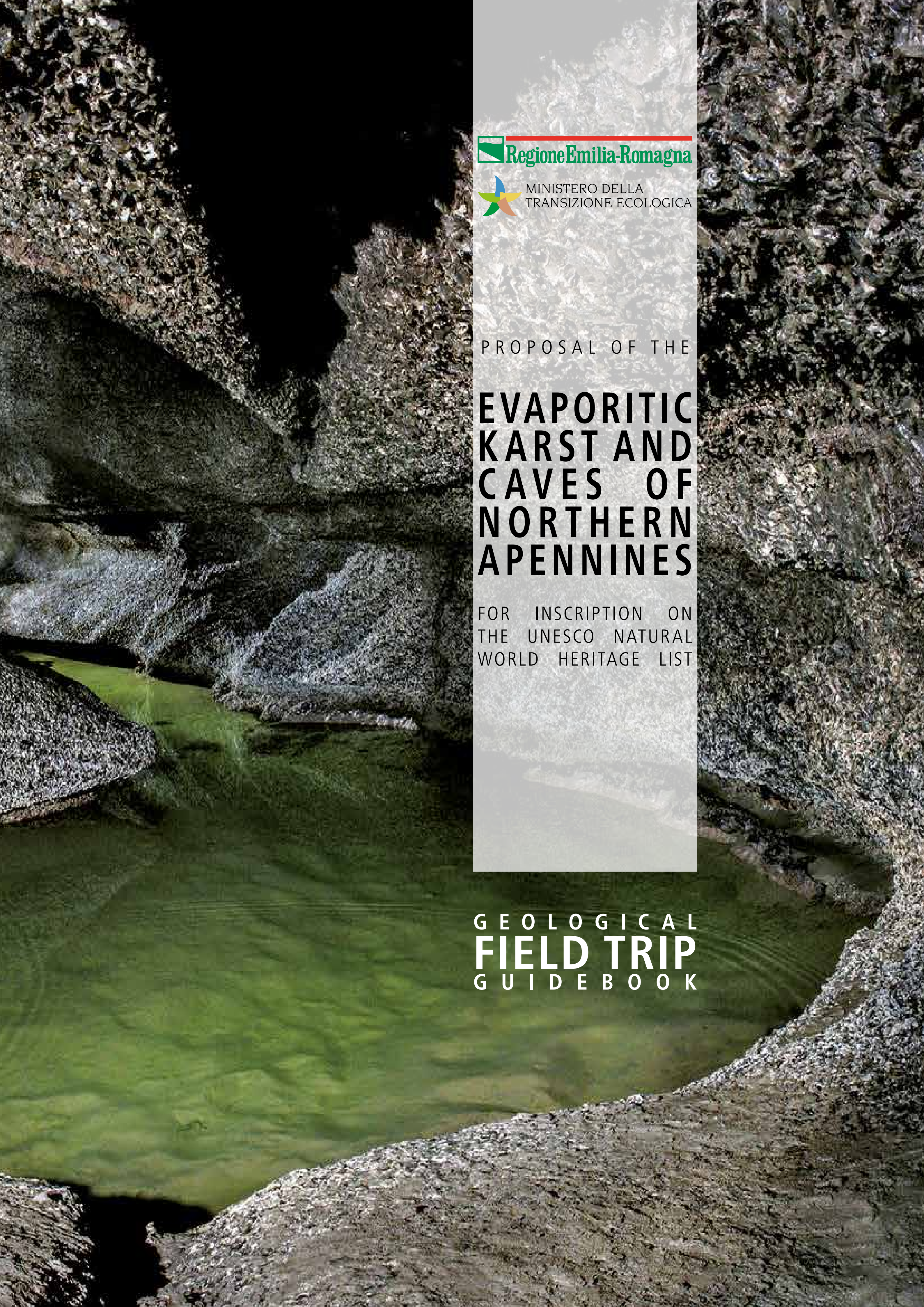


Regione Emilia-Romagna

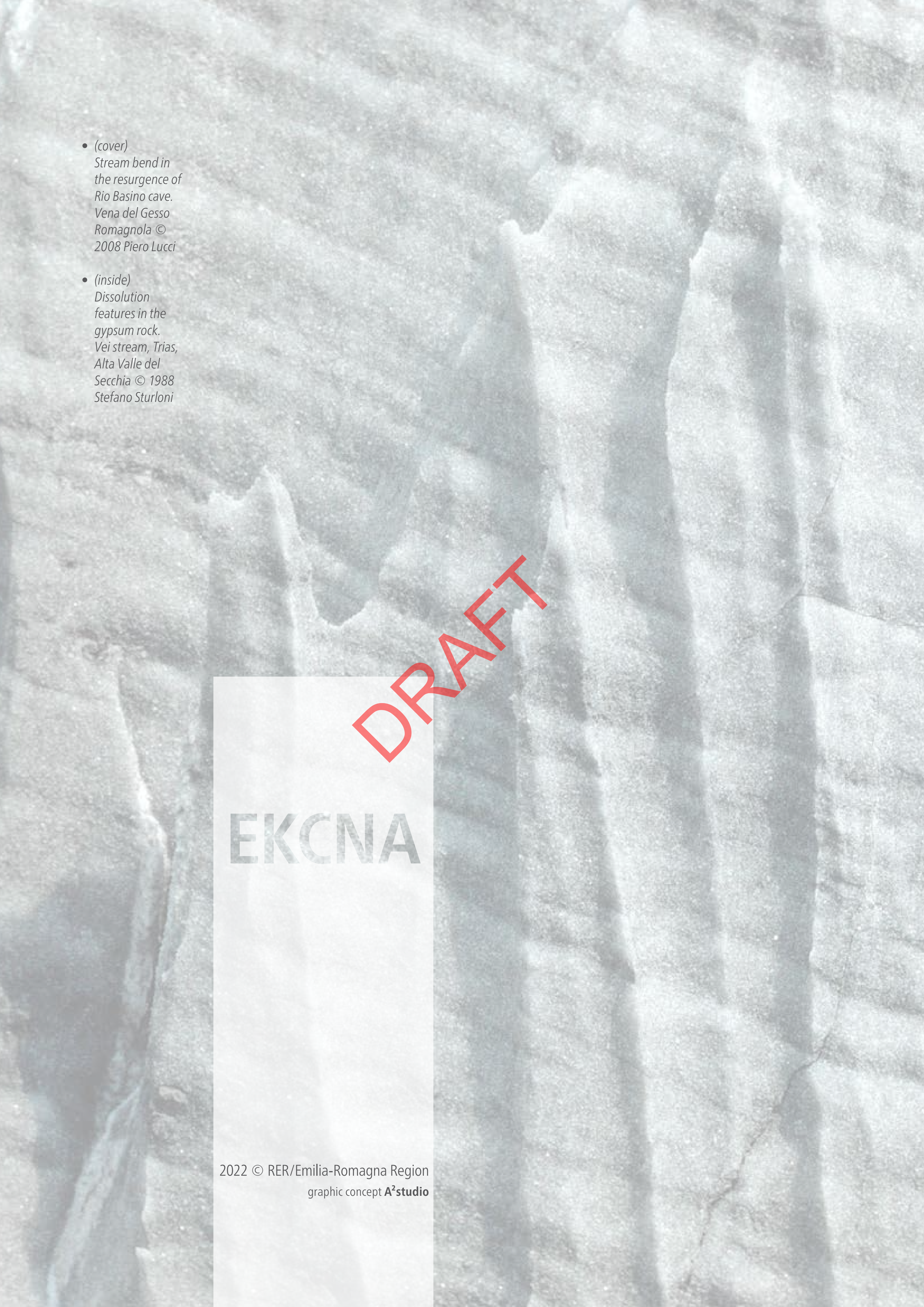
MINISTERO DELLA TRANSIZIONE ECOLOGICA

PROPOSAL OF THE

EVAPORITIC KARST AND CAVES OF NORTHERN APENNINES

FOR INSCRIPTION ON THE UNESCO NATURAL WORLD HERITAGE LIST

GEOLOGICAL FIELD TRIP GUIDEBOOK



- *(cover) Stream bend in the resurgence of Rio Basino cave. Vena del Gesso Romagnola © 2008 Piero Lucci*
- *(inside) Dissolution features in the gypsum rock. Vei stream, Trias, Alta Valle del Secchia © 1988 Stefano Sturloni*

