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GEOLOGICAL AND GEOMORPHOLOGICAL CONTROLS ON FLOOD PHENOMENA IN THE PUTIGNANO TOWN, SOUTHERN ITALY

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ABSTRACT: The geological/geomorphological map of Putignano town (Bari, Southern Italy) contains useful evidence of landforms and sedimentary successions in both urbanized and industrial areas, contributing also to a better understanding of floodings during high-magnitude pluviometric events in the area. The analyzed flooded areas correspond to surfaces karst landforms with different shapes and sizes. Our detailed geological/geomorphological study shows that most of the industrial area of Putignano was built on Cretaceous calcareous units in a depressed area, which corresponds to an extensive endorheic basin (locally called "il Basso"). Part of the local urban expansion, built from 1950 to present day, occupies the most depressed areas of numerous karst valleys that, despite this urbanization, still preserve their hydraulic function. Usually these geological and geomorphological features are not yet completely identified and, unfortunately, not taken into consideration in the planning stages of the urban expansion and industrial settlement.

Keywords: Putignano town, southern Italy, Apulian Foreland, Quaternary, flood, karst

1. INTRODUCTION

Putignano is a small town in the south-eastern Murge, an area frequently exposed to alluvial events that occur despite the numerous mitigation actions taken to reduce or eliminate long-term risk to people and infrastructure.

Environmental degradation and irreversible landscape damages caused by the negative impact of human activities here as well as in other karst territories were described and discussed in several publications (e.g. White, 1988; Gams et al., 1993; Williams, 1993; Nicod et al., 1997; Akdim & Amyay, 1999; Burri et al., 1999; Urich, 2002; Parise & Pascali 2003; Bonacci 2004; Calo` & Parise 2006; Sauro, 2006; Parise & Gunn 2007; Andriani & Walsh, 2009). They cover different environmental issues, which are causing general concern about the need to: i) prevent/control flood events and ii) design and/or redevelop the urban expansion in the way that floods rather than damaging events can be seen as resources for the territory (Muscari, 2016).

This contribution provides new evidence on landforms and correlative Quaternary deposits mapped at a detailed scale (1:10.000 and 1:500) for the entire territory of Putignano. The main objective of our study is to recognize the geological/geomorphological features that predispose the Putignano territory to flooding phenomena and therefore to provide basic information for future risk mitigation strategies and adequate use planning. Within this context, we have also evaluated the different phases of building expansion and the presence of anthropogenic deposits.

2. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING OF THE MURGE RELIEF

The carbonate rocks of the Murge hills, with the Gargano and the Serre Salentine, constitute a portion of the Apulian platform system. The Apulian platform is placed between two orogenic chains and represents the outcropping part of a highly asymmetric structure: the Pliocene to Pleistocene foreland, which is characterized by opposite dipping directions, towards southwest beneath the southern Apennines and towards northeast beneath the Dinaric-Albano-Ellenide Chain (Ricchetti et al., 1988; Funiciello et al., 1991; Argnani et al., 1993; Carminati & Doglioni, 2004; Carminati et al., 2005) (Fig. 1a-c). The Apulian carbonate platform is mainly composed by Jurassic to Cretaceous dolomitic and calcareous units, approximately 5 km thick, downward followed by hydritic and dolomitic Upper Triassic succession, approximately 1 km thick, and Triassic terrigenous deposits (both alluvial and deltaic) approximately 1 km thick (Ricchetti et al., 1988). In particular, the Murge area is composed of a Cretaceous succession with general dipping towards the SSW, affected by gentle folds and faults (Fig. 1b). The folds, arranged with axis in NW-SE, WNW-ESE and ENE-WSW directions (Martinis, 1961; Valduga, 1965; Pieri, 1980; Ciaranfi et al., 1988; Ricchetti, 1980; Ricchetti et al., 1988), have been considered intraplate deformations related to the Alpine compression events, or as a deformation linked to the

