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CRYPTOKARST: A CASE-STUDY OF THE QUATERNARY LANDFORMS OF SOUTHERN APULIA (SOUTHERN ITALY)

CRYPTOKARST (SKRITI KRAS): PRIMER KVARTARNIH OBLIK V JUZNI APULIJI (JUZNA ITALIJA)

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Antonella Marsico & Gianluca Selleri & Giuseppe Mastronuzzi & Paolo Sansň & Nicola Walsh: Cryptokarst: a case-study of the Quaternary landforms of southern Apulia (southern Italy)

Cryptokarst is a karst developed beneath a permeable and not karstifiable formation by percolating waters. The permeable rock acts as a storage of water which feeds slow seepage and infiltration enhancing the alteration of bedrock. The resulting forms consist of depressions, filled by the covering sediments, and pinnacles. The sinking of the permeable cover can produce depressions on the topographic surface. Erosion of the cover exposes a landscape characterised by pinnacles, ruinforms and dolines.

In the Apulia region, cryptocorrosion surfaces are characterized by solution pipes 4-5 meters deep and with variable width (from a few centimeters to about one meter). Pipes walls are covered by a brownish carbonate crust, from a centimeter to more than 10 centimeters thick. The continental sands are only found in these depressions. The cryptocorrosion process took place late in the Middle Pleistocene on Quaternary marine abrasion terraces covered by no-carbonate sandy-silty continental deposits. The process stopped before the Last Interglacial age in response of an abrupt climatic change that induces a calcium carbonate precipitation and the formation of a carbonate crust.

Key words: Apulia, cryptokarst, solution pipes.

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Antonella Marsico & Gianluca Selleri & Giuseppe Mastronuzzi & Paolo Sansň & Nicola Walsh: Cryptokarst (skriti kras): primer kvartarnih oblik v juzni Apuliji (juzna Italija)

Skriti kras (cryptokarst) je kras, razvit pod prepustnim, vendar netopnim pokrovom. Nastane zaradi vode, ki prenika skozi krovne plasti. V krovnih plasteh se zbira voda, se počasi preceja skoznje in razjeda matično kamnino. Zaradi tega nastanejo depresije, zapolnjene s pokrovnim sedimentom, in kraški stebri. Zaradi posedanja prepustnega pokrova, nastanejo na površju ulegnine. Če erozija odtsrani krovnino, se razgali relief, za katerega so značilni kraški stebri, razvalinasti relief in vrtače.

Ključne besede: Apulija, skriti kras, "solution pipes".

INTRODUCTION

In this paper, the first results about Quaternary cryptocorrosion forms occurring in the Apulia region (southern Italy) are reported. In particular, the research focus on forms developed on Plio-Pleistocene porous soft-rocks. Formerly, Nicod (1976) and Fabre & Nicod (1986) indicated some cryptocorrosion surfaces developed on the Mesozoic limestone in this region. Along the Adriatic coastal area and in the central part of Salento, some grike-like forms (Jennings, 1987) and solution pipes (Jennings, 1987), both filled with reddish sands and silts, are formed on these rocks. Apulian pipes have been described by several authors (Maxia, 1950; Blanc & Cardini, 1961; Rudnicki, 1980; Parenzan, 1983; Delle Rose & Parise, 2003). The pipes developed on Pliocene calcarenites at Roca have been interpreted as fossilized trunk casts by Blanc & Cardini (1961). According to Delle Rose & Parise (2003) these pipes formed by solution pans deepening or karst hole enlargement; the filling accumulated later. Similar pipes developed on the lower Pleistocene calcarenites along the Villanova coast have been interpreted as singenetic forms produced by the groundwater downflow to the sea (Rudnicki, 1980). Till now, the pipes have been neither interpreted as cryptocorrosion forms nor ascribed to a single morphogenetic phase.

Research about the geological and geomorphological context of pipe areas, pipe filling and the cover under which cryptocorrosion surfaces developed, has been carried out.

