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"*SASSI*", THE OLD TOWN OF MATERA (SOUTHERN ITALY): FIRST AID FOR GEOTOURISTS IN THE "EUROPEAN CAPITAL OF CULTURE 2019"

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ABSTRACT: The old town of Matera (southern Italy) is an urban area included in the UNESCO World Heritage List since 1993 and Matera has recently been designated as European Capital of Culture 2019. Since prehistoric times, the old town, called "*Sassi di Matera*" ("*sassi*" is the Italian word for stones), has been spectacularly dug in a "soft rock" (a quaternary calcarenite). This rupestrian settlement is perched in the upper part of the right side of the "*Gravina di Matera*", a canyon cutting the so called "*Murgia Materana*", the barren rocky high in front of the town.
An increasing number of tourists is attracted by itineraries crossing the "*Sassi di Matera*", and, due to the intimate connection between the old town and the geological anatomy of the area, each touristic itinerary could become an urban geotour or could be enriched by geological information.
The aim of the present paper is to offer simple geological information to tourists who are visiting the old town of Matera, giving them the opportunity to admire the amazing geology of the area and to be intrigued in understanding the development of the crossed landscape.

Keywords: geology; geotourism; Sassi; Gravina di Matera; Murgia Materana

1. INTRODUCTION

The "*Sassi di Matera*", locally named the "*Rioni Sassi*" (*Sassi* Districts) or simply the "*Sassi*", is the surprising rupestrian old town of Matera, in southern Italy, spectacularly dug in a "soft rock" (an easily workable limestone) and perched in the upper part of the right side of a canyon (the "*Gravina di Matera*"). Since 1993 the *Sassi di Matera*, have been included in the UNESCO World Heritage List with the following justification: "This is the most outstanding, intact example of troglodyte settlement in the Mediterranean region, perfectly adapted to its terrain and ecosystem. The first inhabited zone dates from the Palaeolithic, while later settlements illustrate a number of significant stages in human history". Moreover, on 17 October 2014, the town of Matera has been designated as European Capital of Culture 2019.

Due to the large volume of tourists inspired by cultural interests expected in Matera, and since the old town is well known for being "carved into the rock", city tours may offer the perfect opportunity to divulge the culture of geology to non-expert audiences (Sabato et al., in press). In this regard, the intimate connection of Matera with geology is primarily suggested by the name "*Sassi*" indicating the rupestrian districts representing the old town: "*Sassi*" is the Italian word for “stones”, and the old town of Matera still conveys an idea of symbiosis with the original rocky landscape (Fig. 1). In order to provide a "first aid" to non-specialists, the ambition of this article is to help tourists to read the territory hosting the town of Matera by supplying some useful geological information. The geographical background in which the *Sassi* Districts developed is represented by the "*Murgia Materana*" (or "*Murgia di Matera*"), that is the rocky area in front of Matera spectacularly cut by the "*Gravina di Matera*", the canyon formed after the gradual incision of the stream that still flows at the bottom of the rocky valley. The old town is perched on the right side of the canyon (Figs 1 and 2), which is the main geographic element characterizing the landscape. Without the presence of this canyon and of its two urbanized tributaries (the "*graviglioni*"), which now are the two main roads to enter in the *Sassi* Districts, the rupestrian town could not have existed (Tropeano, 1992; 2003a; 2003b).

Since it is impossible to disregard the development of the *Gravina di Matera* from the geology of both the *Murgia Materana* and the surrounding clayey territory, this article: i) explains the meaning of some used local geographic terminologies and debunks some of the

