V. Festa, A. Fiore, M. Parise, and A. Siniscalchi – Sinkhole evolution in the Apulian Karst of Southern Italy: a case study, with some considerations on Sinkhole Hazards. *Journal of Cave and Karst Studies,* v. 74, no. 2, p. 137–147. DOI: 10.4311/2011JCKS0211

SINKHOLE EVOLUTION IN THE APULIAN KARST OF SOUTHERN ITALY: A CASE STUDY, WITH SOME CONSIDERATIONS ON SINKHOLE HAZARDS

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Abstract: Sinkholes are the main karst landforms characterizing the Salento Peninsula, which is the southernmost part of the Apulia region of southern Italy. They occur both as evolving recent phenomena and old or relict features testifying to ancient phases of karst processes acting in the area. Most of the sinkholes were formed by karst processes that may be reactivated, a risk to the anthropogenic structures nearby. To highlight such a subtle hazard, an area located a few kilometers from Lecce, the main town in Salento, was the subject of geological, morphological, and geophysical investigations. Historical analysis of multi-year aerial photographs, in particular, allowed identification of several phases in the recent evolution of a particular sinkhole, and demonstrated the need to carefully evaluate the likely evolution of similar features in Salento.

Introduction

Sinkholes are among the most common landforms of karst landscapes worldwide. They occur in a variety of sizes and are morphologically expressed as a function of the mechanisms originating them (Waltham et al., 2005). In many countries, sinkholes are among the most significant geohazards of karst areas, with significant negative consequences for society in terms of economic losses (Galloway et al., 1999; Scheidt et al., 2005).

Sinkhole research has gained wide attention from the Italian scientific community in recent years due to frequent occurrences of sinkholes in several regions of Italy. Among these, Apulia is one of the most important, due to outcrops of soluble rocks in most of the Apulian territory. Salento, the southernmost part of the region (Fig. 1), contains a great variety of sinkhole phenomena that display different typologies and states of activity (Parise, 2008a). They affect all outcropping carbonate rocks, including the Cretaceous limestone, the Oligocene, Miocene, and Plio-Pleistocene calcarenites, and the middle-upper Pleistocene terraced marine deposits. Further, Triassic evaporites in the northern reaches of Apulia are also affected by sinkholes (Fidelibus et al., 2011). In many sectors of Salento, sinkholes are so widespread that they have become the main landform, especially along the low shorelines of both the Adriatic and Ionian seas (Delle Rose and Parise, 2002; Bruno et al., 2008). Sinkholes have often been modified by man to gain land for agricultural practices or to be used as swallet sites to mitigate flood hazards during heavy rainfall. In the latter case, however, lack of maintenance and clogging produced by wastes and vegetation has repeatedly resulted in further flooding events, with severe damage to the surrounding land (Delle Rose and Parise, 2010).

Analysis of sinkholes in Apulia is important not only for understanding the processes at the origin of such events, but also for the protection of society. It is important to understand the past in order to forecast future sinkhole episodes. To achieve the two goals above, we present a case study of the Masseria Forte di Morello sinkhole located a few kilometers north of Lecce that illustrates the likely re-activation of sinkholes, the importance in considering sinkholes in land management, and the need to carry out detailed, dedicated studies aimed at mitigating the risk (Parise, 2008b, 2010).

The investigation was carried out using a multi-disciplinary approach. Field mapping and geophysics allowed us to reconstruct the plan view and deep geometry of the sinkhole, as well as to discern the oldest stages of the sinkhole's genesis and evolution. Old aerial photographs, topographic maps, and orthophotos were useful in reconstructing the recent evolution of the sinkhole, especially in relation to anthropogenic activities.

Geological Setting

The Apulian Foreland represents the southern Plio-Pleistocene foreland of the Apenninic and Dinaric-Hellenic orogens (e.g., Ricchetti et al., 1988; Funiciello et al., 1991; Fig. 1A). In Apulia, the exposed foreland is characterized by three main morpho-structural highs. From northwest to southeast, they are Gargano, Murge, and Salento (e.g., Pieri et al., 1997; Del Gaudio et al., 2001; Fig. 1A).

The stratigraphic setting of Salento can be simplified by grouping the different lithostratigraphic units into Cretaceous, Eo-Miocenic, and Plio-Pleistocenic units that are separated by unconformity surfaces (Tropeano et al., 2004, and references therein; Fig. 1B). According to Ciaranfi

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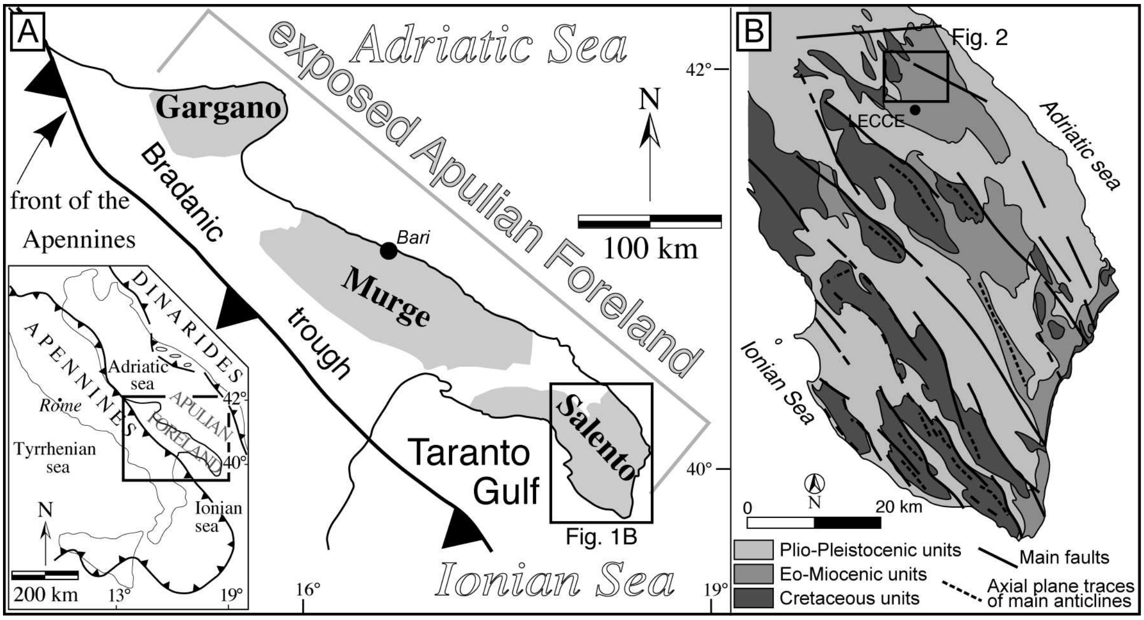