EKCNA

graphic concept **A²studio**

Regione Emilia-Romagna

MINISTERO DELLA TRANSIZIONE ECOLOGICA

PROPOSAL OF THE

EVAPORITIC KARST AND CAVES OF NORTHERN APENNINES

FOR INSCRIPTION ON THE UNESCO NATURAL WORLD HERITAGE LIST

EKCNA

GEOLOGICAL

FIELD TRIP

GUIDEBOOK

Parma
Carpi
Reggio nell'Emilia
Modena
BOLO
BASSA COLLINA REGGIANA
CS 2
GESSI DI ZOLA PREDOSA
CS 3
ALTA VALLE DEL SECCHIA
CS 1
CS 4
GESSI BOLOGNESI
N O R T H E R N A
Taro
Crostolo
Panaro
Parma
Secchia
Samoggia
Lavino
Reno
Setta
Savena
11°0'E
44°0'N
Carrara
Massa
Tirrenian sea
Viareggio
Lucca
Prato
Pistoia
Ombrone
Serchio
IV
MAP OF THE NOMINATED SERIAL PROPERTY
World Geodetic System 1984
(WGS 84 Fuse 32N, also called EPSG: 4326)
Data sources
Topography: EU-DEM - GMES/Copernicus
Land use: REGIONE EMILIA-ROMAGNA; ESRI; OPEN STREET MAP; CTR50K (Emilia-Romagna Region)
SCALE 1 : 500,000
0 10 20 30 km
0 10 20 mi
core zone
buffer zone
highways
roads
large river
river
national boundaries

12°0′E
Reno
Idice
Sillaro
Reno
Lamone
Senio
GNA
ITALY
Ravenna
Adriatic
sea
Imola
Santerno
Faenza
Montone
Ronco
Savio
Forlì
CS 5
VENA DEL GESSO ROMAGNOLA
Cesena
APENNINES
Bidente
Rimini
Rubicone
Marecchia
44°0′N
EVAPORITI DI SAN LEO
CS 6
San Marino
Conca
Savio
CS 7
GESSI DI ONFERNO
Foglia
12°0′E

Preface

With this booklet, based on the IUCN guidelines for field assessments, and with the proposed programme we aim to help IUCN's international evaluators to verify:

- the outstanding universal value (OUV) of the proposed geological attributes;
- the completeness of the nomination;
- whether the boundaries of the property and buffer zone are appropriate;
- whether the integrity of the property is respected;
- the appropiateness of the Management Plan and the required regulatory measures;
- that the current and/or future threats have been taken into account;
- that a good dialogue with the local and national authorities and with local stakeholders and rightsholders has taken place.

During the visit of the IUCN expert, the OUV will be justified on a daily basis, as will the integrity of the territory and its management, thanks to the specialists who will accompany us in the field or during meetings, but also thanks to local actors, whether they are professionals, elected representatives, inhabitants or members of associations.

The National and Regional Agencies, the Parks, the Academic researchers, the Speleological Society and many private actors are in fact sharing a polydecennial collaborative expertise on protection, valorisation and divulgation of the exceptional karst features characterizing the evaporitic rocks of the Northern Apennines.

These are places for everyone: here many people discovered speleology for the first time, and they did it in the exact places where the scientific disciplines of hydrogeology, speleology and geology in evaporites are born. Here everybody can understand the otherwise invisible relationship that exists between the rivers, the underground water circulation, the peculiar rocks and the flora and fauna that develop in them. Here we are preserving an incredible environment characterised by its constant dynamism, an ever-changing setting governed by unique combination of geologic and climatic factors that have continued to attract curiosity for over two thousand years.

The aim of this visit programme is therefore to highlight, trough the combination of all these competences, the uniqueness of the geological and climate settings that contributed to create the outstanding karst here protected. If this nomination will be achieved, it will define a precise direction for the future of this area, which is so dear to all its inhabitants and so valuable for the Humanity.