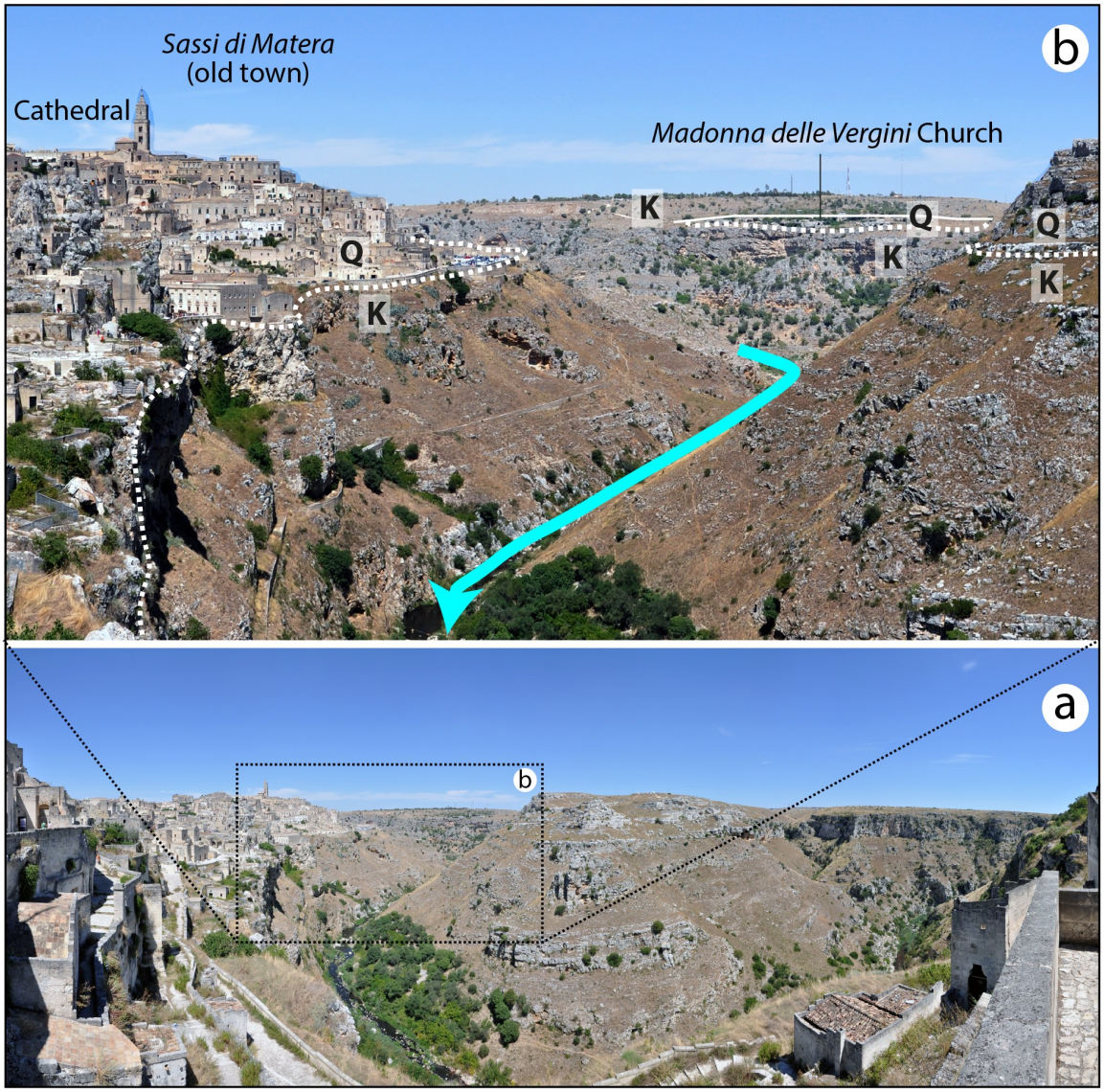

Fig. 1 - a) Panoramic view of the canyon "*Gravina di Matera*" cutting the "*Murgia Materana*", i.e. the rocky region made up of carbonate rocks characterizing the area; b) Detail of the *Sassi di Matera* (the old town of Matera), i.e. the famous rupestrian settlement dug in the upper part of the right flank (on the left in the photo) of the "*Gravina di Matera*" canyon. Geographically, left and right flank of a valley are defined in relation to the river flow direction. Note the presence of two types of carbonate rocks along the flanks of the canyon: Cretaceous limestone (K), older than 65 millions of years, below, and Quaternary calcarenites (Q), not older than 2.5 millions of years, above. The *Sassi di Matera* are dug in the Quaternary carbonates, that are "soft rocks" (i.e. easily diggable rocks) geologically belonging to the "Calcarenite di Gravina" Formation. Source of the panoramic photo: https://www.panoramio.com/photo/39789706. Author: Giorgio Galeotti.

common (geological) myths regarding Matera; ii) describes the development of the *Murgia Materana*, basically realized in the last 2.5 millions of years (i.e. during the Quaternary Period); iii) explores the role that the water has played in this context, as a primary agent for the development of the hydrographic network (of which the *Gravina di Matera* is part), and, eventually; iv) shows how both the presence of water and the wide exposure of soft rocks along the slopes of the *graviglioni* have determined the early reasons for the urbanization of the *Sassi* area.

2. PRELIMINARY WARNINGS

2.1 Terminological assistance

One of the main difficulty that tourists face in Matera is the use of local names to indicate some geographic elements (i.e. "*gravina*" for canyon).

The name "*murgia*" (pl. "*murge*"), with the first letter in lowercase, was a widespread term in southern Italy indicating a rocky hill. The term became a very used toponym that, associated to other words and capitalizing the first letter, has assumed a geographical meaning. For example, "*Timpone delle Murge*", "*Alta Murgia*",

Fig. 2 - Aerial view of the Murgia Materana and the Matera town with some of the toponyms used in the text. The green dotted line indicates the boundary between Cretaceous (below) and Quaternary (above) carbonate rocks; the yellow dotted line indicates the boundary between Quaternary carbonates (below) and Quaternary clay deposits (above). Top of the hills (*Lanera*, Castle, and *Serra Venerdì*) are characterized by sand and gravel. The Sassi Districts were dug in the Quaternary carbonates (i.e. the Calcarenite di Gravina Formation). Base image by Google Earth.

"*Minervino Murge*", "*Murgia Materana*", represent well defined localities or territories. Attention should be drawn to the plural term without specific local indications but with the first letter in uppercase (Murge): it indicates the wide central area of Apulia characterized by the presence of ancient karstic rocks and a series of terraced plateaux. Apulia ("Puglia", in Italian) is the easternmost geographic region of southern Italy forming the spoor and the heel on the "Italian boot", the latter representing the Italian peninsula (Fig. 3a). It is important to underline that, administratively, Matera and the *Murgia Materana* belong to the Basilicata Region, i.e. they do not fall in the Puglia Region, but considering both physical geography and geology of the Matera area, the latter is physically part of the Apulia Foreland, i.e. the geological element in front of the southern Apennines that roughly corresponds to the Puglia Region (Figs 3b and 3c).

The term "*gravina*" is used with different meanings. First of all, it is a generic term to indicate each canyon developed on the southwestern flank of Murge. To indicate a specific one of these canyons, the first letter is in uppercase and the term *gravina* is followed by the name of a locality: i.e. *Gravina di Matera* (literarily: Matera Canyon). The same term *Gravina di Matera* indicates also the ephemeral stream flowing at the bottom of the canyon, and so the *Gravina di Matera* (the stream) flows in the *Gravina di Matera* (the canyon). Another element to complicate the tourists life is that in the vicinity of Matera there is a town named "*Gravina in Puglia*" or "*Gravina di Puglia*", which is indicated on the road signs simply as Gravina. Gravina (the town) is famous for its *gravina* (the canyon) that obviously is called "*Gravina di Gravina*" (literarily: Gravina Canyon). Accordingly, the ephemeral stream running in the canyon is the *Gravina di Gravina* (the stream) in the *Gravina di Gravina* (the canyon) that characterizes Gravina (the town). To create more confusion, along the walls of the *Gravina di Gravina* has been formally defined the "*Calcarenite di Gravina*" Formation, the geologic term that regionally indicates the carbonate rocks in which the *Sassi di Matera* are carved (Figs 1 and 2). Therefore, moving in the *Sassi* districts, tourists touch a soft-rock (a sedimentary rock that can be easily dug and used for buildings; Andriani & Walsh, 2010) locally called "*tufo*" or "*tufi*" (*tufi* is the plural of *tufo*), lithologically called calcarenite (lithified calcareous sand), and geologically belonging to the *Calcarenite di Gravina* Formation.

2.2 Fake geological news

Some improbable geological phenomena attributed to natural aspects of the territory derive from popular myths handed down from generations. One of these anecdotes is the widespread belief that the steep wall of the *Gravina di Matera* known as "*Tempa Rossa*" ("red wall"), a reddish portion of the upper side of the canyon