CRYPTOKARST

Cryptokarst landforms develop by dissolution of the carbonate bedrock beneath a permeable and not karstifiable cover (Fig. 1). The permeable rock allows slow infiltration and it can hold perched groundwater which feeds seepage. The resulting forms consist of depressions, pipes, pinnacles, ruinforms, crypto-kluftkarren, rundkarren (Fabre & Nicod, 1982). Along their walls a layer is formed which is constituted by insoluble residues originated by carbonate bedrock dissolution (Bonte, 1963).

During the cryptokarst evolution, the sinking of the permeable cover due to the dissolution of bedrock can produce a number of closed depressions on the topographical surface which can be partly filled by palustrine and alluvial sediments. Moreover, silico-alluminous mineralization can occur in the cryptokarst pockets (De Putter et al., 2002).

In literature different importance is given to the presence of perched groundwater, to seepage chemical characters, to the role of the vegetation (i.e. Fabre & Nicod, 1986; Nicod, 1992; Walsh & Morawiecka-Zacharz, 2001). In particular, root exudates and root respiration help solutional deepening in small and medium-sized features like pipes (Jennings, 1987). On the other hand, according to Quinif (1998; 1999) this type of corrosion develops when water seepage is forced to infiltrate slowly along joints of the carbonate bedrock as a result of stress distribution. In this case, dissolution acts exclusively on the bedrock top surface since solutions rapidly saturate.

APULIAN GEOLOGICAL AND MORPHOLOGICAL SETTING

Apulia is the emerged part of a plate stretched between the Ionian Sea and the Adriatic Sea, constituting the foreland of both Apenninic and Dinaric orogens (Fig.2). It comprises a Variscan basement covered by Permian terrigenous sediments overlaid by Upper Triassic evaporitic deposits. These deposits are covered by a 3-5 km thick Giurassic-Cretaceous carbonate sequence which widely outcrops on the Gargano promontory, on the Murge plateau and on the Serre Salentine. The carbonate rocks are overlaid by thin transgressive calcareous and marly-calcareous deposits of Tertiary and Lower Pleistocene age. During the Middle and Upper Pleistocene, terrigenous and carbonate marine terraced deposits (*Depositi Marini Terrazzati*) formed during several cycles produced by the superimposition of glacioeustatic sea level changes to the general uplift of the region (Ciaranfi et al., 1998).

The Apulia landscape is characterized by marine and complex karst landforms. Karst formed over the Mesozoic, Miocene and Plio-Pleistocene carbonate rocks in response of several morphogenetic phases. These karst phases took place in different climatic and structural contexts and produced surfaces with different morphological features. Marine landforms are represented by a staircase of marine terraces produced along the coastal area during the Middle and Upper Pleistocene.

APULIAN PIPES

The cryptokarstic landforms recognised in the Apulia region are sub-vertical cylinders filled by reddish silt and sands (Photo 1). Jennings (1987) called these cryptokarstic landforms “solution pipes”. Nevertheless, according to their morphology, these landforms are known in literature with different terms: karst funnels, karst sinks, karst chimneys, karst shafts, geological organs (Walsh & Morawiecka-Zacharz, 2001) or sand pipes. Similar features due to completely different karstic processes have been frequently found in calcareous aeolianites in many parts of the world (Gardner, 1983; McKee & Ward, 1983). The Apulian pipes have been observed only in the Plio-Pleistocene porous soft calcarenites where these have been covered by a silicoclastic deposit. However, solution pipes mark out only some specific areas of Salento peninsula, specifically along the southern Adriatic coast and in the inland area.

GEOLOGICAL AND MORPHOLOGICAL CONTEXT

Solution pipes developed in soft rocks with different litho-stratigraphical characteristics. In the area between Torre Pozzelle and Torre Specchiolla, at the foot of Murge plateau, and in the central part of the Salento, they are in the *Calcarenite di Gravina* Formation whereas along the northern Adriatic coast of Salento they are in the *Sabbie di Uggiano la Chiesa* Formation.