(Stefano Furin)

Introduction: The outstanding values

The nomination of the Evaporitic Karst and Caves of the Northern Apennines contributes to fill a void in the World Heritage List- At present, no karst sites developed in evaporite rocks have ever been proposed by the member states.

The property contain two evaporite geological units: an older Upper Triassic (216-203 million years ago) gypsum-anhydrite Formation and a younger Messinian (Latest Miocene, 5.96-5.60 million years ago) gypsum Formation. The deposition of these two evaporite rocks represent major steps in the history of our planet: the breaking up of the supercontinent Pangea, the formation of the Northern Apennines orogeny and the ecological catastrophe that affected the Mediterranean Sea almost 6 million years ago.

These Formations are cropping out in two distinct area of the Northern Apennine chain and show completely different karst features.

Evaporite karst is less common than limestone karst and is characterized by different dissolution features. The first striking difference is that evaporite karst geologic evolution is extremely more rapid, enhanced by the high solubility of evaporite rocks. The result of these is that caves in evaporites evolve not only by karst, but also by internal rock fall.

This characteristic is evident to the extreme in the old evaporite rock formation of the property, the Upper Triassic gypsum, which was affected by strong deformation during the Northern Apennines mountain chain formation. The result is a unique possibility to witness impressive geological processes in action today, such as collapse structures, rockfalls, landslides, new karst springs and cave openings and old karst systems disappearance at less than human lifespan.

The other significant difference is that gypsum, the most common evaporite mineral, has a very low tendency to form concretions (stalactites and stalagmites, for example). For this reason, the caves appear rather naked compared to their limestone counterparts. As we will show, this is one of the most important aspect of evaporite cave fascination: the walls are smooth, not decorated by concretions, but are sparkling because millions of gypsum crystals are exposed, shining like mirrors.

The older evaporite rocks (Upper Triassic) of the property are virtually devoid of fossil remains, due to the extremely rapid evolution of the conduits, but the younger gypsum rocks (Latest Miocene) retain a very important paleontological significance, both ,at depositional scale for its paleokarst remains, and for the later Pleistocene fossils.

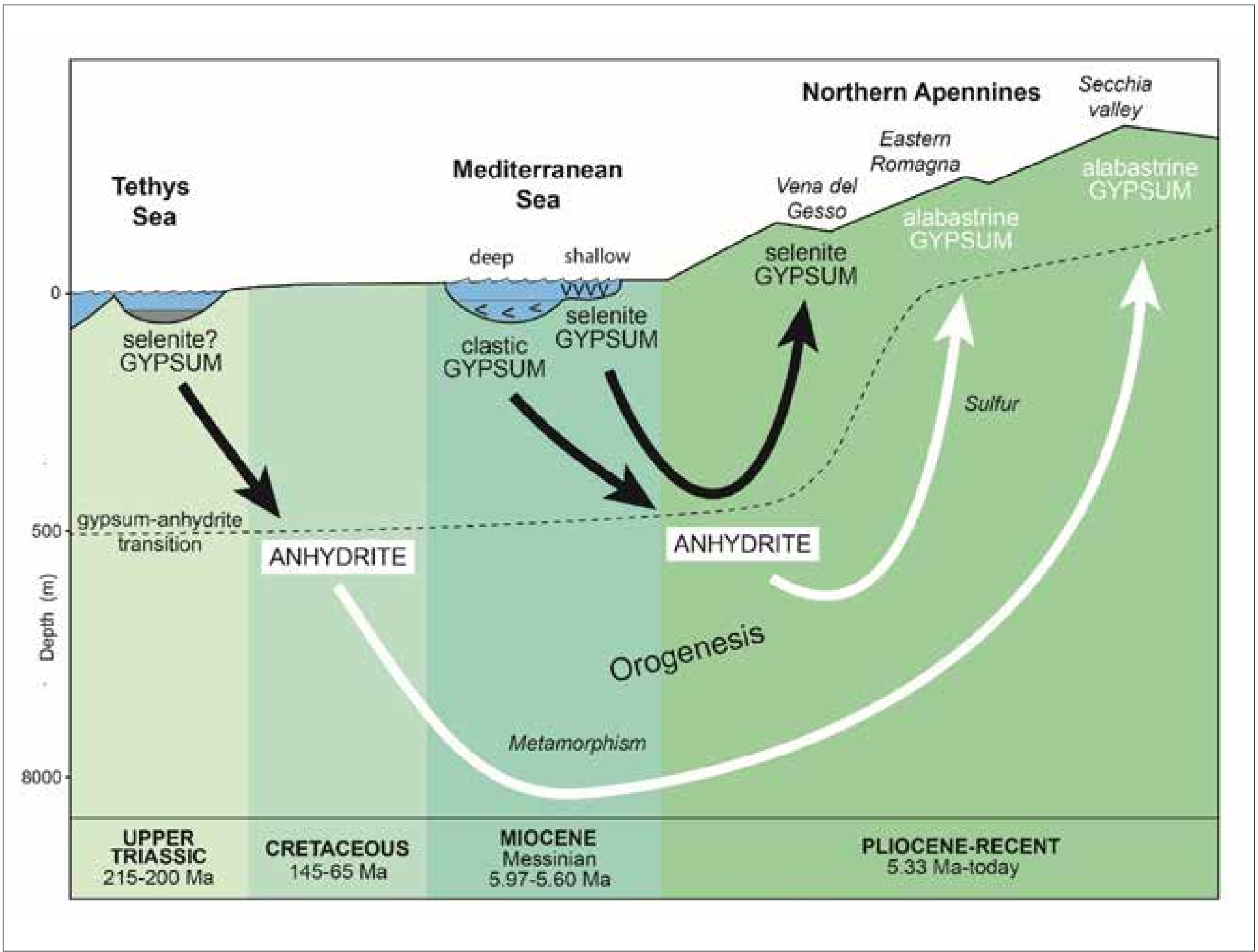
The caves of the younger gypsum formation saw also a stable human frequentation starting from the Late Neolithic-Early Copper Ages and were later exploited for their transparent gypsum crystals (*lapis specularis*) that were used by the Romans as substitute for glass in window panels.