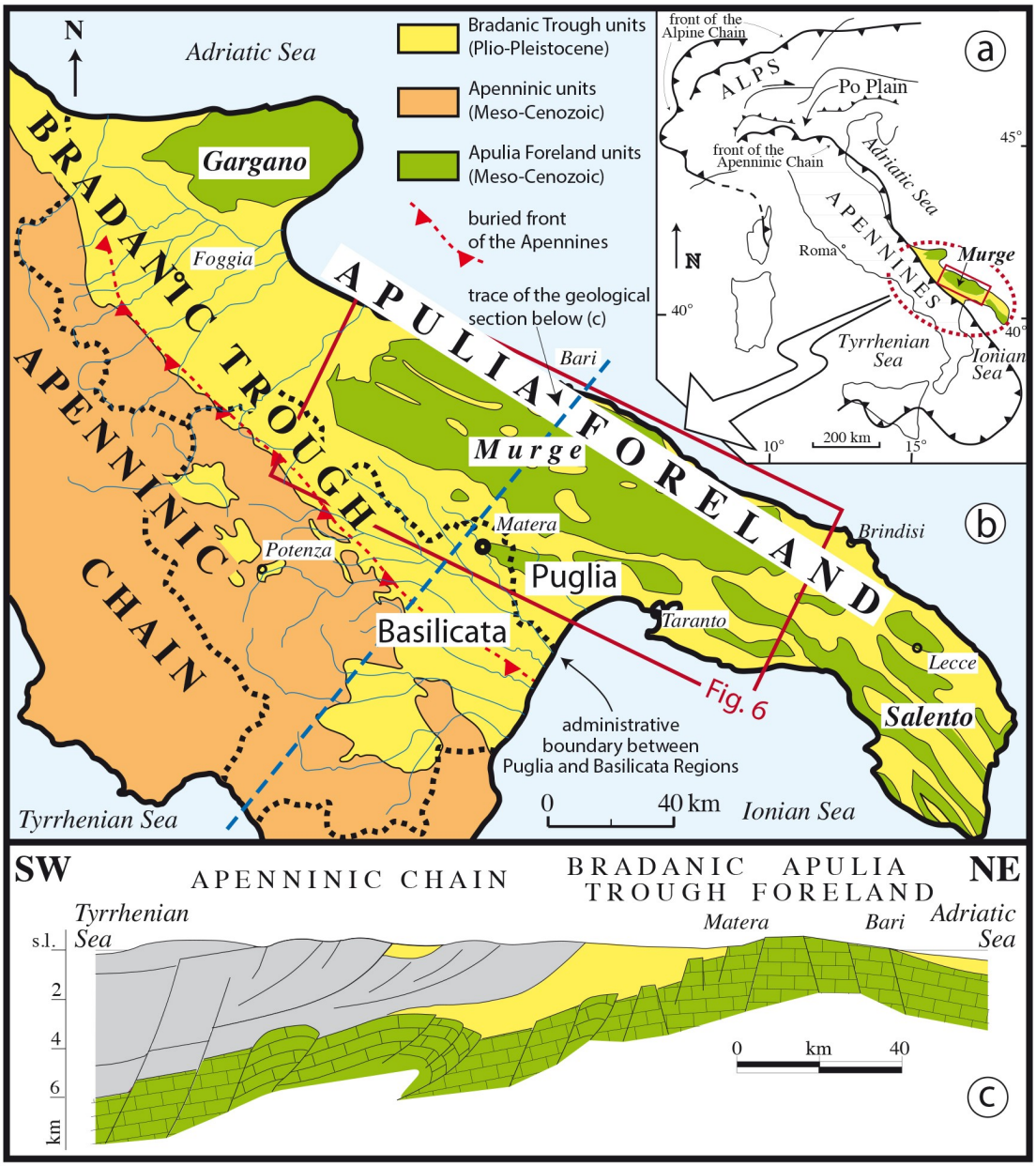

Fig. 3 - a) Structural sketch of Italy showing the position of the spoor and the heel of the "Italian boot"; they correspond to the Apulia Foreland (the green area), a geological term indicating the area that has not yet been reached directly by the Apennines deformations. Apulia (Puglia Region) is an administrative term; political boundaries of Apulia do not correspond to geological boundaries of the Apulia Foreland; b) simplified geological map of southern Italy (from Pieri et al., 1997, mod.). Note the position of Matera inside the three units of the orogenic system (Apulia Foreland, Bradanic Trough, and Apennines Chain). Geologically, Matera belongs to the Apulia Foreland while, administratively, it belongs to the Basilicata Region. The Murge area is the set of karst plateaux located in the middle of the Apulia Foreland, and the *Murgia Materana* represents an isolated karst hill of the Murge area within clay-rich lands; c) simplified geological section crossing the southern Italy (after Sella et al., 1988).

in front of the town and visible from any panoramic position in the *Sassi* Districts, is a volcano that has been active in "historical old-times" (i.e. "not now but during the life of my grandfather's great-great-grandfather") (Tropeano et al., 2016) (Fig. 4). Unfortunately, this old lore found formal truth in an old geography treaty, quoted in some relatively recent documents aimed at preventing citizens from natural hazards. Actually, *Tempa Rossa* is only a subvertical wall of the *Gravina di Matera*, whose origin is due to the deepening of the watercourse favoured by the uplift of the region, as discussed in the following sections. Its reddish colour is related to the presence of eluvial material coming from the flat top of the left side of the canyon; this material is

Fig. 4 - Panoramic view of "*Tempa Rossa*", a name that means "red wall". People believe that it corresponds to an active volcano. Actually, it is the highest wall of the *Gravina di Matera* where outcropping Cretaceous limestones show a reddish colour, due to the presence of residual material rich in iron and aluminum oxides. Photo by M. Tropeano.

rich in iron and aluminum oxides (reddish residual substance due to the dissolution of the exposed carbonate rocks). Moreover, no volcanic rocks crop out around the "volcano", and any geothermal anomalies have never been recorded along the *Gravina di Matera*. Therefore the Tempa Rossa Volcano does not exist and never existed in the Matera area.

Another belief is that the *Gravina di Matera* could "absorb" earthquakes, despite many of the inhabitants who verbally report this theory believe that the *Gravina di Matera* is a sort of large fissure (a rift) due to an ancient earthquake. In geology, any break of the Earth's crust is a mechanical discontinuity, which is called fault if the adjacent blocks move relatively each other creating a rocks displacement. This movement can release energy in the form of earthquakes, which propagate in the Earth's crust. Both the depth of the seismic source (at least several kilometers) and the nature and energy of the waves produced by an earthquake exclude that pellicular elements of the Earth's surface, like a canyon, could "absorb" waves propagation. Moreover, it has been observed that during the major disastrous earthquakes, the movement of the two blocks along the faults is of the order of decimeter/meter. This relatively "small" size of the displacement is absolutely not comparable with the *Gravina di Matera* current dimension, more than 100 m of both width and depth. Finally, the youngest rocks (early Quaternary in age, i.e. not older than 2.5 millions years) exposed along the two flanks of the canyon do not show significant displacements, even if some normal faults could be observed in the area (Tropeano et al., 1994; Festa et al., 2018) (Fig. 5). Anyway, there are rumors linking earthquakes to *Tempa Rossa*: "if the *Tempa Rossa* volcano becomes active again there will be a strong earthquake (poor us)!". Luckily no earthquake may generate from an imaginary volcano!

Unfortunately, in addition to the proper attention and sensitivity for the correct management of the territory, the growing interest in the *Sassi* and the *Murgia Materana* is leading to an exponential increase in "opinions" rather than "facts" about several phenomena and/or attributes of the area. These interpretations, which are not data-supported but amplified by social networks or self-published "studies", are turning into scientific truths. In this way, prehistoric rock falls could become boulders moved by old inhabitants to protect the entrance of some caves, and N-S striking fractures or natural rocky walls could become witnesses of solstice celebrations. As a consequence, many natural and small features of the area, or many anthropic choices linked to original natural peculiarities, are now attributed exclusively to the ingenious of prehistoric inhabitants

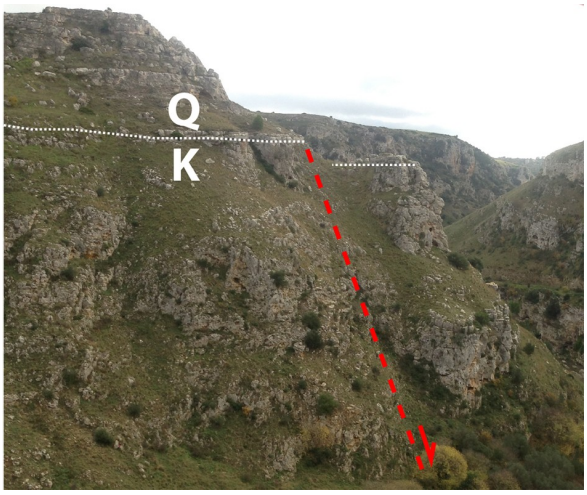

Fig. 5 - One of the few normal faults cutting both the Cretaceous bedrock and the Quaternary calcarenite. This fault can be observed from the square of the *San Pietro Caveoso* Church, located in the lower part of Sassi. According to Festa et al. (2018), Cretaceous carbonates are intensely fractured and affected by several faults but only a few of these structures propagate in the Quaternary units. Photo by V. Festa.