Figure 1. A: The exposed Apulian Foreland (Apulia, southern Italy) in the framework of the Apenninic and the Dinaric-Hellenic orogens (after Festa, 2003, modified). B: Schematic geological map of the Salento area (after Ciaranfi et al., 1988; Tozzi, 1993; and Tropeano et al., 2004).

et al. (1988), the Cretaceous-age Calcare di Altamura formation is the lowest and oldest unit cropping out in the overall area. Recent chronostratigraphic studies by Schlüter et al. (2008) indicate that its age is between 66 and 86 Ma. The formation is mainly characterized by well-stratified limestones, locally represented by dolomitic limestones and dolostones. According to Tulipano and Fidelibus (2002), these Cretaceous rocks constitute the main aquifer in Salento, with water table elevations reaching maximum values of 4 m above sea level.

Rocks belonging to the Calcare di Altamura underlie the zone in which the sinkhole in this case study is located (Ciaranfi et al., 1988; Bossio et al., 1999; Fig. 2). Here the water table of the main aquifer is at about 2 m above sea level, and the Calcare di Altamura rests below both the Eo-Miocenic and the Plio-Pleistocenic units (Tulipano and Fidelibus, 2002). The first are represented by the Pietra Leccese and the Calcareniti di Andrano formations (Fig. 2). The Pietra Leccese consists of thin glauconitic calcarenites with planktonic foraminifera, upper Burdigalian to lower Messinian in age. The Calcareniti di Andrano are characterized by bioclastic calcarenites rich in algae and mollusks that are lower Messinian in age (Bossio et al., 1999; Bosellini, 2006). The Plio-Pleistocenic units are mostly represented by biocalcarenites and biocalcirudites (Bossio et al., 1999) that may belong to the Calcarenite di Gravina formation, middle Pliocene (?) to lower Pleistocene in age (Ciaranfi et al., 1988; D'Alessandro et al., 2004; Tropeano et al., 2004; Fig. 2).

According to Martinis (1962), Palmentola and Vignola (1980), and Parise (2008a), a general correlation between morphology and tectonics is found in the Salento area. The physical landscape is delineated by a set of sub-flat surfaces, variously extended, arranged at different heights, and often connected by small scarps related to faults mainly striking north-northwest—south-southeast and northwest-southeast (Fig. 1B). These faults were active during the Pliocene and Pleistocene and show high-angle planes, with opposite dip directions, along which a maximum extensional offset of about 200 m can be estimated. However, according to Tozzi (1993) and Gambini and Tozzi (1996), a transcurrent component characterizes their kinematics as well. The activity of the faults would be responsible for the formation of open to gentle folds, especially in the Cretaceous and Eo-Miocenic units (Martinis, 1962; Tozzi, 1993; Fig. 1B). The site where the Masseria Forte di Morello sinkhole is located is morphologically an alternation of morpho-structural ridges and depressions elongated roughly northwest to southeast and interpreted as horsts and grabens (Martinis, 1962; Palmentola and Vignola, 1980) or pull-aparts (Tozzi, 1993). In Salento, such ridges are called Serre Salentine and reach a maximum altitude of 199 m above sea level. They are modeled on both Cretaceous and Eo-Miocenic units, while the intervening depressions are generally occupied by Plio-Pleistocenic units (Parise, 2008a, and references therein). This occurs at the study site (Fig. 2), where the Calcarenite di Gravina crops out in structurally depressed sectors produced within the pre-Pliocenic units (Bossio et al., 1999). Recent meso-structural analyses by Di Bucci et al. (2009) indicate that the Salento carbonates have been affected by middle and late Pleistocene extensional tectonics that formed joints that mostly strike northwest-southeast, and subordinately northeast-southwest.