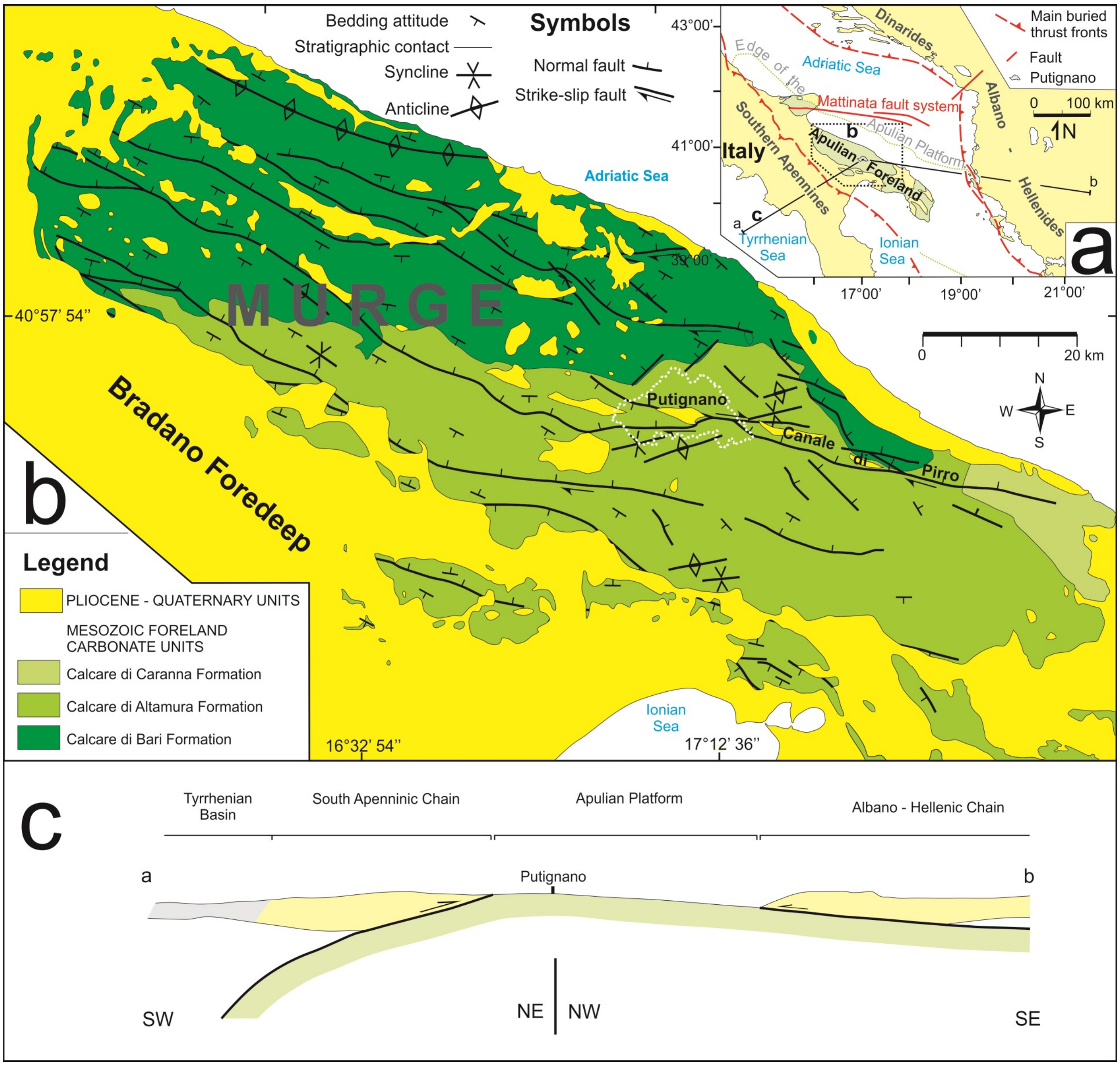

Fig. 1 - a) Geological sketch map of the southern peri-Adriatic region. The Apulian Platform represents the foreland sector shared by both the southern Apennines and the Albano-Hellenides fold and thrust belts. b) Schematic structural-geological map of the Murgia area, showing the Putignano territory (modified after Festa, 2003). c) Regional cross-section, modified after Carminati & Doglioni (2004).

Neogene compressive tectonics, responsible also for the South-Apennine building (Pieri, 1980; Festa, 1999). More in particular, Festa (1999) considered that the folds might be related to the second interpretation. This setting is observed in the north-western sector of the Murge where the foreland is close to the thrust belt (Fig. 1a).

The main regional faults, mainly N-S, NW-SE, WNW-ESE, NE-SW and E-W oriented, divide the Murge into different structural blocks separating the high Murge hills from the adjacent morpho-structural depressions (Martinis, 1961; Ricchetti, 1980; Iannone & Pieri, 1982; Gambini & Tozzi, 1996; Pieri et al., 1997b). In the Apennines and Apulian foreland system, this structure is connected to extensional and transtensional deformation regimes associated with Pliocene to Middle Pleistocene tectonics (Pieri et al., 1997b, and references therein; Schiattarella et al., 2005). The NW-SE normal faults of the northern Murge and the E-W transtensive faults of the southern Murge (Canale di Pirro area; Fig. 1b) determined, in the Upper Cretaceous, both the regional south-west dipping of the Cretaceous succession and the calcareous depositions (Festa, 2003). The carbonate succession outcropping in the Murge relief is subdivided in the "Calcare di Bari" (Valanginian - later Cenomanian; 2 km thick), "Calcare di Altamura" (Upper Turonian - Santonian; 1 km thick), and “Calcare di Caranna” (early Campanian -later Maastrichtian; 25 m thick) formations (Valduga, 1965; Pieri, 1980; Ciaranfi et al., 1988, Luperto Sinni, 1996 and references therein; Luperto Sinni &

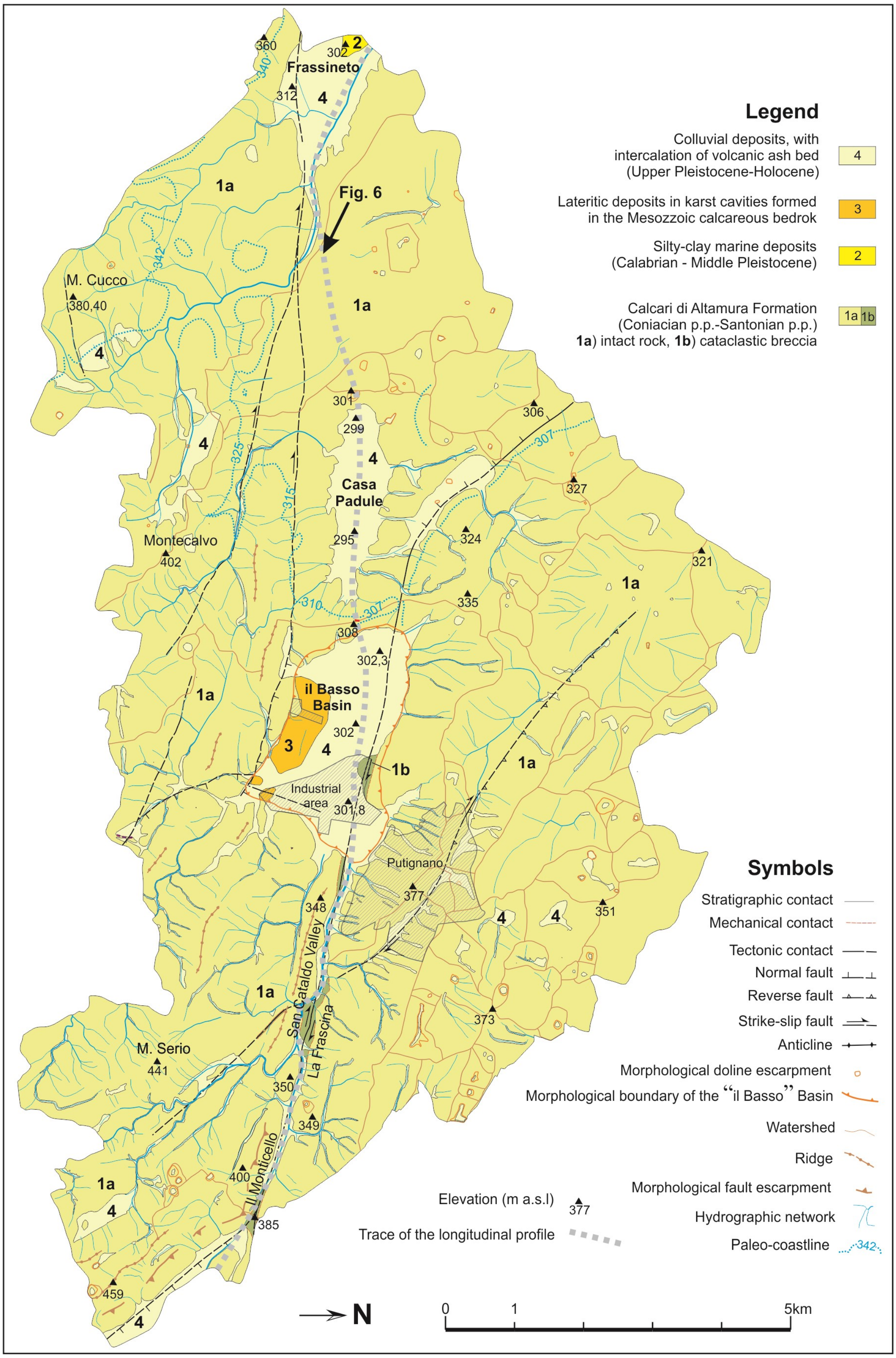

Fig. 2 - Schematic geological sketch map, with geomorphology elements of the Putignano territory.