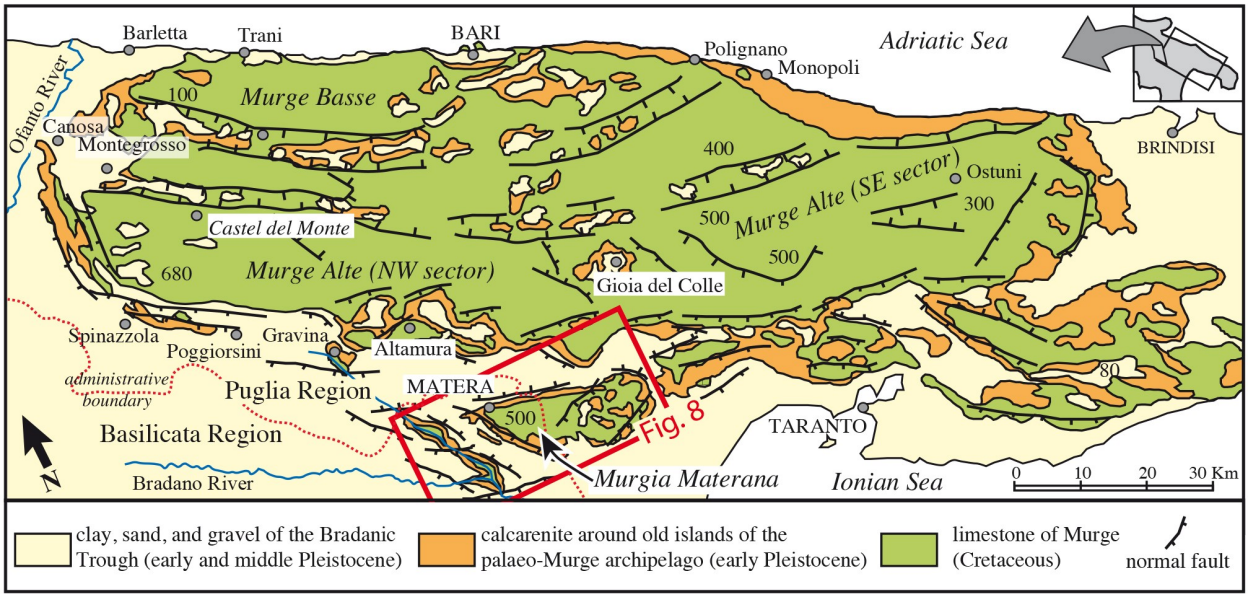

Fig. 6 - Structural sketch of the Murge area (see Fig. 3 for the location; from Pieri et al., 1997, mod). The *Murgia Materana* is an isolated sector of the Murge that records the Quaternary geological development of the whole region. Green areas are made up of Cretaceous limestones and roughly correspond to the islands of the palaeo-Murge archipelago, developed in this part of the Apulia Foreland at least from about 2.5 millions years ago (at least from the beginning of the Early Pleistocene)(see Fig. 7). The calcarenite around old islands corresponds to the *Calcarenite di Gravina* Formation, the soft rocks in which the *Sassi di Matera* are dug. This calcarenite derives from the lithification of shallow-marine and coastal carbonate sands deposited on the flanks of the islands during their drowning. In later times, the same areas were reached by clays and successively by sands and gravels coming from the Apennines. The middle and upper Quaternary uplift of the region determined the exhumation of the old islands and their subsequent erosion by the drainage network, including the "*Gravina di Matera*".

and to their high capacity of transformation of the landscape, a fascinating but distorted reading of the superimposition of man on the natural features of the region ("tourists: be careful about the source of information!").

3. THE "MURGIA MATERANA" IN THE GEOLOGICAL FRAMEWORK OF THE APULIA FORELAND

The *Murgia materana* is an isolated portion of the Murge (Fig. 6) and its development may be outlined in the context of the development of the entire Apulia Foreland. In particular, the area of Matera with: i) its canyon (the *gravina*), ii) the almost barren karstic plateau cut by the canyon (the *Murgia Materana*), and iii) the clayey hills on which the modern districts spread (among others, the districts/hills named *Lanera*, *Serra Venerdì*, *Serra Rifusa*) (Fig. 2) synthesize all the geomorphological and geological features that can be recognized along the western edge of the Murge. In this framework, a favourable geographic-geological opportunity to inhabit the region was offered by the urbanization of the upper part of the right side of the *Gravina di Matera*, with the excavation of a complex network of caves, tunnels and cisterns in the exposed rocks. From this original "residential strategy", the *Sassi di Matera* were born.

The Murge anatomy reflects a long geological history, whose documented field-evidences date back to about 140 million years ago, during early Cretaceous times (Ricchetti et al., 1988; Spalluto et al., 2005). At that time, the region that was going to be the Apulia Foreland, was a wide shallow-marine inter-tropical area basically comparable to the present-day Bahamas. There, on the Apulia Carbonate Platform, carbonate muds, which gradually were becoming limestones, deposited over millions of years up to about 65 million years ago (up to the end of the Cretaceous), when the platform underwent subaerial exposure. Later, in the area now corresponding to the Murge, limestones were tectonically displaced forming a horst and graben structure (Pieri, 1980) in a domino faults array (Festa, 2003). This structural configuration led the area to be characterized by topographic highs and lows (Iannone & Pieri, 1982; Tropeano et al., 1997). Susequently, at least from the beginning of the Quaternary Period (about 2.5 million years ago), this region was affected by subsidence (a slow dropping, in this case induced by the migration of the Apenninic orogenic system) that caused the return of the sea in Apulia creating a wide archipelago (Tropeano & Sabato, 2000; Tropeano et al., 2002a; 2002b) (Fig. 7a). The islands corresponded to the structural highs of the previously described faults system and comprised exclusively Cretaceous limestone. These hard whitish rocks, that today characterize the Murge karst landscape, were the bedrock of both the islands (one of the highest of which would became the future *Murgia Materana*) and the structural depressions (straits) among islands, such as the Viglione Graben (Tropeano, 1992) (Fig. 8). A more important and deeper seaway, the Bradanic Trough ("*Fossa bradanica*"), connected the central-northern Adriatic Sea to the Ionian

Sea between the migrating Apennines and the Murge archipelago. The slow subsidence of the whole Murge region caused the progressive submersion of the archipelago (Fig. 7b). In this geographic context, coarse-grained coastal deposits formed by a mix of skeletal carbonate fragments (bioclasts, i.e. parts of shells of mollusks living in those coastal areas) and detritus eroded from the exposed limestones accumulated on the sides of the islands (Tropeano & Sabato, 2000; Pomar & Tropeano, 2001; Mateu-Vicens et al., 2008).

