to the water table, at depth of −264 m below the topographic surface. This was the starting point for diving explorations that led to a total cave depth of −324 m below the ground (Parise and Benedetto 2018).

The cave presents very impressive underground environments. During the explorations, cavers have documented marvelous white speleothems (Fig. 4), with active dripwater feeding the many stalactites and stalagmites. The beauty and fragility of underground environments at *Inghiottitoio di Masseria Rotolo* can be found not only in speleothems but also in many places showing calcite-crystals deposits inside paleolakes (Fig. 5).

Further, at several locations, hanging deposits related to past levels of karstification, nowadays suspended above the main cave level, are visible (Fig. 6). At the cave bottom, an impressive waterfall supplies the water table with a constant water flow. This allows the deposition of a majestic and extraordinary carbonate flowstone (Fig. 7), some tens of meters high above the water table. The *Inghiottitoio di Masseria Rotolo* surprised cavers also under the water table, where very large flooded galleries are present, once again to testify the impressive dimensions and remarkable richness of this cave system. The flooded area of the cave is enriched by very high massive columns and other types of speleothemes, evidence of previous stages of development in the life of the cave system.

Cave Relevance

Inghiottitoio di Masseria Rotolo represents one of the two only sites in Apulia where the presence of a cave accessible to man, and the long development of the karst system, allows to reach directly the water table. It is therefore a wonderful place where to explore the potentiality for hydrogeological and karst researches and an extraordinary natural laboratory for studying groundwater complexity and its hydrogeological processes and dynamics.

The recent outcomes from a project dedicated to monitoring the quality and quantity of groundwater resources at *Inghiottitoio di Masseria Rotolo* (Liso et al. 2018; Parise et al. 2019), included the analysis of the stygofauna (Fig. 8), aimed at evaluating the presence of species which could be used as indicators of the quality of groundwater, as already carried out in other karst areas of the region (Masciopinto et al. 2006). Further, finding new species in this sector of Murge could also provide significant insights toward the understanding of the evolution of the Apulian karst, starting from the paleogeographic reconstruction of the whole region (Inguscio et al. 2009).

According to the number of individuals for each species, they represent an excellent indicator of clean water, or of conditions untouched by anthropogenic pollution. The study of these animals can be used to improve knowledge about underground environments because they represent an effective control for the reference parameters of undisturbed water bodies. The specific values of chemical and biological parameters found in water samples, in turn, become thresholds for clean water in such peculiar underground environment. In the

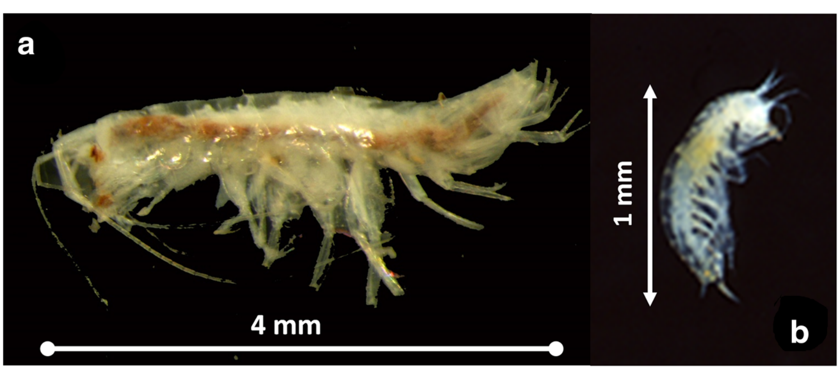

Fig. 8 Stygofauna species found in the underground aquatic environment: (A) *Hadzia minuta*; (B) Salentinella gracillima (photo courtesy Salvatore Inguscio). They appear blind and depigmented due to specific adaptations to the dark environment

Inghiottitoio di Masseria Rotolo, various species of stygofauna have been recognized. Some of them are very rare, as *Hadzia minuta*, and, for the first time, other species were found away from Salento Peninsula, located in the more southern sector of Apulia Region.

Conclusions

History of the site at *Inghiottitoio di Masseria Rotolo* witnesses the relevance of historical documentation in karst (Shaw, 2004, 2005), and the need to take into account even its small features, often neglected, aimed at acquiring a proper knowledge about karst. The original site of this cave system was luckily identified and kept active, pointing out to the need of "reading" the karst landscape even at the surface, aimed at a full comprehension of its hydraulic functioning and at contributing to define the most proper management actions in this fragile environment.

The data from caving explorations and scientific research at the site are offering remarkable opportunities for the study of the Apulian karst, with particular reference to past and recent evolution of the specific karst system, to its relationships with sea-level stands (Rudnicki 1980; Dini et al. 2000; Mastronuzzi and Sansò 2002; De Waele and Parise 2013) and with a primary concern about quantity and quality of karst aquifers in the region (Stevanović 2015, and contributions therein). These latter, in particular, represent a very important matter in Apulia, a region where water availability is certainly a significant issue, that is, typically amplified by a huge touristic pressure during the summer season and with severe problems of saline intrusion from both the Ionian and Adriatic sides since several decades (Cotecchia 1977; Tulipano et al. 1990; Tulipano & Fidelibus 2002; Masciopinto and Liso 2016; Masciopinto et al. 2017a, b).

The knowledge acquired, still to be widened through continuation of the project, can represent the scientific basis for a variety of actions aimed at spreading the data about karst and its importance in Apulia. By recognizing *Inghiottitoio di Masseria Rotolo* as an underground geosite, where it is possible to practice visits for expert cavers, would inevitably produce a further positive effect on the visibility of karst to a wide public. Apulia during the summer is among the most visited sites in Italy, and therefore there is a great opportunity to interest and attract tourists and visitors toward initiatives addressed to valorization of the natural heritage of the land, which main peculiarity is represented by karst and by the surface and subsurface landforms produced by such processes.

Description of the main morphological, speleological, and hydrogeological features of the cave system, through a number of didactic and photographic panels, could be a nice way to transfer the beauty and interest of the underground world to the great public. These panels could be settled in specific locations, as small museums, shops, and restaurants in the *Canale di Pirro* area, and/or be arranged in a nearby *masseria* (mansion house, typical of the Apulian countryside) to attract tourists and to provide the basic information about the local karst and the historical vicissitudes of the area as well. Even though the access to the real visits in the cave has necessarily to be limited to experienced cavers, these activities could play a significant role in spreading the information about karst in the area and in informing great number of tourists about the geological history of Apulia. Further, presence of the Castellana Caves, one of the most important show caves in Italy, with over 350,000 visitors per year, at few kilometers of distance from the site of *Inghiottitoio di Masseria Rotolo* is certainly an additional element of attraction toward these issues.

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