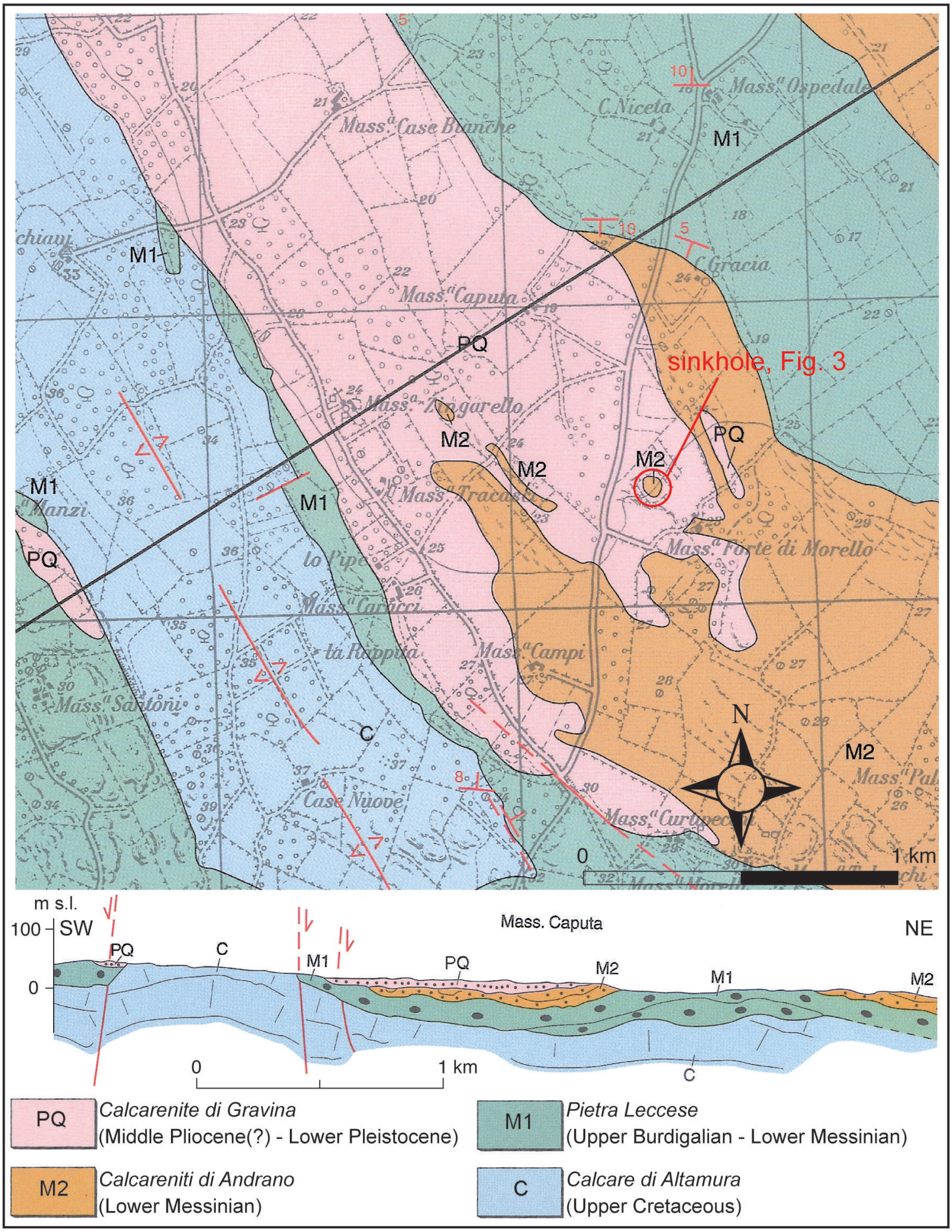

Figure 2. Geological map of the zone around the sinkhole (after Bossio et al., 1999, with modifications according to Ciaranfi et al., 1988; D'Alessandro et al., 2004; Tropeano et al., 2004; and Bosellini, 2006).

Materials and Methods

A combination of geological, geomorphological, and geophysical analyses has been implemented to study the sinkhole at Masseria Forte di Morello. Integration of different approaches is, as a matter of fact, a crucial point in the reconstruction of the local geology of the sinkhole and the understanding of its formation mechanism. The geological survey was conducted over an area of several square kilometers around the sinkhole and in greater detail at the sinkhole. Besides stratigraphic analysis and identification of the lithotypes at outcrops, attention was paid to the structural geology of the different formations to define the likely control of tectonic features on sinkhole formation and evolution.

An important part of the work consisted of the geophysical analysis of site features and morphology. Geophysics provides important non-invasive tools that can be used to predict where and within what limits sinkholes are likely to occur, to determine the underlying cause of an existing or forming subsidence or depression, and to evaluate the success or failure of ground-improvement programs intended to remediate sinkhole conditions (Zhou et al., 2002). Among geophysical methods, electrical resistivity imaging is well suited to mapping sinkholes because of the ability of the technique to detect resistive features and discriminate subtle resistivity variations in karst environments. A number of researchers have used two-dimensional 2D electrical resistivity tomography to examine sinkholes and the underlying weathered bedrock (e.g., van Schoor, 2002; Zhou et al., 2002). The raveling zone is characterized by increased porosity and reduced percentage of fine sediment. Depending on the depth to the local groundwater table, the raveling zone can either be shown as a high-resistivity anomaly (if dry) or a low-resistivity anomaly (if saturated). Deeper void space is typically characterized by a low-resistivity feature that is indicative of carbonate materials being replaced by looser clastic sediments or by water. Of course, an air-filled void would generate a high-resistivity anomaly, but this would not constitute a sinkhole, strictly speaking. ERT sections acquired in a karst area outside an urbanized environment should clearly display the types of anomalies routinely encountered in sinkholes (Dobecki and Upchurch, 2006; Schwartz and Schreiber, 2009).

Many karst features, including the irregular bedrock surface, cavities within the bedrock or in the soil mantle (air-filled, water-filled, or clay-filled), buried sinkholes, raveling zones at the bedrock-overburden interface, and preferential groundwater flow paths can be detected by resistivity investigations, providing electrode configurations are designed for the setting. Zhou et al. (2002) conducted numerical forward-modeling and experimental analysis of dipole–dipole (DD), Schlumberger, and Wenner arrays that produced markedly different anomaly shapes for a conceptual model of a cover-collapse sinkhole. The results from the dipole–dipole array appeared to be better than those from the Wenner and Schlumberger arrays in displaying the sinkhole collapse area. Compared with the DD array, the Wenner and Schlumberger arrays, and their hybrid configuration (Wenner-Schlumberger), have symmetric configurations allowing high data quality, but lower horizontal resolution for identifying vertical and dipping structures, such as those likely characterizing sinkhole features. A dipole-dipole array was therefore chosen for this investigation to ensure a good horizontal resolution.

To complete the study, the geomorphological evolution of the sinkhole was assessed by means of a chronological analysis of the available maps, aerial photographs, and orthophotos. The use of historical data in the analysis of natural hazards is recognized as a fundamental tool for evaluating hazards (Varnes, 1984). Historical data may disclose the timing of events (Calcaterra and Parise, 2001; Glade et al., 2001). Among the many possible sources of historical information, aerial photographs are particularly useful for reconstructing the recent evolution of the landscape. In particular, multi-year analysis of aerial photos, which requires availability of photos from different years and the work of an expert photo-interpreter is a powerful and economical tool (Soeters and van Westen, 1996; Parise, 2001). Comparing several air photos allows detection of the recent evolution of natural phenomena, land use changes, and the efficacy of remediation works to mitigate specific hazards (Parise and Wasowski, 1999). Such an analysis has been performed at the Masseria Forte di Morello sinkhole using eight sets of images covering the time span 1955–2006; the most recent temporal and spatial changes in the study area were assessed through field controls. The stereoscopic analysis of aerial photos was carried out by using a Wild APT2 stereoscope equipped with zoom magnification (maximum 15×). In addition, old maps were also examined (see Table 1 for details).