After diagenesis, this compositional mixing (*sensu* Chiarella et al., 2017) formed by biodetritic and lithic carbonate sands would became the easily-dug porous carbonate-rocks locally and commercially known as "tufo" and formally defined as "*Calcarenite di Gravina*" Formation (Figs 6 and 8). These soft-rocks, a few meters to several tens of meters thick, lie on the Cretaceous limestones (harder rocks) and represent the bedrock on which the *Sassi* Districts developed (Fig. 1). It should be noted that, at the moment of the sedimentation of deposits that would became these soft-rocks, the area was almost completely submerged by the sea and the still not existing *Gravina di Matera* stream had not yet cut the *Murgia Materana* (Fig. 7b).

About 1.5 million years ago there was the maximum rise of the sea on the islands of the palaeo-Murge archipelago; this phenomenon left only the highest reliefs uncovered by the sea, including the flat culmination of the future *Murgia Materana* (Fig. 9). At the same time the detritus brought by rivers running in the Apennines began to fed the Bradanic Trough seaway, which was progressively reached by offshore clays and filled with coastal sands and gravels (Pieri et al., 1996; Sabato, 1996; Sabato et al., 2004). These same sediments also reached areas of the old archipelago, filling all the straits located between the old islands; the latter were almost completely buried by sediments except for the most elevated ones (Tropeano et al., 2002a; 2002b) (Fig. 7c).

Accordingly, about one million years ago, almost the entire region was a flat area, except for the protruding culmination of the old islands, one of which was the topmost part of the present-day *Murgia Materana* (Fig. 9a). This is the geological "moment" when the watercourse that would became the present-day *Gravina di Matera* Stream, as well as the entire hydrographic network that characterizes the Murge area, established (Gioia et al., 2011). At the same time, the region began to suffer a still active tectonic uplift (Doglioni et al., 1994; 1996), which would progressively brought: i) the Murge and the culmination of the *Murgia Materana* to exceed 500 m of altitude, ii) the drainage network to dissect the flat area, now at more than 400 m of altitude (Fig. 9b), where watercourses began to develop, and iii) the Ionian Sea to retreat towards the present-day Metaponto Coastal Plain. With the beginning of the regional uplift, the rivers running on sands and gravels of the alluvial plain progressively cut these deposits, reaching the underlying clays. Locally, the drainage network reached deeper and more ancient carbonate rocks too, creating the canyons locally called "*gravine*" (the plural of "*gravina*"). In areas where the drainage network has not yet reached the deep bedrock, fluvial valleys develop in clays with sections much wider than those ones of canyons. The valley of the Bradano River, just south of Matera, is the perfect example of both the phenomena: its erosion has locally reached the carbonate bedrock, creating a spectacular canyon (a *gravina* with subvertical walls) that contrasts with the clayey slopes of the hills of Miglionico and Matera (new town), representing the flanks of the fluvial valley just above the *gravina* of the Bradano River (Figs 8 and 9b).

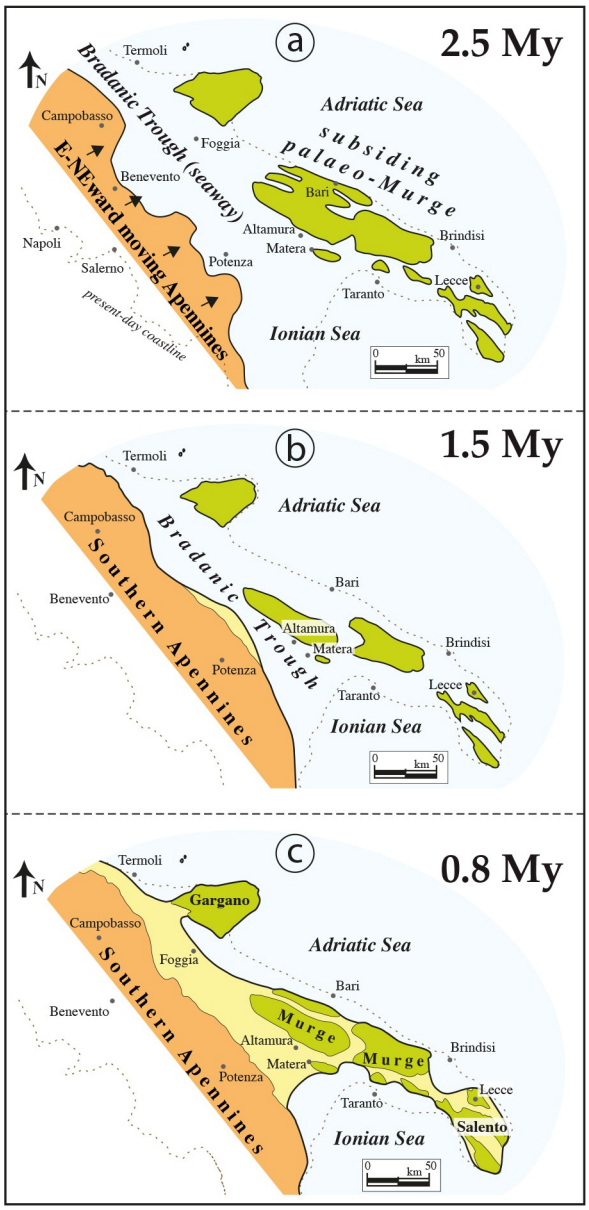

Fig. 7 - Development of the Apulia Foreland during the Quaternary within southern Italy. Note the development from the palaeo-Murge archipelago to the present-day Murge and the position of the Matera area in the three reported different steps. During the Quaternary, the region was affected at first by subsidence and, later, by uplift. a) beginning of the Early Pleistocene; b) middle of the Early Pleistocene; c) end of the Early Pleistocene - beginning of the Middle Pleistocene.