The *Calcarenite di Gravina* Formation is constituted of whitish-yellowish litho-bioclastic stratified calcarenites of medium and coarse size. In the Salento peninsula these calcarenites are locally clino-stratified. The calcarenites are formed by whole shells or fragments of marine organisms, lithoclasts of Meso-Cenozoic limestones and biochemical carbonate sedimentation products (Iannone & Pieri, 1979). The calcarenites are composed mostly of carbonate (>95%) with an insoluble residue consisting mainly of clay minerals (kaolinite, illite, chlorite, smectite and halloysite) and negligible quartz, felspars, gibbsite, goethite (Andriani & Walsh, 2003). The laboratory tests assess that porosity ranges between 40% and 47% and the hydraulic conductivity (*K*) is about $6x10^{-5}$- $7x10^{-5}$ m/s for the coarse calcarenite and it is $3x10^{-5}$ m/s for the medium calcarenite (Andriani & Walsh, 2003).

The *Sabbie di Uggiano la Chiesa* Formation is constituted of a sequence of calcareous marls and fine marly calcarenites. The upper part of the sequence is constituted of fine calcarenites with variable cementation degree. *In situ* tests assess that porosity and hydraulic conductivity (K ranges between

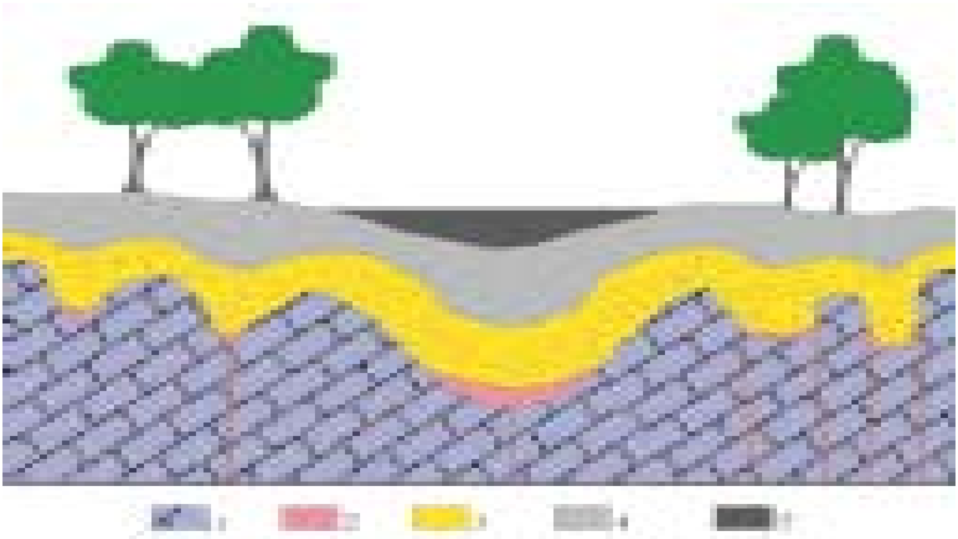

Fig. 1: Crypptokarst landforms result from the dissolution of the top of the limestone under a permeable cover; the deepening of the forms provokes the deformation of the sediments. In the cover, depressions can store palustrine and alluvial sediment. a: carbonate bedrock; b: insoluble residues of the carbonate bedrock dissolution; c: marine sands; d: continental sands; e: palustrine deposits.