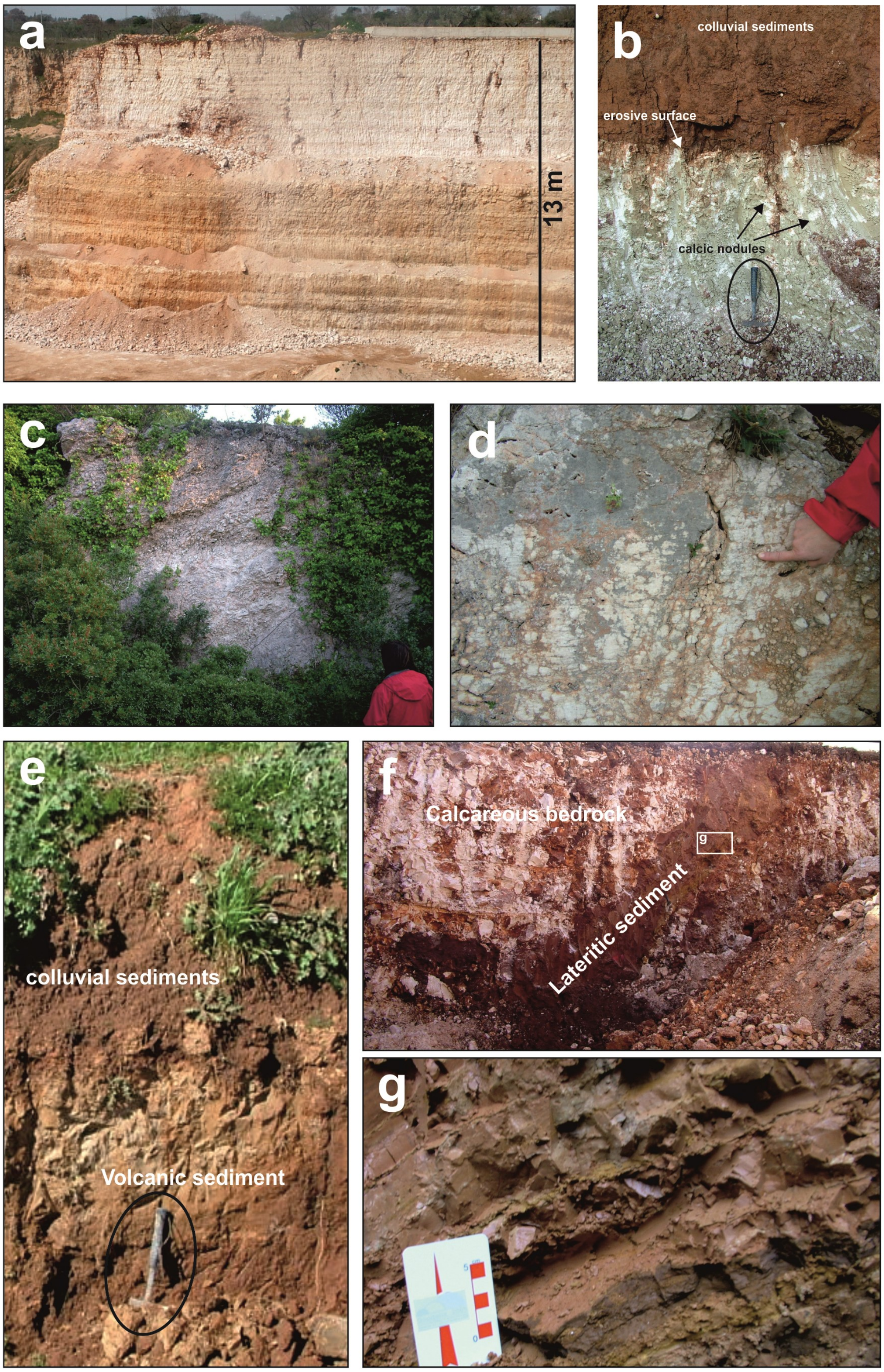

Fig. 3 - a) Litho-stratigraphic features of the carbonate bedrock. b) Pleistocene marine silty clayey sediments overlain by laminated colluvial reddish sandy sediments c) Cataclastic breccia showing in d) kinematic indicators. e) Volcanic sediments represented by fine-grained ash overlain by colluvial reddish sand. f) lateritic deposits in karst cavities formed in the Mesozoic calcareous beds. g) lateritic deposits constituted of fine-laminated reddish clay.

Reina, 1996). These units are separated by unconformities (Ciaranfi et al., 1988), locally highlighted by the presence of reddish residual clay deposits (bauxite of Spinazzola; Crescenti & Vighi, 1964; Maggiore et al., 1978; Iannone & Laviano, 1980; Luperto Sinni & Reina, 1996).

The Cretaceous limestone formations represent the bedrock of the Pliocene-Quaternary transgressive succession made up of Pliocene-Pleistocene shallow-marine coarse-grained carbonates (Calcarenite di Gravina Formation) overlain by lower Pleistocene hemipelagic clay (Argille subappennine Formation) (Iannone & Pieri 1979; Ricchetti et al., 1988; Giannandrea et al., 2014). Middle-Upper Pleistocene silty–clays deposits and coarse calcarenite (Depositi Marini Terrazzati) disconformably overlay the Mesozoic and Pliocene-Pleistocene successions (Ricchetti et al., 1988). Finally, Upper Pleistocene - Holocene reddish-brown colluvial deposits (''Terre rosse'') are found as a mantle over the valley floors.