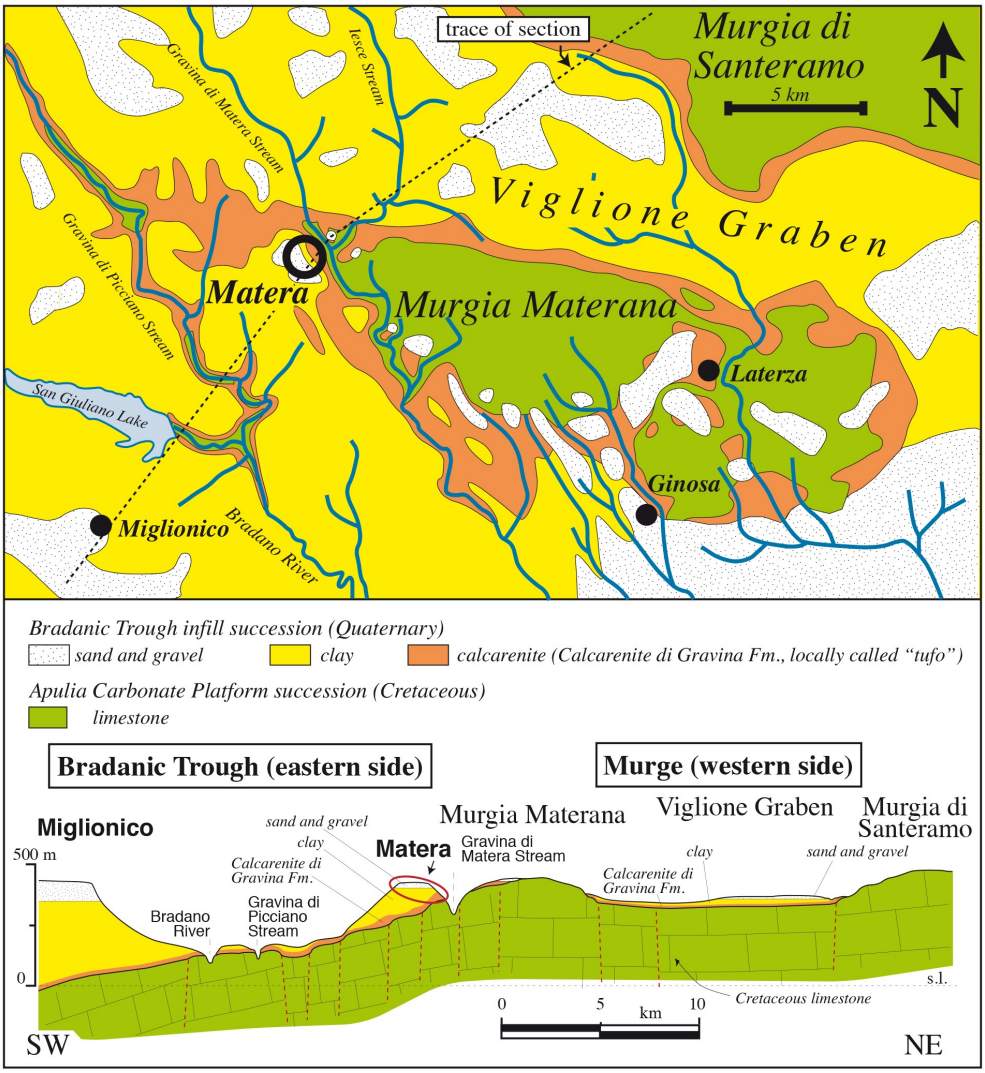

Fig. 8 - Schematic geological map and section of the *Murgia Materana* (see Fig. 6 for the location; from Beneduce et al., 2004, mod.). Note the position of Matera, at the same time on the rocky flank of the *gravina* and on clay, sand and gravel of the top of the hill.

4. THE "GRAVINA DI MATERA"

The *Gravina di Matera* is a rocky valley deeply cutting the "soft" Quaternary calcarenites and the underlying "hard" Cretaceous limestones (respectively Q and K in Figs 1 and 5). It is worth noting that, by definition, the *gravina* is a canyon cut by the watercourse that still flows at its bottom. The width of the valley is linked to the long and complex phenomenon of recession of the slopes and should not be imagined as originating from a wide river progressively reduced to the present-day stream. Indeed, all the valleys start out as small and narrow V-shaped incisions; the lowering of the base level of the watercourse led their progressive deepening, causing the retreat of the flanks (mainly due, along canyons, to the frequent collapse of the rocky walls) and the subsequent valley expansion.

The original course of the stream creating the *Gravina di Matera* developed on a sandy-gravelly alluvial plain, and ran at the toe of the topmost part of the north-western corner of the *Murgia Materana* (Fig. 9a). Very soon, the deepening of the watercourse allowed to cut the buried edge of the ancient island, firstly reaching the soft-rocks of the *Calcarenite di Gravina* Formation and, successively, the Cretaceous limestones (Fig. 9b). The boundary between these two different types of carbonate rocks can be identified at the base of the *Sassi* (Fig. 2) and, on the other side of the *Gravina di Matera* (Figs 1 and 5), just below the rupestrian churches of the Belvedere (the town's panoramic lookout, part of the all tourist itineraries) (Figs 2 and 9b).

Unlike the other *gravina*-like canyons, which developed along dip (i.e. according to the exposed slope of the flank of the exhumed old island), the *Gravina di Matera* incised the flank of the exhumed island along strike (i.e. perpendicular to the buried old slope) (Fig. 8). This led to a different exposure of the rocks on the opposite sides of the *Gravina di Matera*, which is particularly

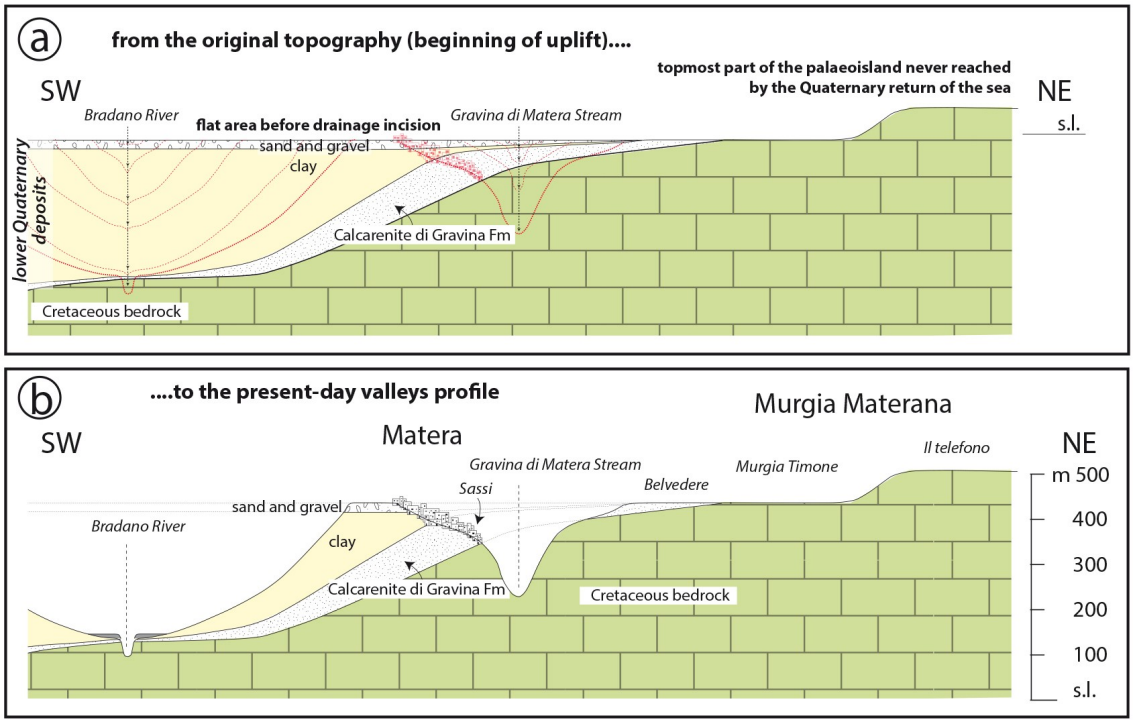

Fig. 9 - a) Stratigraphic scheme showing the original distribution of Quaternary deposits on the southwestern flank of the palaeoisland corresponding to the future *Murgia Materana*. Note the position of both the Bradano River and the *Gravina di Matera* Stream before they reached the carbonate bedrock. Red dotted lines indicate the progressive development of valleys. b) Schematic geological section (not to scale) of the southwestern flank of the *Murgia Materana*, showing the present-day valleys (after Beneduce et al., 2004). Matera developed on the flank of the *gravina*, due the presence of both "easily diggable" soft rocks (the *Calcarenite di Gravina* Formation) and water in the upper part of the hill.

clear considering the thickness of the *Calcarenite di Gravina* Formation, thin in front of the *Sassi* Districts and thick in the *Sassi* themselves (Figs 1b and 9b).