Results

Field Survey

Detailed mapping of the geology of the sinkhole area was carried out. In agreement with the stratigraphic setting shown in the geological map (Fig. 2), the bedrock is calcarenites and calcirudites belonging to the Calcareniti di Andrano and the Calcarenite di Gravina formations (Fig. 3). These carbonate rocks, with sub-horizontal bedding, are affected by two main systems of joints (Figs. 4A, 4B) with sub-vertical planes roughly oriented northwest-southeast and northeast-southwest (Fig. 4C). In agreement with Di Bucci et al. (2009), these directions indicate that such joints can be related to extensional tectonics that affected the Salento area during middle and late Pleistocene times. As shown in Figures 4A and 4B, the original joints have been enlarged by karst processes, so that they now appear as flutes and runnels. A scarp rim (I, in Figs. 3A, 3B) on the bedrock surrounds the depressed area where the recent evolution of the sinkhole occurred. It clearly separates the depression from the flat surrounding topography (Fig. 3B) that extends to about 25 m above sea level. In plan view, the scarp rim appears to be very regular in the northern sector, where it is northeast-southwest and north-northwest–south-southeast oriented (Fig. 3A). In contrast, the southern reach has a sub-circular shape. This rim delimits the upper scarp of the sinkhole. The scarp is characterized by a gently-inclined slope that is slightly steeper in its south-western sector (Fig. 3A).

Table 1. Sources used for the historical analysis of the Masseria Forte di Morello sinkhole.

Type	Date	Scale
Aerial photos	June 5, 1955	~ 1:35,000
Aerial photos	July 29, 1972	~ 1:20,000
Aerial photos	July 07, 1987	~ 1:18,000
Aerial photos	July 13, 1996	~ 1:13,000
Aerial photos	May 07, 2003	~ 1:18,000
Topographic maps	1874	1:50,000
Topographic maps	1912	1:100,000
Topographic maps	1954–55	1:25,000
Cadastre maps	1900–10	1:2,000
Orthophotos	1994	1:10,000
Orthophotos	2000	1:10,000
Orthophotos	August 2006	1:5,000

Downslope, a carbonate breccia crops out at the contact with the bedrock, exhibiting an overall thickness of about 4 m (Figs. 3A, 3C). This breccia is composed of calcarenite and calcirudite clasts (Fig. 4D) that reach a maximum size of 80 to 100 cm, with widespread terra rossa between the clasts (Fig. 4E). The larger clasts often show honeycomb features generally infilled by residual clay deposits. Toward the inner depression, the breccia body is exposed along the above-mentioned gently-inclined slope that leads to the intermediate scarp of the sinkhole. This scarp is steeply inclined, with a maximum drop of about 3 m, and surrounds a depression located near the south-southwest margin of the sinkhole area (Fig. 3A). In plan view, the shape of its rim (II in Figs. 3A and C) is ovoid, with the longest axis striking about north-northeast–south-southwest.

The base of this scarp coincides with the contact between the breccia and a succession of siliciclastic

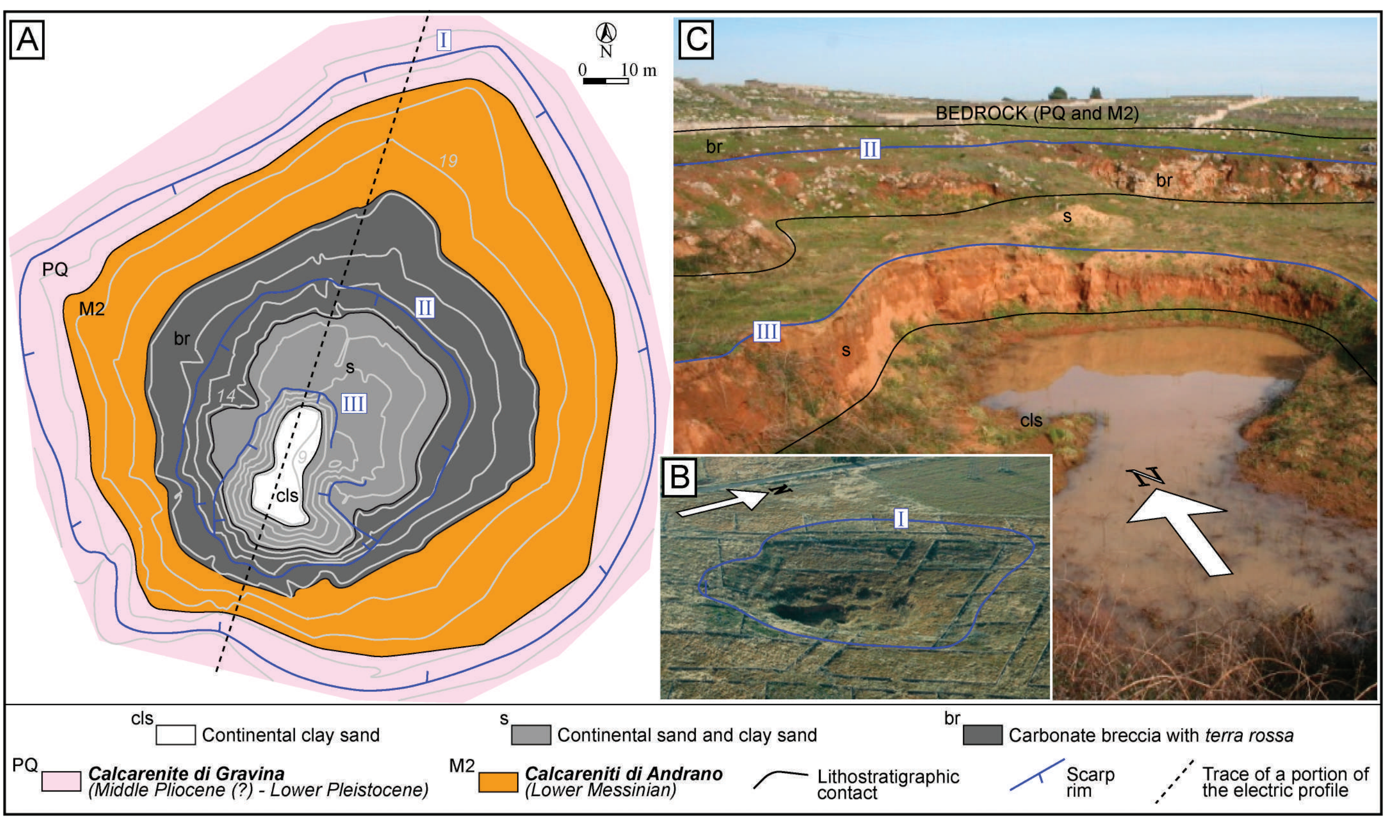

Figure 3. A: Geological map of the sinkhole. B: Aerial photograph of the sinkhole (courtesy of M. Sammarco, Univ. Salento). C: View of the central-northern sector of the sinkhole. Scarps I, II, and III are discussed in the text.