The morphology of the Murge plateau, in close relationship with its lithological composition, geological structure, and climatic variations, is attributable to karstic processes which start to develop from the Cretaceous (Anelli, 1962). In particular, the Murge is a NW-SE orientated rectangular plateau bounded by steep slopes (Campobasso & Olivieri, 1967; Di Geronimo, 1970) with small endoreic basins which rise some reliefs, predominantly conical in shape, that testify a Miocene relit karstic landscape (Sauro, 1991a, b). The karst landforms recognizable on the Murge include shallow holes, dolines, dry (blind) valleys, and poljes (Parise, 2011). The most remarkable karst features are, in the Northwestern Murgia, some sinkholes (*sensu* Gutierrez et al., 2014) with circular shape and vertical slopes (high: some tens of meters) called "Pulo, Gurgo, etc." (Colamonico, 1917a, b;1919a, b; 1919-20), and in the southeast sector, along an E-W orientated transtensive faults system (Festa, 2003), an alignment of some endoreic karst basins called "Canale di Pirro" (Fig. 1b; Pieri et al., 1997a) and interpreted as polje (Parise, 2006; Parise & Benedetto, 2018). Also, during the long period of exposure of the Murge, different phases of karstification produced the genesis of several caves with vertical and horizontal development, ranging in size from a few square meters wide to large and complex systems, with overall length on the order of some kilometers. The largest and longest cave, of considerable tourist interest, is the cave of Castellana Grotte (Anelli, 1954). It consists of a complex endokarst conduits system that develops for a total length of 3348 m, reaches the maximum depth of 122 m from the surface, and is reachable through a sinkhole (locally called "Grave") 60 m deep (Reina & Parise, 2004). The latter was formed by gravitational collapses that proceeded upward and were controlled by the main fracturing system in the rock mass (Lollino et al, 2004; Parise & Trisciuzzi, 2007; Parise, 2008). The karts valley consists of dry blind valleys and canyons, known respectively as "lame" and "gravine" (Parise, 2008). The "lame" can develop into three different landforms depending on the position and dipping of the substrate. In particular, they are (Boenzi, 1988, and references therein): i) short and deep, with a transverse V profile, along the Bradano slope; ii) flat-bottomed and with a sinuous trend, in the high and middle Murgia area and iii) flat-bottomed with sub-vertical sides along the Adriatic coast. The "Gravine", localized on the Ionian side of the Murge, from Taranto to Matera towns, are canyons with sub-vertical slopes up to 100 m high (Azzaroli et al., 1968) developed from the top of the plateau (400 m a.s.l.) to the coastal plain (50-100 m a.s.l.). These valleys, generally dry for long periods of time, host water channels only during and immediately after abundant rains (Baldassarre & Francescangeli, 1987; Andriani & Walsh, 2009). Often the alluvial valleys are included in contexts of endorheic basins, where the karst valleys pour out into flat-floored depressions, with or without a swallow-hole (Pace, 1995; Parise, 2006 and references therein), where temporary small lake can be formed in case of intense periods of precipitation (Orofino, 1990; Parise, 2009 and references therein; Delle Rose, 2007; Lopez et al., 2009). The floodwaters, through a complex system of fractures and karst cavities, percolate into the subsurface up to a deep water table. A detectable water table interests the entire Murgia plateau with a convex piezometric surface sloping toward the Bradano River, to the southwest, and the Adriatic Sea to the northeast (Maggiore & Pagliarulo, 2004; Tulipano et al., 2008).

3. GEOLOGICAL AND GEOMORPHOLOGICAL FEATURES OF THE PUTIGNANO AREA

Our field survey allowed the production of a 1: 10.000 scale geological map (Fig. 2 for a sketch) and revealed that the geological structure of the Putignano municipal territory is entirely composed by a Mesozoic carbonate succession (i.e. the Calcare di Altamura Formation, Fig. 2) which consists of weakly undulating layers dipping toward the southwest (Fig. 3a). The Coniacian to Santonian sedimentary succession consists of 30-70 cm thick layers (Fig. 3a) of biocalcilutites alternated with thin layers of biocalcarenites organized in different facies and grouped into sequences of 1-3 m thick layers (Luperto Sinni et al., 1988). The complete sequence is made up of four lithofacies: a) rudist rich beds; b) micritic limestone with isolated fragments of rudists and foraminifera; c) stromatolytic or criptoalgal laminated limestones; d) limestone with drying fractures. Metric layers of bioclastic concentrations of rudists, laterally extended for several hundred meters, are visible at different stratigraphic levels of the succession. In the Monticello and Frascina localities, in the northern side of the Industrial area of Putignano, and at the base of the left side of the San Cataldo Valley (Fig. 2), the calcareous succession is characterized by a cataclastic breccia (Fig. 3c) along a N105°-striking vertical tectonic structure. The kinematic indicators for this structure show a right-lateral movement (Fig. 3d). The beginning of tectonic activity is traced back to the same phase of sedimentation of the Calcare di Altamura Formation (Upper Cretaceous) (Festa, 2003). The Pleistocene tectonic evolution led to the formation of extensive depressed areas submerged by the sea. The evidence of this event is clearly visible in the Frassineto locality (Fig. 2), where Pleistocene marine silty-clay sediments unconformably

Fig. 4 - a) View of a valley filled by anthropic coarse grained breccia deposits. b) Straight river erosion furrow, showing channel incision.

overlay the calcareous bedrock (Fig. 3b) (Servizio Geologico d'Italia F. 190 Monopoli, 1988). Isolated calcic nodules occur in the upper part of the silty-clayey sediments (Fig. 3b), and are associated with the erosive surface presents to the top of the unit (Fig. 3b). They suggest a long period of exposure with development of a paleosol (10^3 to 10^4 yrs; Mack & Madoff, 2005) followed by an erosional phase which excised its upper portion (layers A and B of the paleosol). The age of this unit is referred to the Lower Pleistocene-Middle Pleistocene transition, during the maximum transgression of the sea level in the Bradano Foredeep Basin (Corrado et al., 2017, and references therein). Upper Pleistocene-Holocene colluvial deposits are detectable, as a mantle over the karst valleys floor, above the Cretaceous and Pleistocene marine sediments. They consist of reddish-brown silty clay (2-10 m tick), with interbedded volcanic ash levels and scattered calcareous stones. The volcanic deposits (Fig. 3e) generally consist of a basal volcanic ash layer (10 cm thick) overlain by epiclastic sediment (80-110 cm thick). The basal bed consists of fine-grained structureless ash (fall deposit) and the upper layer consists of grayish fine-grained, fine-laminated ash mixed with reddish-brown, fine- laminated silty clay (colluvial deposit). The origin of volcanic ash can be related to the eruptions of the Quaternary Campania volcanoes, because the Putignano territory is localized in the dispersion area of the tephra generated by the activity of these volcanoes (Sulpizio et al., 2003). Finally, in the southern sector of the "il Basso" (Fig. 2), several caves with oblique (Fig. 3f) and vertical development (2-10 m large) and filled by reddish-brown fine laminated clay (i.e. lateritic sediments; Fig. 3g) have been detected. In this sector the calcareous bedrock shows moderate to high fracturing with two fracture sets: N70-80°, associated to closed, 50-cm spaced, sub-vertical joints; N 130°, dipping of about 75°, with 40-cm spaced joints, 1-2 mm open. The rock is altered by deformation to a limestone breccia and a matrix-supported breccia, with clasts of a maximum size of 36.5 cm and matrix composed of silty-sandy reddish clay in the portion with intense fracturing. Finally, in the Putignano town some karst valleys were filled by anthropic deposits made up of a clast-supported calcareous breccia (Fig. 4a).