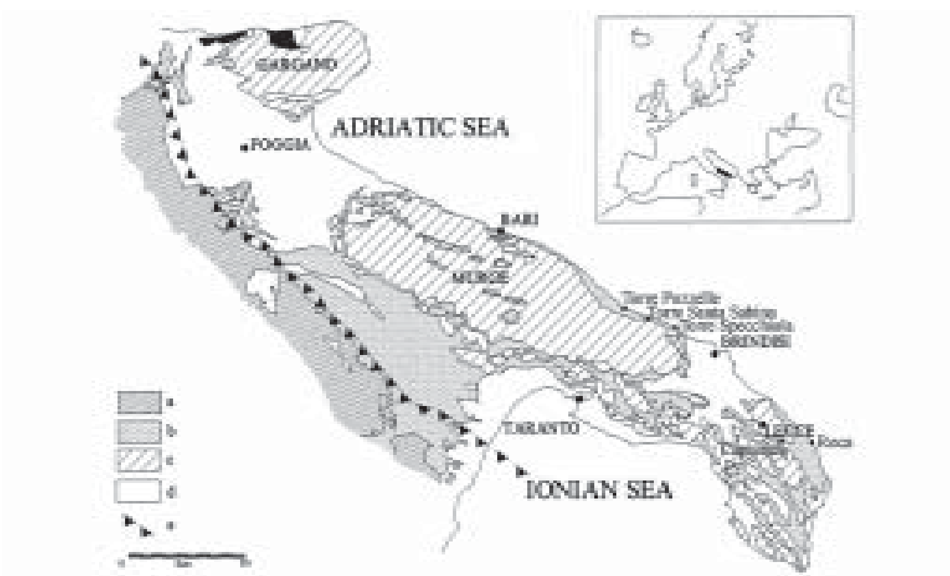

Fig. 2: Geographical position and schematic geological map of Puglia. a: Apenninic Units; b: Foredeep Units; c: Apulian Foreland Units; d: Plio-pleistocenic cover Units; e: limit of apenninic fault.