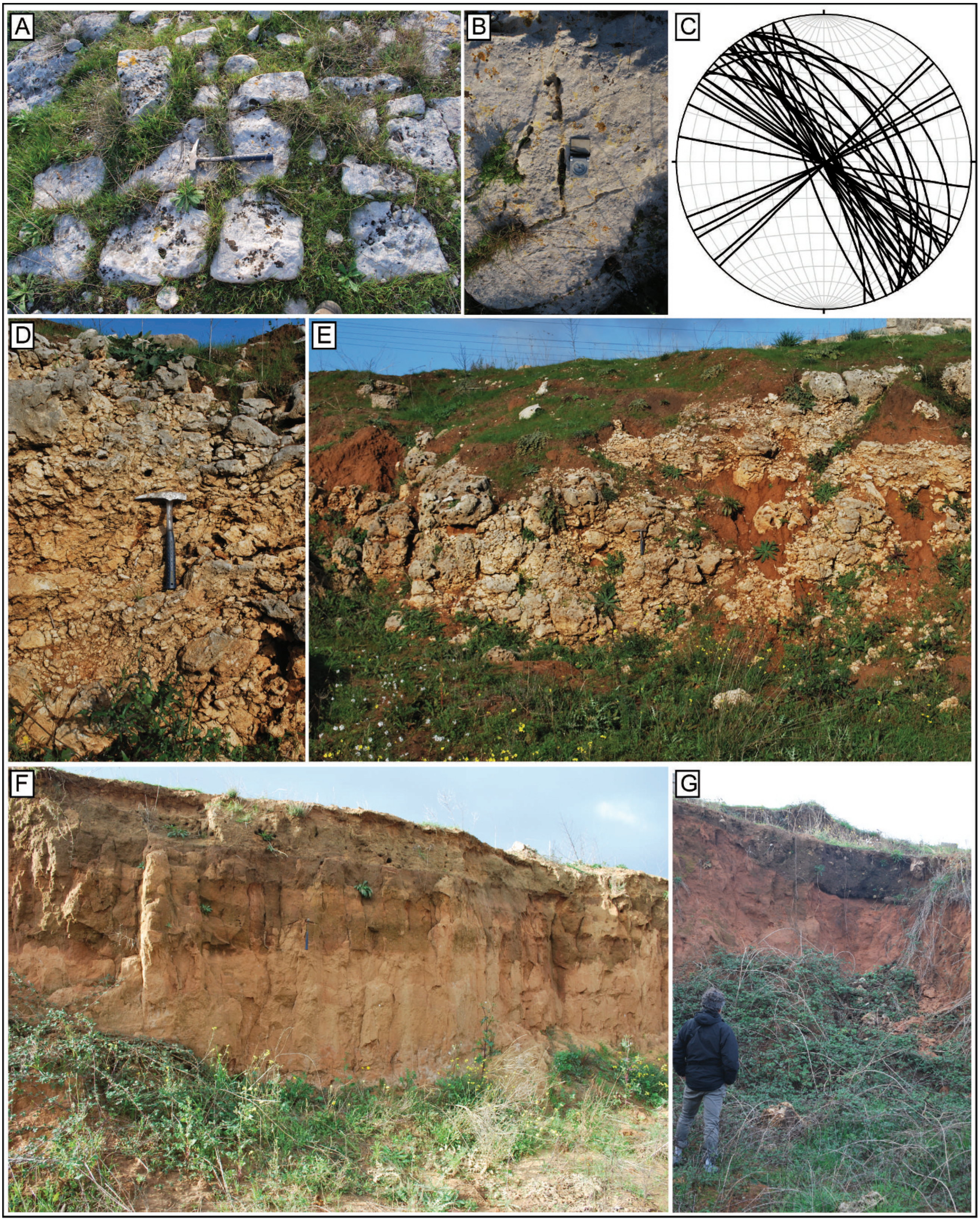

Figure 4. A and B: Tectonic joints in the calcarenite bedrock. Note their flutes-and-runnels appearance. C: Orientation diagram of the joints (n = 39) within the calcarenite bedrock. Equal area projection, lower hemisphere. The data were processed with the software Stereonet 6.3.2X by R. Allmendinger. D and E: carbonate breccia composed of calcarenite and calcirudite clasts with terra rossa. F and G: Siliciclastic continental sands and clay sands. Note the decimeter-thick soil at the top of the succession.

continental sands and clay sands (Figs. 3A and C) that have a maximum thickness of about 5 m. These sediments are generally stratified (Fig. 4F), even though they appear locally massive (Fig. 4G). At the top of the succession, a decimeter-thick soil is present, characterized by dark matrix clay and centimeter-sized carbonate clasts (Fig. 4G). The exposed surface at the top of this succession is sub-horizontal, and its inner edge contains the lower scarp (Fig. 3C). Here, the siliciclastic sediments are well exposed (Figs. 4F and G). The scarp is sub-vertical, reaching a maximum drop of about 4 m, and in its south-western sector represents the downward continuation of the intermediate scarp. Here, a total depth of about 8 m is reached. In plan view, the shape of its rim (III, in Figs. 3A and C) is approximately 8-shaped, with its maximum elongation striking about north-northeast–south-southwest. The bottom of the depression, located about 9 m above sea level, is occupied by thin deposits of clay sands (Fig. 3A) whose sedimentation is still ongoing in a palustrine-type environment (Fig. 3C) strongly characterized by colluvial contributions.