The geomorphological features recognized in the Putignano territory permit to describe three main morpho-structural sectors, two of which are hilly and one sub-flat, distributed in three E-W-oriented elongated areas (Fig. 5). The sub-flat area, with altitude between 342 and 295 m a.s.l., is centrally located (sector 2, Fig. 5), and gently sloping northwards, between the "il Basso" and Frassineto localities. The northern side portion of the Putignano territory (sector 1, Fig. 5) shows numerous dolines (size ranging from 50-100 m^2 to 500 m^2) and small endorheic basins, with colluvial deposits (few meters thick) over the valley floors (Fig. 2). Elevations vary from about 377 m a.s.l. in the southeastern sector, to 321 m a.s.l. in the northwestern sector. Finally, karst valleys prevail in the southern portion of the Putignano territory (sector 3; Fig. 5), with well-developed hydrographic networks: many channels of the first, second, and third order, three valleys of the fourth order and a valley (San Cataldo Valley) of the fifth order are recognized. The valleys of the fourth and fifth order converge into the sector 2 (Fig. 5). The highest altitudes in the areas 3 vary from a maximum of 440-460 m a.s.l., in the eastern sector, to a minimum of 380 m a.s.l., in the western sector. The Putignano urban area is located on the southern portion of the sector 1 (Fig. 5), along the right side of the San Cataldo Valley. In this sector the slope is cut by some channels of the first order filled with colluvial deposits covering old channel incisions (Fig. 4b). Such morphologies record the events during which the alluvial valleys were cut by large quantities of water with high solid transport.

The sector 2 includes three wide valleys (Frassineto, Casa Padula, and "il Basso"; Figs. 2 and 5) with a flat-bottom one kilometer square large (Fig. 2): the Casa Padule and "il Basso" valleys were filled by colluvial deposits, whereas the Frassineto valley by marine sediments (Servizio Geologico d'Italia F. 190 Monopoli, 1988; Fig. 2). The morphological limits on the southern and northern sides are characterized by steep slopes (>50%) along E-W directed faults, interpreted by Festa (2003) as oblique transfer faults. The three valleys are separated from each other by gentle hills that rise up to eight-meters, between "il Basso" and Casa Padule, and just two meters, between Casa Padule and Frassineto (Fig. 6). Geomorphological analyses (Figs. 2 and 5) revealed that Casa Padule and "il Basso" are depressed areas of extensive endorheic basins, whereas the Frassineto area is crossed by tributaries karst valleys of a watercourse that, near the Bari city, spreads into the Adriatic Sea (Mossa, 2007). Moreover, the areas of the Casa Padule and Frassineto are included in a slope change line traceable from 342 to 307m a.s.l. (Fig. 2) that, given the presence of marine fine sediments, can be interpreted as a point of maximum ingression of the sea level during the Pleistocene marine transgression. Subsurface karst forms (22 caves) have been documented in the Putignano territory (Catasto delle Grotte e delle cavità artificiali della Puglia, 2013), among which the "Grotta del Trullo" (PU_1) is a tourist cave and the "S. Michele in Monte Laureto" (PU_4) and "S. Maria delle Grazie" (PU_5) caves are places of worship.