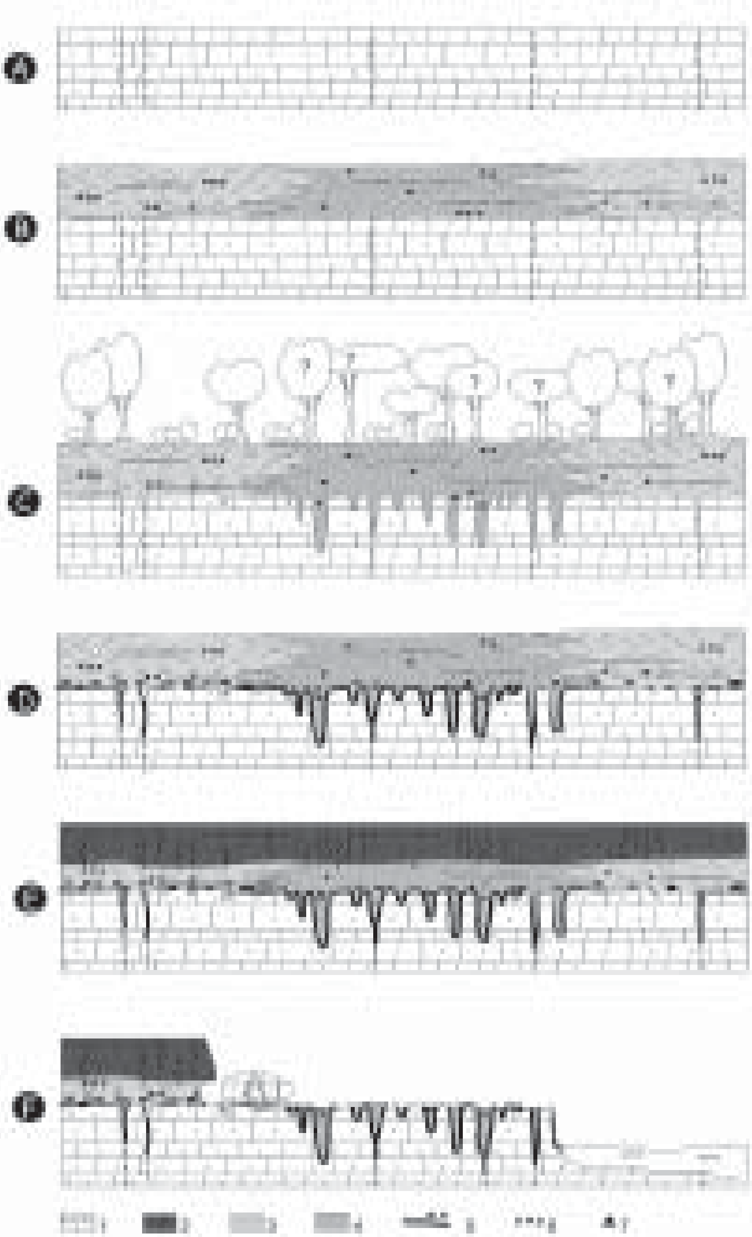

Fig. 3: Reconstruction of the morphogenetic phases sequence responsible for the development and fossilization of solution pipes. a: Plio-pleistocenic calcarenites; b: Last Interglacial calcarenites; c: sandy clayey silt; d: silty clayey sands; e: carbonate crust and carbonate nodules; f: gastropods; g: man-splinted flint.

$6*10^{-4}$ and $8*10^{-6}$ m/s) of this unit are lower than Calcarenite di Gravina formation values so that it can storage perched groundwaters. Near Roca, recent geophysical surveys highlight that the rock body is characterized by a remarkable porosity, irregularly distributed (pers. comm. G. Leucci).

The cryptocorrosion processes acted on Middle Pleistocene marine abrasion terraces which are covered by colluvial deposits. This cover (Photo 2) is preserved at Torre Santa Sabina beneath brownish bioclastic calcarenites, most likely referable to the Last Interglacial period (Mastronuzzi & Sansň, 2002). The colluvial deposit is constituted of sandy clayey silt or silty clayey sands of reddish colour, up to 1.5 meter thick. In the coarse fraction, the silty and sandy portions are constituted almost exclusively of sub-spherical and well rounded quartz grains, showing the surface covered by thin layer of reddish oxides. The finer fraction is composed of subangular grains with smoothed edges and reddish or dark rounded oxides aggregates. The other silicates are accessories and these are concentrated in the finer fraction. Several pyroxenes with a well preserved crystal habit can be found. Among the opaque grains, ferromagnetic minerals are frequent.

The carbonate fraction is almost exclusively constituted of fragments of continental gastropods shells scattered in the sediment or grouped in discontinuous and thin layers at different height in the succession.

More frequently, lenses and thin layers of sands with well rounded pebbles (grain size 2 mm – 15 mm) of cherts or, subordinately, limestones are present in the lower part. The sediment has an irregular cementation at the contact with the underlying calcarenites. The sediment probably originated by erosion, transportation and deposition of soils developed on terrigenous deposits of the older parts of the "Depositi Marini Terrazzati" cycle (Middle Pleistocene in age). This sandy-silty deposit is mostly constituted by silico-clastic minerals like quartz, feldspar and heavy minerals; among these magnetite is present (De Marco, 1982).

Probably the colluvial deposit formed not before the Middle Palaeolithic Age. In fact, a man-splinted flint has been found in the colluvial deposit and in this area the human frequentation is well documented since the Middle Palaeolithic Age (Coppola, 1983).

SHAPE AND SIZE OF SOLUTION PIPES

The shapes of pipes are quite similar although the bedrock shows unhomogeneous textural and lithological characteristics. The pipes are nearly cylindrical and concave-bottomed; some of them are coalescent (Photo 3, Photo 4). The cross section changes from circular to slightly elliptical and the diameter from a few centimeters to around 1.5 m, decreasing in depth. In some pipes the diameter increases at the bedding planes. The maximum depth is about 4 m, but some forms are a few decimetres deep in which the fill has been completely removed. No morphological relationship exists between the mean diameter on the surface and the depth of pipes observed. Pipe distribution is not homogeneous: they are grouped in many forms of any sizes, separated by large areas where the pipes are almost absent. In the test site, pipe distribution and geometry are not affected by frequency, geometry and position of the joints.