Geophysics

Electrical resistivity tomography measurements were carried out at the Masseria Forte di Morello sinkhole using a computer-controlled system. Forty-eight electrodes were laid out along a 235 m straight line at 5 m intervals. Each electrode location was surveyed using a Nikon DTM-720 total station and prism in order to include surface topography in the inversion process. The ERT was acquired in a rural setting, ensuring a generally good quality of measurements.

The dipole-dipole ERT was inverted using the method proposed by Oldenburg and Li (1999). A uniform half-space was chosen as the background reference model, and subsequent inversions were made with different values for its resistivity, ranging between 10 Ωm and 10000 Ωm. This procedure allows the depth of investigation (called the DOI index) to be evaluated. In practice, the DOI index, which ranges between 0 and 1, quantifies the change between the models obtained by the different background resistivities. DOI values not exceeding 0.1 for reference resistivities differing by two orders of magnitude indicate that the resulting model is well constrained by the data in that area.

The resulting 2D resistivity model (normalized RMS = 2.1) in the well-constrained area is shown in Figure 5A and has several important features. The higher resistivities (> 1000 Ωm; Fig. 5A) identified the calcarenitic rocks outcropping at both sides of the section (Figs. 3A, 5B). Note the apparent breaches in the bedrock indicated by finger-like projections of lower-resistivity materials into the carbonate rocks (Fig. 5A). An anomalous conductive zone

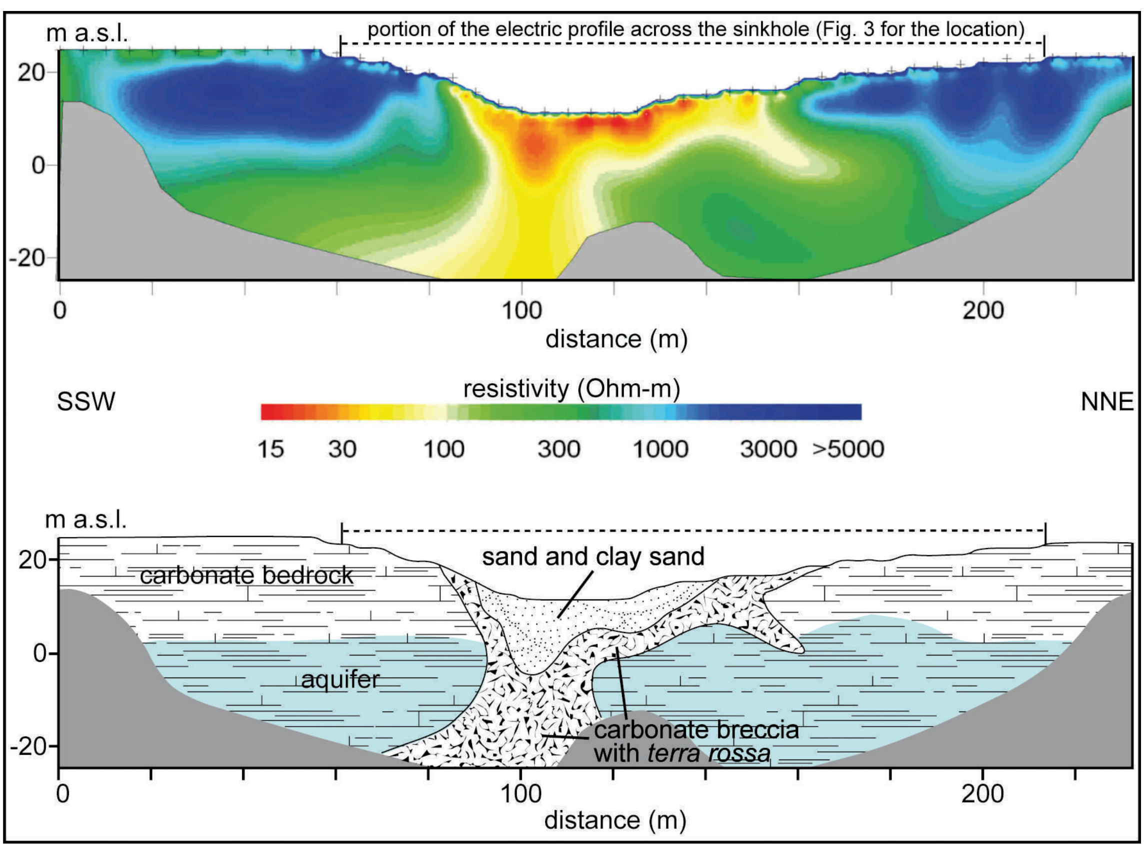

Figure 5. Top: Recovered resistivity model across the sinkhole. Bottom: Geological interpretation of the resistivity model.

is observed sloping toward the south-southwest in the resistivity model, where we can hypothesize penetration of low-resistivity materials into the calcarenites, potentially indicating dissolution features that have been filled by sediments or areas with extensive weathering of the carbonate rocks (e.g., along fractured volumes; Fig. 5A). A second anomalous conductive area is located on north-northeastern half of the resistivity model, but it is shallower (Fig. 5A). Elsewhere, downward from and starting slightly above the 0 m elevation, we recognized an abrupt resistivity lowering (Fig. 5A), which is in agreement with the presence of the aquifer within the carbonate bedrock (Tulipano and Fidelibus, 2002).

The lowest resistivity values (3 to 100 Ωm) are located in the central part of the section in the sinkhole (Fig. 5A). Here, resistivity values between 3 and 30 Ωm are consistent with the siliciclastic continental sands and clay sands (Figs. 3A, 5B), whose depths reach the elevation of about −5 m (Fig. 5B). In agreement with the geological map of Figure 3A, these sediments occupy the uppermost part of a funnel-shaped zone, above resistivity values between 30 and 100 Ωm that are associated with the presence of carbonate breccia with terra rossa to the elevation of about 20 m (Figs. 5A and B). In addition, a belt of fractured carbonate rocks is responsible of the abrupt lateral resistivity lowering recorded in the bedrock near the funnel-shaped body (Fig. 5A).