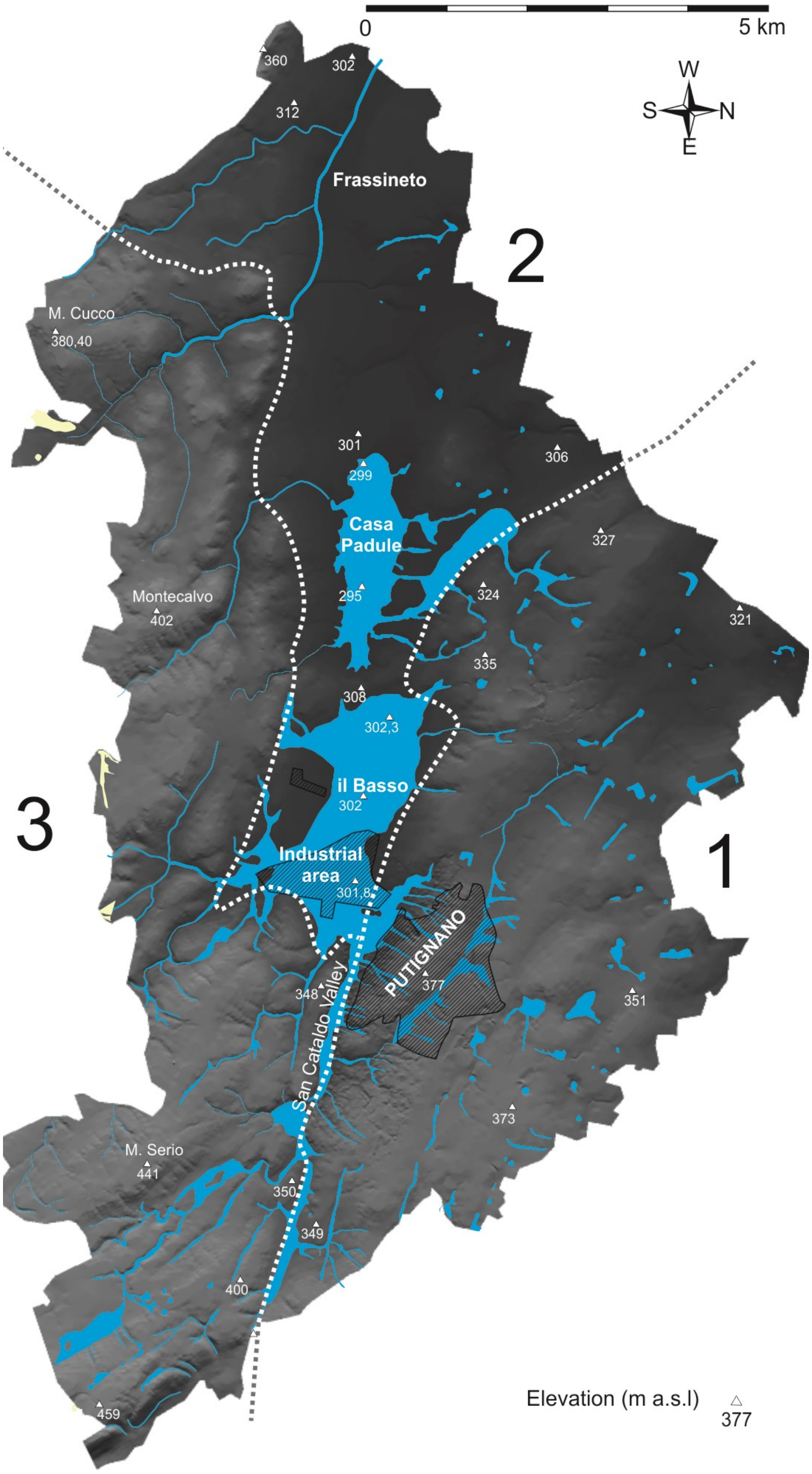

Fig. 5 - Digital Terrain Model (DTM) of the Putignano territory showing three different geomorphological areas characterized: 1) karstic geomorphology with dolines, 2) sub-flat depressed geomorphology, 3) karstic valleys geomorphology.

4. FLOODS IN THE PUTIGNANO TERRITORY

The karst terrains of Putignano are characterized by a very limited or absent surface hydrography. Normally the water tends to quickly infiltrate in the underground through a complex fractures network and karst conduits in the rock mass. However, such network might not be able to allow flowing of large amounts of water during concentrated rainfall, as well as in case of prolonged precipitation, causing the occurrence of the floods in the karstic valleys (Figs. 5 and 7). Historical information on the floods occurred in the Putignano territory can be

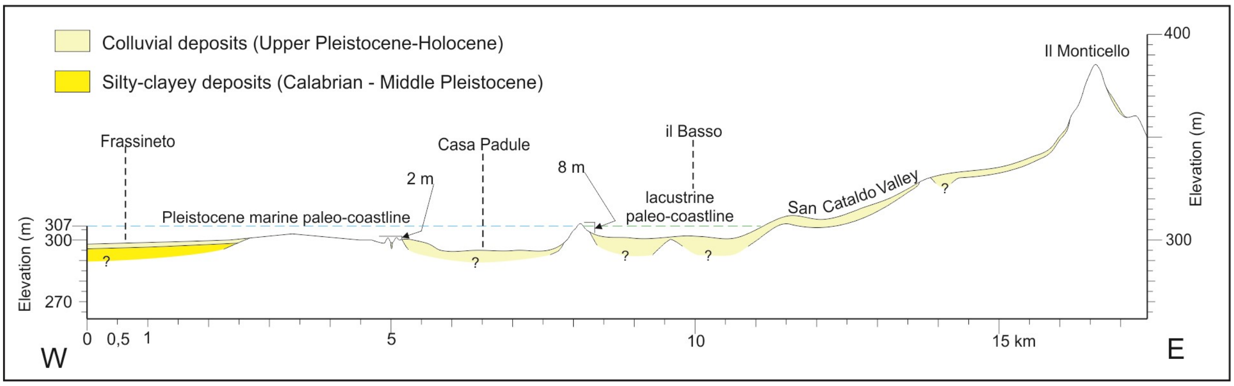

Fig. 6 - W-E geologic profile across the San Cataldo, “il Basso”, Casa Padule, and Frassineto valleys (the trace of profile is reported in Fig. 2) showing their fills.

Locality	Date	Provenance
Putignano	23.08.1929	CNR: AVI Project, 1998
Putignano	21.04.1959	CNR: AVI Project, 1998
Putignano	12.11.1964	CNR: AVI Project, 1998
Putignano	08.10.1966	CNR: AVI Project, 1998

Tab. 1 - Floods occurred in the Putignano territory in the 20th century; after Cardinali et al. (1998).

found in Cardinali et al. (1998) (Tab. 1). In 1929 some people testified that rainfall caused such an intense flood in the “il Basso” area that people and animals were saved using boats from the nearby Monopoli village. The walls of the historical building "trullo" (Fig. 8) keep the trace of the water level corresponding to the maximum depth (about 2.035 m.) reached by water in ephemeral lake (Fig. 9). In Tab 2 are reported the meteorological information for rainfall events occurred from 2000 to present day. The event that produced more damages occurred in September 2006 with a rainfall of 349 mm. The main precipitation started at 01.00 a.m., until 10.00 a.m. This event led to floods of the industrial area, countryside, and some zones of the town, causing serious damages and the death of one person. Other floods of minor magnitude happened in 2008 and 2009. Furthermore, from the 2015 to the present, important flash floods (up to 20 mm of water precipitated in less than 20 minutes) have been occurring annually. Flash floods do not promote flooding in the karst valleys of the countryside, and are constrained mainly in the town (the

Fig. 7 - Flooding of a doline (a), and of the San Cataldo valley (b and c).