PIPE FILLS

Pipes are filled of sandy silty clay or clayey sandy silt. The silty and sandy fractions are constituted almost exclusively by spherical and well rounded grains of quartz. In the finest portion quartz grains with smoothed edges are present. The carbonate fraction is nearly absent. Pyroxenes, often showing a well preserved crystal habit, can be recognized at Torre Santa Sabina and at Torre Specchiolla localities. Grains of ferromagnetic minerals are frequent among the opaque minerals. Manganese oxide patinas have been found in the Roca pipes filling. The clay rate increases toward the pipe bottom.

The pipe filling shows the same textural and mineralogical characteristics of the colluvium fossilized beneath the Last Integlacial calcarenites at Torre Santa Sabina.

Pipe surface is covered by a brownish carbonate crust, from a centimetres to more than 10 centimetres thick (Photo 3, Photo 4). The crust is made up of whitish-reddish, micritic and sparitic *laminae* with variable clayey minerals contents (Delle Rose & Parise, 2003). Brownish carbonate nodules of different size are frequently present inside pipes, near the walls and at the bottom. This crust also covers the Plio-Pleistocene calcarenitic bedrock; it is discontinuous because it has been partially eroded, but it can be observed filling joints and bedding planes near the bedrock surface. In Tab.1 the ^{14}C age of a crust sample taken at Torre Santa Sabina is shown. It confirms a very old age, too old to be dated by ^{14}C analyses.

Sample	Material	ä$^{13}C_{pdb}$ (‰)	ä^{18}O (‰)	Uncalibrated Age(years BP)
TSS25	Carbonate crust	-10.82	-4.81	32633 +/- 1570

Table 1 – Radiocarbon age determination performed on Torre Santa Sabina carbonate crust.

At Torre Santa Sabina, root traces have been recognized inside the carbonate crust which covers pipes (Photo 5). They are vertical, tubular and twisted calcitic concretions, 2-5 mm thick and with convex endings. The tubes are made up by cryptocrystalline calcite and they have concentric structure in cross section. These data allow us to suppose that the calcium carbonate has not gradually replaced the vegetable structures but that it precipitated in the void originated by roots degradation.

THE ORIGIN OF THE PIPES

The lithostratigraphical, morphological, palaeoethnological and geochronological data collected at Torre Santa Sabina allow the morphogenetic phases sequence responsible for the development and fossilization of solution pipes to be reconstructed (Fig. 3). The Torre Santa Sabina model could be extended to other sites of Apulian Adriatic coast even if some differences occur in function of the local characteristics. This sequence developed since the Middle Pleistocene.

During the Middle-Upper Pleistocene the superimposition of glacioeustatic sea level changes to the general uplift of the region produced along the Apulian coast the formation of staircase marine terraces. Marine terraces have been overlaid by colluvial sediments which result from the erosion of soil developed on higher surfaces. Pedogenesis was very intense since the colluvial sediment is almost exclusively made up by quartz grains and reddish oxides. The colluvium shows different textural characteristics and permeability as a result of variability, in time and in space, in sediment transportation and deposition processes.

Based on the lithostratigraphical and palaeoethnological data we can suppose that colluvial cover accumulated during the final part of middle Pleistocene, probably linked to fast passage from biostasis to rhexistasis conditions (phase A and B).

Photo 1: A view of Torre Santa Sabina dissolution pipes partly covered by Holocenic continental sands.

Photo 2: A viev of the cover fossilized by calcarenites probably in the Last Interglacial age at Torre Santa Sabina.

Photo 3: A view of a pipe with complex shape produced by coalescence (Roca).

Photo 4: A view of Torre Specchiolla dissolution pipe; in particular the carbonate crust which mantles the pipes is visible.

The cover accumulated on an abrasion platform shaped on Plio-Pleistocene weak calcarenites crossed by different joint sets with irregular trends. The cover surface was colonized by plants. It promoted cryptocorrosion process and the development of solution pipes which cluster in the areas with greater cover permeability (phase C).