Historical Data Analysis

For this study, a multi-year analysis was performed to gain insights about the evolution of the Masseria Forte di Morello sinkhole over the last 55 years. Five couplets of aerial photographs, three historical topographic maps, ancient cadastre maps, and different sets of orthophotos were used; details of the sources are listed in Table 1. The analysis was associated with periodic field surveys over the last four years.

The sinkhole area is shown in the 1955 air photos (Fig. 6A) as a topographically depressed area bounded on all sides by alignments of limestone rocks. An overall rectangular shape, clearly produced by human activity, characterizes the area. This indicates that the sinkhole, or at least a depression produced by karst processes, was already present in 1955.

The same shape is recognizable on the 1:25,000 topographic maps produced by the Italian Geographic Army Institute in 1952. Blocks are aligned following the first morphological scarp in the landscape, and the lineations are well visible along the southwest-northeast and northeast-southwest, the joint directions. Toward the west, the morphology is less steep than on the other sides. The bottom of the depressed area is flat and regular, with a sub-circular plan.

Surprisingly, the area was considered for building purposes in the late 1960s, and 1 m high walls in calcarenite rocks were placed at the site to delimit a construction zone. The walls partially cover the limestone rock alignments visible in the 1955 air photos. These walls are also visible in the 1972 air photos (Fig. 6B). In 1972 there was no evidence of sinkhole reactivation.

In 1987 (Fig. 6C), the circular depression was again recognizable in the landscape without any particular deformation, but the calcarenite walls, even though not completely disrupted, showed the first signs of irregularity, probably related to deformations in the soil at the NE side of the sinkhole.

The situation strongly changed after 1987. Between July 1987 and late spring or summer 1994 (Figure 6D), the northern sector of the sinkhole collapsed, affecting a significant portion of the walls. The newly-formed sinkhole was encompassed within the boundary of the original depression and showed sub-vertical walls. The shape was circular, a few meters deeper than the surrounding landscape, and bounded at the south-southeastern edge by the spur that would become in the following years the testimony within the sinkhole.

A further collapse occurred between July 1996 (Fig. 6E) and 2000 (Fig. 6F). It affected the southern sector in the original depression, creating an 8-shaped sinkhole that is slightly aligned along a north-south strike. The aforementioned spur separated the areas involved in the two collapses.

Eventually, another event occurred between May 2003 (Fig. 6G) and August 2006 (Fig. 6H), again in the southern sector, thus producing a landform aligned east-west. In the same 2006 orthophotos, at least three other depressions can be recognized not far from the Masseria Forte di Morello sinkhole, disrupting once again the man-made calcarenite walls.

Discussion and Conclusions

The present research on the Masseria Forte di Morello sinkhole allowed us to reconstruct the history at the site. We identified five distinct phases of evolution, three of them recent activity over the last twenty years.

Genesis of the sinkhole began with a phase affecting the Miocene and Plio-Pleistocene carbonate bedrock. The collapse produced the carbonate breccia with terra rossa (Figs. 3 and 4D and C) and the funnel-shaped body (Fig. 5). The geological setting likely controlled the sinkhole formation, as shown by the agreement between the limits of the northern sector of the depressed area (Fig. 3A) and the strike of the tectonic joints surveyed in the outcrop of the carbonate bedrock (Figs. 4A to C). The morphological evidence of this first stage is given by the scarp rim I, as shown in Figures 3A and 3B.

The second phase produced a depression in the upper part of the funnel-shaped body (Fig. 5) which was later filled by sand and clay sand deposits (Figs. 3A and C, 4F and G). The depression created scarp rim II (Figs. 3A