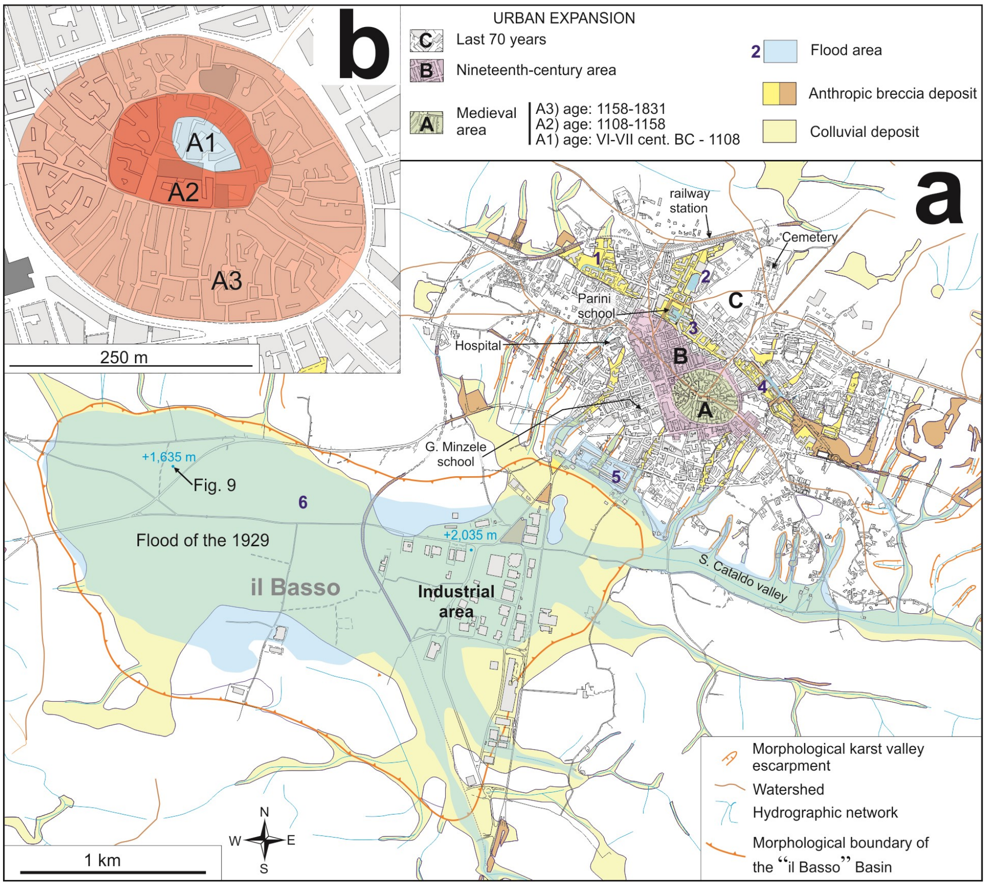

Fig. 8 - Tow map showing in a) the urban and industrial expansion of the Putignano Town, with elements of the geomorphology and Quaternary deposits, and flood areas, and in b) details of expansion of the medieval town.

flooded areas are identified in Fig. 9 with numbers 1, 3, 4 and 5).

5. URBAN EXPANSION OF THE PUTIGNANO TOWN

The urban structure of Putignano has developed in three different historical periods corresponding to three distinct parts of the town: i) the original Medieval nucleus; ii) the nineteenth-century orthogonal structure; iii) buildings developed from the post-war period up to the present time (Fig. 8a).

The Medieval town (Fig. 8b), originally closed in a circle of walls, consists of two concentric rings on the hill (highest point approximately 374 a.s.l.) around an original nucleus expanded between the 6th-7th century B.C. (primitive Apulian settlement) and 1108. The first ring was built around the millstone and the church of San Pietro between 1108 and 1158, after the concession made by Boemondo di Altavilla to Benedictines of S. Stefano Abbey in Monopoli; from this moment onwards, the community began its own social and religious organization. The cross-distribution of roads indicates a favorable relationship with the territory and a strategic position that affected the subsequent development. The Knights of Malta ruled Putignano from 1317; the population increased and the second ring was completed in 1472 with the construction of the second town wall that was subsequently demolished in 1831, when the historical center was shaped in its current setting (Fig. 8b).

The nineteenth-century part was built close to the ancient nucleus and is characterized by two orthogonal roads, from the highest points up to the alluvial valley area to the north-east (Fig. 8a). The nineteenth-century setting remained basically unaltered until the 1950s when some public building were built, such as the hospital, the Parini and Minzele schools, and the railway station. The railway station, built on the opposite side of the karts valleys in North-East, and the Parini School are the most important buildings for the following expansion of the town (Fig. 8a). A disorganized urban development started after the '50s in Putignano, as well as in other towns in Italy. Indeed, despite the numerous urbanistic planning laws, in this period the town developed without a precise urban plan.

6. DISCUSSION AND CONCLUSIONS

The geological structure of the subsurface, geomorphological features, flood events that occurred in the past and recent time, and stages of urban expansion of

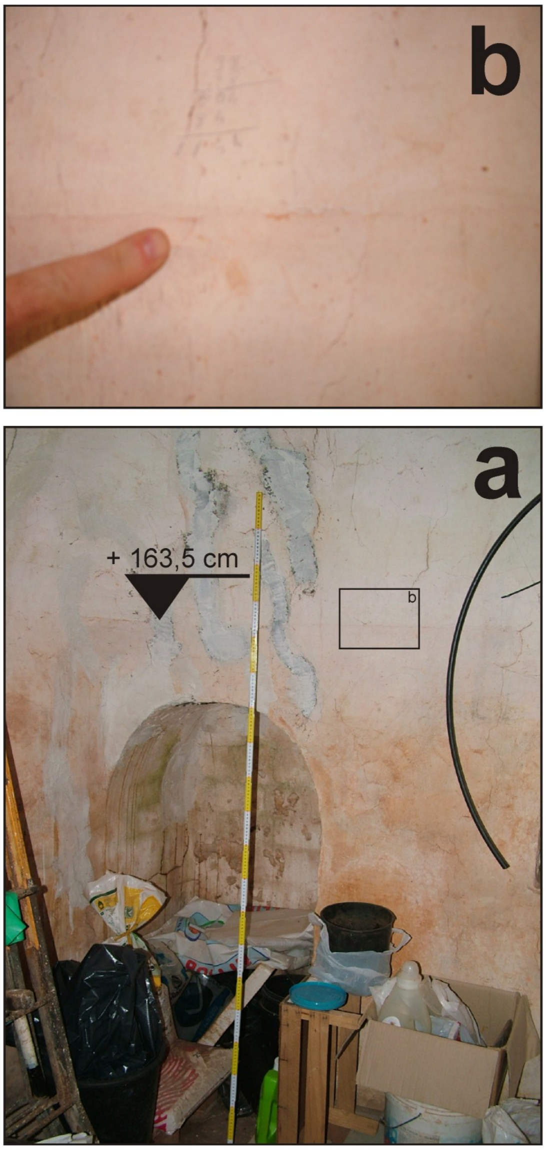

Fig. 9 - Level reached by the 1929 flood detectable by preserved traces on the wall of a historical building (trullo).