The process of cryptocorrosion probably stopped in response of an abrupt climatic change that induced the precipitation of calcium carbonate; the formation of a carbonate crust took place at the contact between the cover and the bedrock. Many traces of roots, of the plants that colonized the colluvial cover, have been preserved in this way (phase D). During the last interglacial period the colluvium has been fossilized by the beach calcarenitic deposits (phase E). It has been exposed during the Holocene by sea action which partially eroded the cryptokarst surface.

DISCUSSION

The solution pipes shaped on the Plio-Pleistocene calcarenites recognized along the Adriatic coast of southern Apulia have been the subject of different genetic interpretations (Blanc & Cardini, 1961; Rudnicki, 1980; Delle Rose & Parise, 2003). However, the new data collated suggest a different model for pipes and related landscape evolution.

Photo 5: A root trace in the carbonate crust which mantles the Torre Santa Sabina pipes.

The development of cryptosolution landforms during the Quaternary in Apulia region has been promoted by a number of climatic and tectonic factors. These landforms developed on the flat top surface of marine terraces. Some examples of erosion surfaces affected by cryposolution forms have reported (Quinif et alii,1997; Morawiecka & Walsh, 1997), even if the influence of pre-solution morphology has not been investigated. In the Apulia case study, the flatness and the horizontality of marine terraces top surfaces allow the accumulation of silico-clastic colluvial cover. The flatness of the colluvial cover surface and its small thickness promoted the infiltration of surficial waters through the cover and in the underlying bedrock.

The colluvial cover shows about the same characteristics throughout the southern Apulia region since it is produced by the erosion, transportation and deposition of soils developed during a period of intense pedogenesis occurred in the Middle Pleistocene. The colluvial cover accumulated during the upper part of Middle Pleistocene (as indicated by the Middle Palaeolithic age flint found in the deposit at Torre Santa Sabina locality) most likely in response to semi-arid climatic conditions.

Cryptosolution forms developed subsequentely, during a new phase marked by humid climatic conditions. Root traces found in the carbonate crust which mantles pipes at Torre Santa Sabina indicated the presence of a vegetation cover during this phase. Vegetation can help pipes deepen by increasing water aggressivity through root activity which enhances the deepening of small size forms (Jennings, 1987). The distribution of pipes, which are grouped and separated by large areas where they are absent, is most likely influenced by the variability of the colluvium permeability. The areas of bedrock covered by a colluvium with low permeability area sheltered from water seepage and dissolution processes. On the other hand, cryptocorrosion is enhanced in the areas marked by a cover with high permeability.

Cryptocorrosion processes stopped most likely in response to a climatic change which induced calcium carbonate precipitation and the development of the carbonate crust which has fossilized the cryptokarst surface.

Cryptocorrosion processes have been effective only in the soft porous Plio-Pleistocene rocks, most likely because of their low permeability. Moreover, the infiltration of surficial water was impeded through joints since these do not affect the development of pipes. This could be due to the sealing of joints produced by calcium carbonate precipitation before the starting of cryptocorrosion processes. However, a low grade of permeability in the bedrock due to joints can be determined also by the tectonics which induce local compressive and distensive fields of stress. This condition influences directly groundwater circuit and the dissolution process of bedrock (Quinif, 1998).

The absence of cryptokarst forms in other areas marked by soft Plio-Pleistocene rocks outcroppings and by no-carbonate colluvial covers could suggest a complex tectonic behaviour of southern Apulia during the Middle Pleistocene.

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REFERENCES

Andriani, G.F. & Walsh, N. (2003): Fabric, porosity and water permeability of calcarenites from Apulia (SE Italy) used as building and ornamental stone. Bull. Eng. Geol. Env., 62, 77-84.

Blanc, A. C. & Cardini, L. (1961): Saggi nei pozzetti di erosione del « tufo » di Roca Vecchia (Lecce). Quaternaria, 5, 306-308.