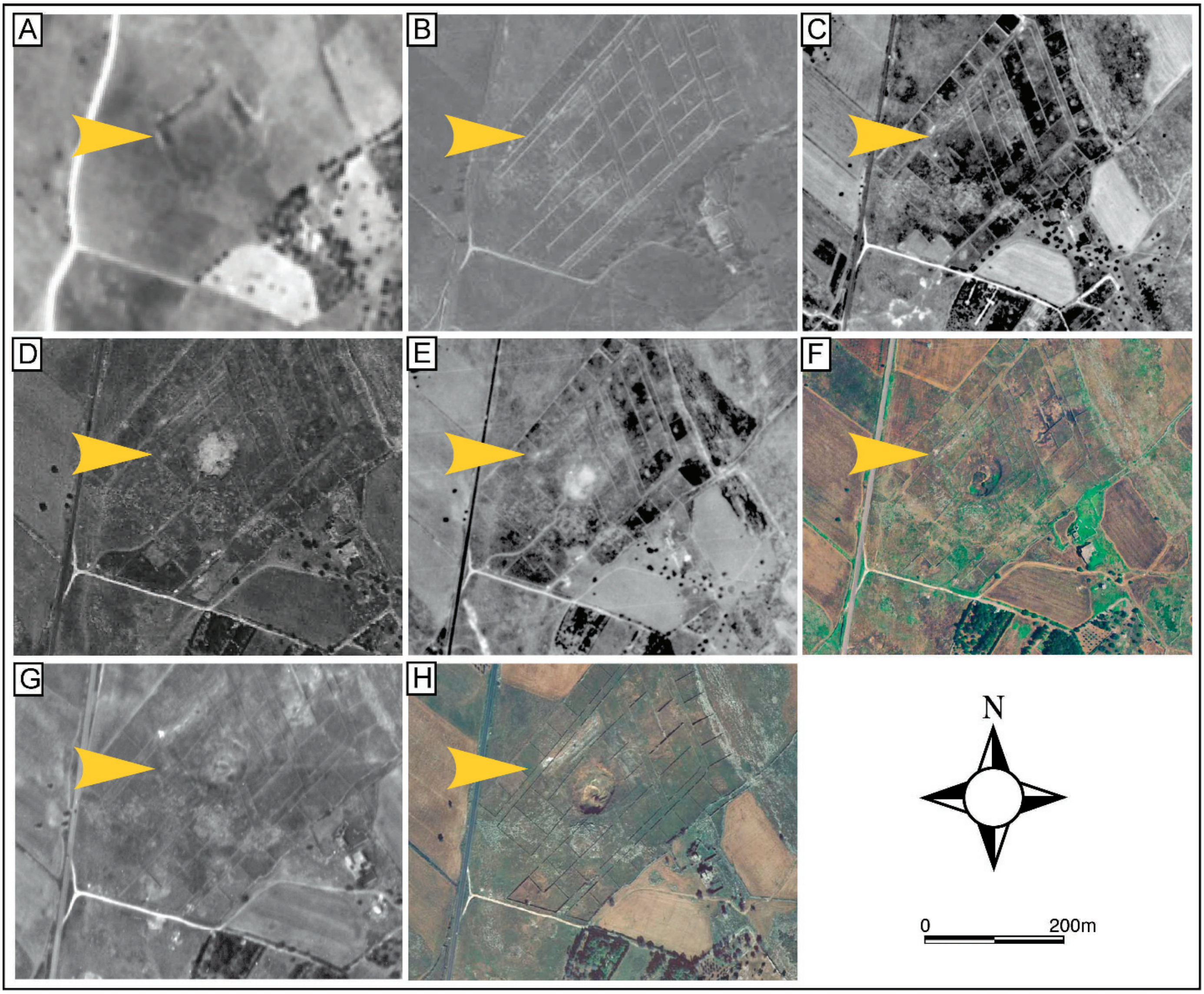

Figure 6. Historical analysis of the Masseria Forte di Morello sinkhole, performed by means of aerial photos and orthophotos. A: 1955 air photo. B: 1972 air photo. C: 1987 air photo. D: 1994 orthophoto. E: 1996 air photo. F: 2000 orthophoto. G: 2003 air photo. H: 2006 orthophoto. Details of the sources are listed in Table 1.

and C) that was likely recognizable in the early twentieth century and is seen on the 1955 topographic map. Since 1955, three re-activation events occurred over the last twenty years, as indicated by aerial photographs and orthophotos (Fig. 6). These events were responsible of the formation of the lowermost scarp rim III (Figs. 3A and C).

The first of these three events, that is, the third in the overall sequence, occurred between 1987 and 1994, with the formation of a circular sinkhole in the northern part of the depression. In the time span 1996 to 2000, another collapse affected the southern sector and created a depression that reached the same depth as in the northern sector to produce an 8-shaped sinkhole. Since 2003, the final phase in the evolution of the Masseria Forte di Morello sinkhole occurred. A collapse in the southern sector formed an elliptical sinkhole with major axis along the east-west strike. Eventually, minor failures along the margins of the sinkhole produced the present shape.

Overall, if the centroids of maximum depth of the three most recent phases are considered (Fig. 7), a migration toward the south-southeast can be observed. The low-resistivity vertical feature in Figure 5 strongly suggests that the greatest potential for further collapse may lie within the southern portion of the depression.

The different phases of evolution identified for the Masseria Forte di Morello sinkhole, with particular regard to those occurred in the last several decades, point out the importance of studying this type of natural phenomena using multiple methods. Until the 1980s, the area was not considered susceptible to any hazard, even though the

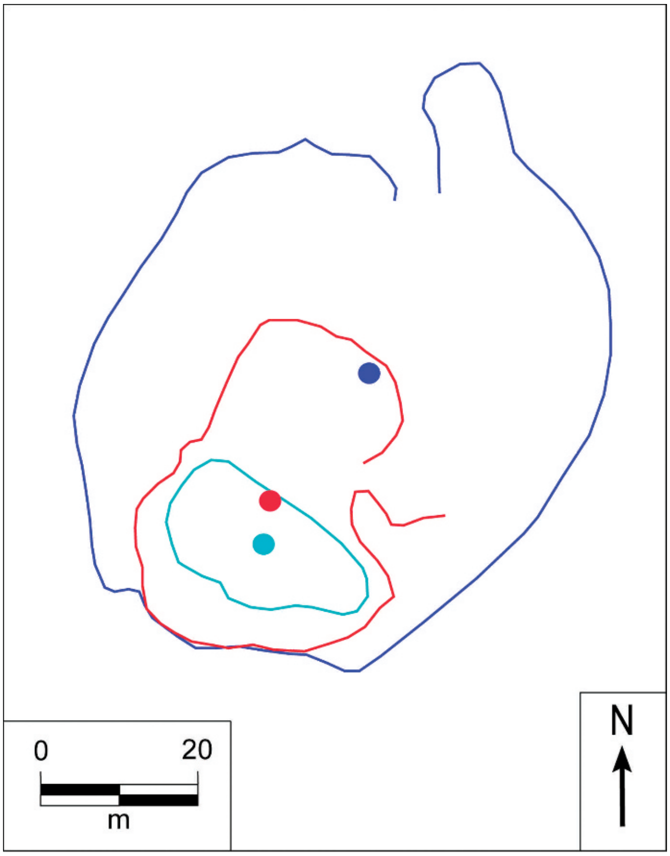

Figure 7. Map showing the centers of the three most recent events of evolution of the Masseria Forte di Morello sinkhole (dark blue, between 1987 and 1994; red, between 1996 and 2000; pale blue, between 2003 and 2006).

depressed area would have brought an expert karst scientist to warn about the site, and a plan for construction at the site was produced. The subsequent evolution, with multi-phase re-activation of the sinkhole, clearly shows the danger and the dramatic ways karst landscapes can change. If any buildings had been built, they would have suffered serious damage.

Salento has a great number of sinkholes and depressed areas that are considered very old, inactive karst features. Nevertheless, the case here indicates that it is necessary to perform detailed, site-specific analyses before considering areas inactive and devoid of hazard risk. In particular, the link between the presence of sinkholes and tectonic discontinuities should be properly investigated. Any program devoted to mitigating the sinkhole risk in Salento should therefore start from a careful study aimed at identifying the genesis of the sinkhole and the likely factors that might cause its re-activation.

Acknowledgments

A warm thank you to Gianfranco Quarta, who helped us during the topographic survey of the Masseria Forte di Morello sinkhole, and to Cosimo Magrì and Gianni Piras (Geoprosys), who contributed to the geophysical data acquisition. The software used for ERT data inversion was developed at and licensed from UBC, Canada.

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