Locality	Date	Rain (mm)	Provenance
Putignano	Sept. 2006	349, with 140 in 5 hours	Putignano wather-station
Putignano	Nov. 2008	60 in a day	Putignano wather-station
Putignano	Oct. 2009	60 in a day	Putignano wather-station
Putignano Castella Grotte	20 Nov. 2015	60 in a day	Putignano wather-station
Putignano	20 Sept. 2015	~20 in 20 min.	Putignano wather-station
Putignano	20 May. 2016	~20 in 20 min.	Putignano wather-station
Putignano	20 May. 2017	23 in 20 min.	Putignano wather-station

Tab. 2 - Floods occurred in the Putignano territory from the year 2000 to present day.

the Putignano town have been described in the previous sections. The urban and industrial areas (Fig. 8), during high- and medium-magnitude flood events, were damaged by flooding events. The geological/geomorphological characteristics of the Putignano territory show a typical karst environment that can be subdivided into three morpho-structural subunits (Fig. 5). These subunits are related to the development of the Murge relief with E-W trending tectonic structures that allowed the formation of the central lowered area called sector **2** (Fig. 5) occupied by a paleo-sea, in the Frassineto and Casa Padule areas (Fig. 10) during the Pleistocene marine transgression. As a result of the sea level rise, we can identify the piezometric paleo-surface of the water table at a higher level in the carbonate massif of the Murge. This suggests a perennial paleo-lake or, at least, a marshy environment, in the "il Basso" locality (Fig. 10), as a consequence of the rise of the piezometric surface. The present day morphological characters allowed us to identify the "il Basso" and Casa Padule areas as a base level of extensive endorheic basins (Figs. 2 and 5) that in winter season or during a high-magnitude rainfall events (for example 349 mm in 1-2 days; Tab. 1) can develop in a large ephemeral lake (Fig. 5). The Medieval and nineteenth-century sectors of the Putignano town were built on the highest portions of the karst territory, on the right side of the San Cataldo Valley (Figs. 2 and 8). During modern expansion, some valleys in the northeast and southwest of the old town of Putignano were filled by anthropic breccia deposits and new buildings (Fig. 8). In this territory however, the urban expansion has not completely erased the morphologies of the karst valleys that remain buried. Nowadays, these buried forms represent flooded areas during high-magnitude pluviometric events and an underground network of waters flows that infiltrate from the surface or leak from the pipes of the urban network. Part of the industrial area was built on the bottom of the "il Basso" area that may be submerged by water up to 2 m deep (Fig. 8).

By analyzing the floods data, it follows that alluvial phenomena occur for periods less than 30 years (Tab. 1). Particular attention must be placed to the very high-magnitude and very short-lived events, occurred annually in 2015, 2016 and 2017 (Tab. 2), that caused the flooding of the urbanized areas identified in Fig. 8 with numbers 1, 3, 4 and 5. These areas are located on buried alluvial valleys (Fig. 2).

The overlapping of the urbanizations on the geological-geomorphological map of the Putignano town (Fig. 8) shows that up to the first half of the twentieth century the town grew respecting precise urban guidelines and geological constraints (the town expands on a hill with calcareous bedrock). Instead, after this period, an indiscriminate growth reveals the absence of an urban project: the town expands throughout the territory, occupying the valley areas. Currently (area 5; Fig. 8) we are assisting a continual consumption of the territory without an urban planning and accurate geological/geomorphological analyses, increasing the hydraulic risk.

A detailed geological map of Quaternary deposits

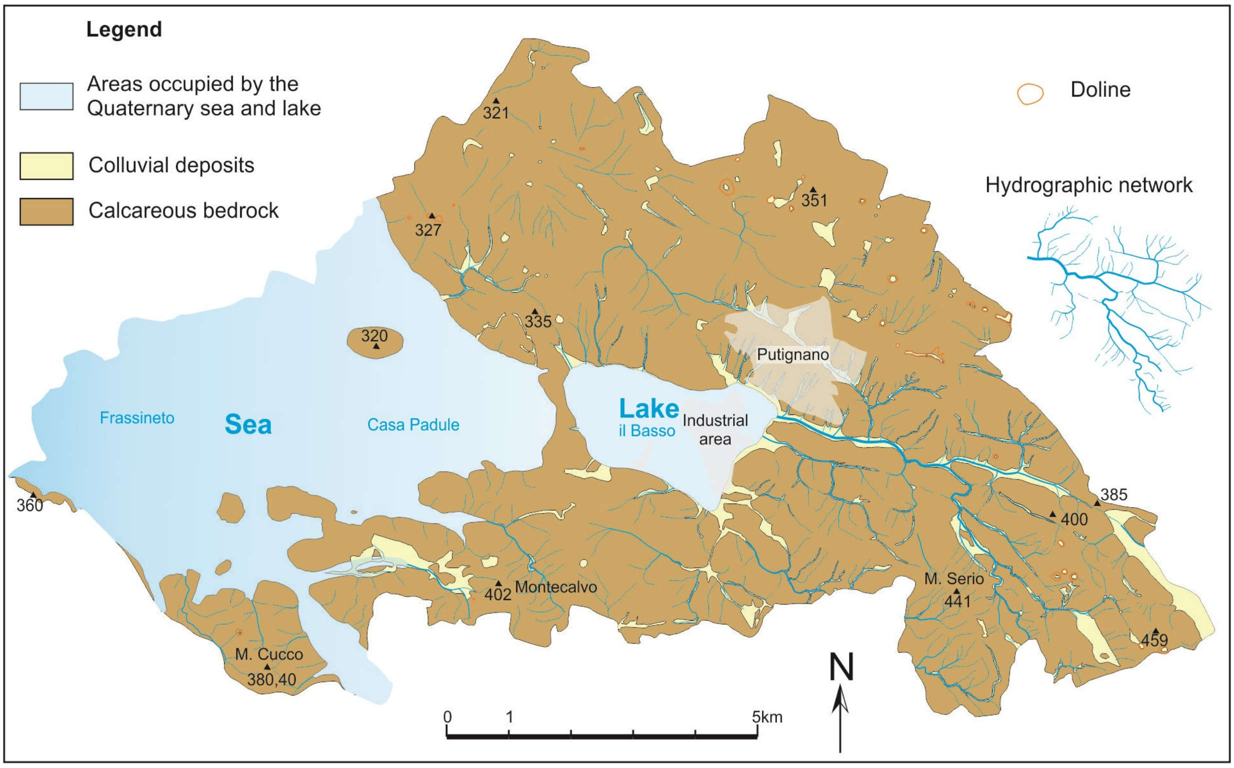

Fig. 10 - Paleogeographic reconstruction of the Putignano territory showing the areas occupied by the Quaternary Frassineto - Case Padule sea, "il Basso" lake and the ancient hydrographic network.

and landforms, as well as the survey of the urban expansion and anthropic deposits, may provide useful indications about the locations where floods effect will hit in the future (Fig. 8). This tool appears to be essential in the perspective to mitigate the damage to people and infrastructure.

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