Ciaranfi, N., Pieri, P. & Ricchetti, G. 1992: Note alla carta geologica delle Murge e del Salento (Puglia centro-meridionale). - Mem. Soc. Geol. It., 106, 449-460.

Coppola, D. (1983): Le origini di Ostuni. Testimonianze archeologiche degli avvicendamenti culturali. Arti grafiche pugliesi, 336.

De Marco, A. (1982): Ricerche mineralogiche sui depositi quaternari di San Vito dei Normanni e di Latiano (Brindisi): applicazioni cronostratigrafiche. Rend. Soc. It. Min. Petrol. 38 (2), 857-869.

De Putter, Th. & Andrč L.& Bernard A.& Dupuis Ch.& Gjedwab J. & Nicaise D. & Perruchot A. (2002): Trace elements (Th, U, Pb, REE) behaviour in a cryptokarstic halloysite and kaolinite deposit from Southern Belgium: importance of "accessory mineral formation for radioactive pollutant trapping". Applied Geochemistry, 17, 1313-1328.

Delle Rose M. & Parise, M. (2003): Pozzetti carsici e processi geomorfologici a Roca Vecchia. Grotte e Dintorni, 5, 35-48.

Fabre, G. & Nicod, J. (1982): Modalité et rôle de la corrosion crypto-karstique dans les karst méditerranéen et tropicaux. Z. Geomorph. N. F., 26 (2), 209-224.

Iannone, A. & Pieri, P. (1979): Considerazioni critiche sui "Tufi Calcarei" delle Murge – Nuovi dati litostratigrafici e paleoambientali. Geogr. Fis. Dinam. Quat., 21, 33-58.

Jennings, J.N. (1987): Karst Geomorphology. Basil Blackwell Ltd. Oxford, 293.

Mastronuzzi, G. & Sansň, P. (2002): The last interglacial deposits. Workshop on Late Quaternary sea level changes and coastal zone evolution, Ostuni (Br) 30-31/05/2002, Field Guide, 21-23.

Maxia, C. (1950): Particolari aspetti erosivi e concrezionari nel "tufo" calcareo quaternario di Roca Vecchia (Terra d'Otranto). Contributi di Scienze Geologiche, La Ricerca Scientifica, CNR, Roma.

Morawiecka, I. & Walsh, P. (1997): A study of solution pipes preserved in the Miocene limestones (Staszów, Poljska). Acta Carsologica, 26 (2), 337-350.

Nicod, J. (1976): Corrosion du type crypto-karstique dans les karsts Méditerranéens. Karst Processes and Relevant Landforms (ed. I. Gams), Department of Geography, Ljubjlana University, 71-80

Nicod, J. (1992): Le karst sous coverture (sableuse, argileuse et/ou détritique) en France, d'aprés les travaux récents. Quadernos de seccion. Historia, 20, 165-185.

Parenzan, P. (1983): Puglia marittina. Congedo ed., Galatina, 1, 403.

Quinif, Y. (1998): Dissipation d'énergie et adaptabilité dans les systčmes karstiques. Karstologia, 31, 1-11.

Quinif, Y. (1999): Fantômisation, cryptoalteration et alteration sur roche nue: le triptyque de la karstification. Colloque européenne – Karst 99, 159-164.

Quinif Y. & Baele J. M.& Charlet J. M. & De Putter, T. & Dupuis C. & Rorive, A.& Vandycke S. (1987): A la recherche du karst perdu des craies du bassin de Mons (Belgique). Ann. Soc. Géol. du Nord, T.5 (2éme série), 361-371.

Rudnicki, J. (1980): Karst in coastal areas – development of karst processes in the zone of mixing of fresh and saline water (with special reference to Apulia, southern Italy). Stud. Geol. Polon., 65. Wyd. Geol. Wasszawa.

Walsh, P., Morawiecka-Zacharz, I. (2001): A dissolution pipe paleokarst of mid-Pleistocene age preserved in Miocene limestones near Staszów, Poland. Palaeogeography, Palaeoclimatology, Palaeoecology, 174, 327-350.