Once the stream reached the hard bedrock, it progressively adapted its course to the trend of the main fracture zones of the Cretaceous limestone, developing a slightly angular drainage network (Beneduce et al., 2004). At present, the *gravina* shows either straight sections (mainly oriented about NE-SW and NW-SE) with flanks having symmetrical slope profiles, or sinuous stretches (meanders) with flanks having asymmetric slope profiles (Tropeano, 1992).

Several suspended dry valleys represent ephemeral tributaries unable to reach the base level of the *Gravina di Matera*. Even the so-called *graviglioni*, now identified into the two main roads going down the *Sassi*, were two tributaries with suspended valleys on the *Gravina di Matera* (Fig. 2). Soft-rocks of the *Calcarenite di Gravina* Formation crop out extensively on the sides of these two tributaries and led to the easy and wide development of the peculiar urban fabric of the *Sassi* Districts. The suspended valleys are connected to the *gravina* by means of jumps (knickpoints) acting like waterfalls during main rainfalls; at the base of jumps some evorsion cavities, called potholes (cylindrical holes in rock) or giant's pots, are present (evorsion is the erosion of rocks due to vortices of water). These potholes can also reach relatively large dimensions (several tens of meters in diameter), such as, for example, along the Jesce Stream (*Torrente Jesce*), where some ponds probably represent old "giant's pots". Numerous smaller pots are visible on the right side of "*Masseria Passarelli*" ford, where the *Gravina di Matera* stream locally expands its valley partly running in clays.

Moreover, some isolated reliefs of conical shape, shoving variable sizes and heights between some tens to one hundred of meters, are linked to the development of the drainage network of the *Gravina di Matera*. Two of these reliefs are well recognizable in the *Sassi* Districts: the most evident is represented by the "*Monterrone*" (Fig. 10), the relief hosting the "*Madonna dell'Idris*" Church that appears isolated from the slope of *Sassi* through an old and abandoned meander of the canyon (Fig. 2); the less evident relief is represented by the "*Civita*", the hill on whose side stands the Cathedral (Figs 1 and 2), which is isolated by another abandoned meander, a residual segment of which partly corresponds to "*Piazza San Francesco*" and "*via Ridola*". Other prominent isolated reliefs are represented by the rocky hill hosting on top the "*Madonna degli Angeli*" Church and by the rocky hill located in front of the "*Madonna delle Vergini*" Church, both clearly visible from high panoramic points of the *Sassi* Districts (Fig. 11, see also Fig. 2). As mentioned above, these isolated reliefs are evidence of abandonment of old segments (meanders) of the canyon, later reworked by the hydrographic network (Fig. 2).

Fig. 10 - The isolated conical relief of "*Monterrone*" hosting the "*Madonna dell'Idris*" Church. Photo courtesy of Silvia Zapelloni.

5. GEOLOGY AND URBAN DEVELOPMENT OF SASSI

In general, it is not easy to perceive the original reasons for the establishment of prehistoric settlements representing the origin of future cities. At the beginning, the choice must have been mainly linked to the presence of favourable geographical conditions, often a consequence of the interconnection between the geological nature of the territory, climate, presence of natural defenses, and availability of resources (water in the first place). Later, ideal conditions for commercial exchanges or military defenses became among the primary reasons for the historic expansion of towns (Gisotti, 2016). This "recent" development has made it difficult to read the original natural requisites that favoured the first step of settlement of very old urban areas.

Some of the previously described geological and morphological elements of the Matera area have been crucial for favouring the peculiar human colonization of this territory. At the beginning, karst cavities developed in the Cretaceous limestone, like the famous "*Grotta dei pipistrelli*" (Cave of bats) facing the *Gravina di Matera*, offered safe refuge during the Palaeolithic. This archeological period covers a time span running between 2.58 millions and 11,700 years ago and almost coincides with the geological period named Pleistocene. The Palaeolithic remains in Matera are not older than 0.8 million years (Boenzi et al., 2017) and this is confirmed by the age of deposits connecting the filled Bradanic seaway to the *Murgia Materana* (Fig. 7c). In fact, before the "construction" of this sedimentary bridge, the *Murgia Materana* was an island which was impossible to reach by men of the early Palaeolithic.

However, the first human settlements began in the

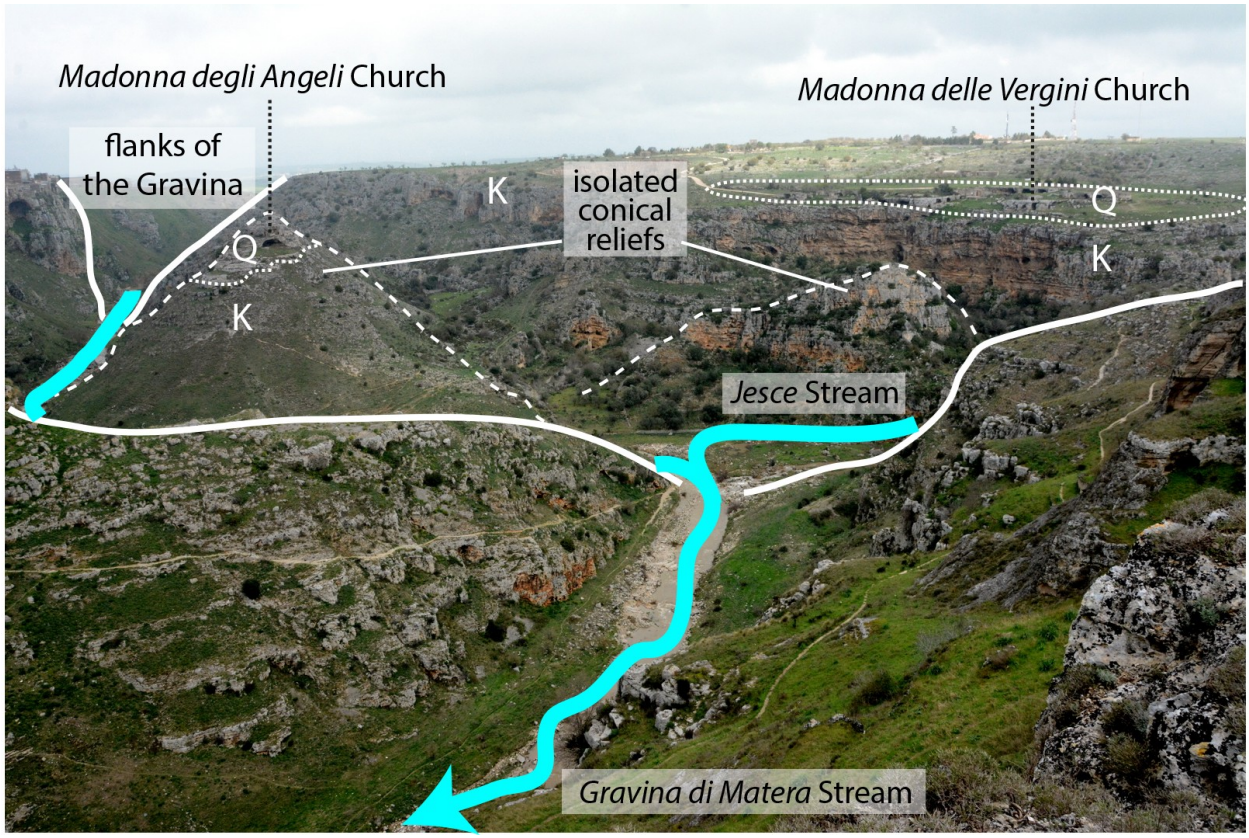

Fig. 11 - Isolated conical reliefs within the *Gravina di Matera* canyon, in front of *Sassi*. Note that the thin Quaternary succession hosting the "*Madonna delle Vergini*" Church represents the uppermost wedge of the *Calcarenite di Gravina* Formation (Q) onto the flank of the *Murgia Materana* palaeoisland (compare it with the position of the *Belvedere* in Fig. 9b). Photo by G. Schiuma.

Fig. 12 - Group of researchers and students from the University of Natural Resources and Life Sciences of Vienna (Austria), discussing about the downward expansion of *Sassi*. The boundary between the *Calcarenite di Gravina* Formation (Q), above, and the Cretaceous limestone (K), below, represents the limit of the urbanization (dotted line). Compare with the dotted line in Fig. 1 and with the green dotted line in Fig. 2. Photo courtesy of Franz Ottner and his students.

Neolithic period (11.700 to 6500-4000 years BP), when the first "entrenched" villages developed on some flat areas of the *Murgia Materana* (Rota, 2011), characterized by a thin soil covering the calcarenite bedrock. The presence of soft-rocks at shallow depth allowed the excavation of trenches and the embedding of wood piles in the ground. Moreover, the water was relatively abundant in the area; in fact, even in dry periods, the *Torrente Jesce* (the Jesce Stream, a tributary of the *Gravina di Matera* Stream) (Figs 8 and 11) shows a series of deep ponds, represented by some large evorsion pots called "*Jurio*", the dialectal term for whirlpool.

From the Bronze Age (5300-3200 years BP) the social life moved on the right side of the *gravina*, in particular on the so-called *Civita*, a morphological high now incorporated in the *Sassi* with the Cathedral (Rota, 2011) (Figs 1 and 2). This side of the *Gravina di Matera* was characterized by perennial water sources, represented by diffuse but hidden springs placed at the base of the sandy deposits of the hill of the Castle of Matera (the clay hill in Figs 2, 8 and 9b). Here the aquifer lies onto the clays that cropped out along the present-day "*Via Lucana*" (Lucana street). These springs, along with those pouring from the other hills of the new town of Matera and that are now completely buried below the buildings and almost forgotten by the local people, also fed the *graviglioni*, the two tributaries of the *Gravina di Matera* crossing the *Sassi* Districts. In the *Sassi*, the run-off water was collected in a lot of small cisterns dug into the rock. Then, also the water of the springs as well was collected in large cisterns. One of these cisterns is the "*Palombaro Lungo*", dug in the upper part of one of the *graviglioni* and located in the ground of the main square of Matera ("*Piazza Vittorio Veneto*"). In the same area, a historical fountain was fed by the capture of the water of the same springs.

The phenomenon of the development of the anthropization of the *Sassi* area, as well as the presence of water, was also favoured by the particular morphology of the right side of the *Gravina di Matera*. This side is favourably cut by the *graviglioni* and by the abandoned loop that isolates the *Monterrone* ("*Madonna dell'Idris*" Church) (Fig. 10), incisions that allow exposing long sections of calcarenite on easily accessible slopes. The development of the *Sassi* did not reach the bottom of the *gravina* because the lower limit of the urbanization was influenced by the presence of the Cretaceous limestone that crops out from the stream bed up to the base of the *Sassi* Districts (Festa et al., 2018) (Fig. 12, see also Figs 1 and 2).

6. CONCLUSIONS

Before the human colonization, the natural landscape of the Matera area had been shaped on an old island of the palaeo-Murge that was: i) mantled by calcarenite, ii) almost completely buried by clayey and sandy-gravelly sediments, and, eventually, iii) largely exhumed by erosion. Near the old island, after the easy erosion of the thin Quaternary cover, flanks of the ancient morphostructural high have been exposed again (i.e. the rocky slopes of the *Murgia Materana* either dipping toward North, along the Matera-Taranto road, or toward the southwest, along the "*Matera sud*" connecting road). Simultaneously, far from the old high, the erosion molded the gentle hills where the most recent districts of Matera developed since the '50s. These hills, with their clayey sides and flat sand-gravelly top, characterize the whole province of Matera, i.e. every village of the Bradanic Trough.

In this scenario, the course of the stream that today flows at the bottom of the *Gravina di Matera* was defined when the area was a flat sandy-gravelly alluvial plain, whose remnants are today represented by the top of the hills in the new town, at about 425-440 m of altitude. The deepening of the watercourse induced by regional uplift

caused the stream to reach the bedrock, and to cut the buried western edge of the old island and its southern flank. The erosion of the main watercourse (i.e. the *Gravina di Matera* stream) and of its tributaries (i.e. the *graviglioni*) exposed wide and gentle slopes in the middle-upper part of the right flank of the rocky valley (the *Gravina di Matera* canyon) molded on the *Calcarenite di Gravina* Formation. This latter was an easy-diggable rock that favoured the creation of rupestrian houses frontally closed either by a simple wall with a door (and a window above) or by an entrance/living room passing to the cave. Moreover the urbanization of the area was also possible thanks to the presence of water, that, emerging along the clayey and sandy-gravelly hills located above the *Sassi*, was stored in small (domestic) and very big (urban) dug cisterns.

In conclusion, the *Sassi di Matera* represent an extraordinary example of how pre-existing physical features and human imprints can live together in close connection, often ignored or underestimated. Many ancestral human choices have been determined by the geological nature of the territory and by its geography, which has unconsciously pushed humans to assume peculiar urban solutions. Therefore, the keys to read the landscape, especially where the natural elements are still evident, cannot ignore the knowledge of the physical substrate on which humans have superimposed their activity. From this point of view, the *Sassi di Matera* represent a spectacular geological training ground.

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