These outstanding and unique characteristics are are beautifully exposed and are easily readable in the hills and in the ridge areas of the Northern Apennines.

Another fundamental aspect of the nomination is the highest level of scientific knowledge of these karst areas. The dissolution phenomena have been described here since the late 16th century and their study contributed to shape the international nomenclature of evaporite karst, still used today all over the world.

This field trip has been conceived to provide a detailed description of all the outstanding peculiar karst features of the two distinct evaporite formations, which have been shaped by impressive geological processes.

(Stefano Lugli)



The complex geologic evolution through time and burial depth of the Triassic and Messinan sulfate deposits in the Northern Apennine (Lugli 2022). Their peculiar distinct depositional features and mineral transformations contributed to shape unique karst phenomena.

The Northern Apennines chain is an orogenic belt with a fold and thrust structure developed as a result of the convergence motion of the European and Adria (Apulia) plates. The Adria plate was a promontory that separated from the African plate since the Middle and Late Triassic. In the Eocene and early Oligocene, the plate moved to the north and the north-east, contributing to the formation of the Alpine and Dinarides systems. In the Late Oligocene, the motion reversed and the Apennine orogenic phase started with the complete subduction of the oceanic crust (Ligurian-Piedmont Ocean), followed by the continental collision from the middle-late Eocene. During the collisional phase, the Ligurian units advanced to the east thrusting over the Tuscan-Umbria units. The Ligurian units formed by the deformation of the Ligurian-Piedmont Ocean (Alpine Tethys) during the Cretaceous-Paleogene tectonic phases.

The Tuscan-Umbria units were originated by the deformation of the continental margin of the Adria plate, involving the Variscan basement and its Permian- to Cenozoic cover.

Starting from the middle-late Miocene, the back-arc region was involved in the rifting process, which was responsible for the extension forming the Tyrrhenian Sea. The result was the eastwards migration subduction, of the foreland basins and of the extensional tectonics.

The Upper Triassic Burano Formation acted as the main detachment horizon for the Tuscan Nappe and represents one of the most striking example of plastic deformation induced by burial and tectonics.

On the other hand, the younger Gessoso-solfifera Formation is relatively undeformed and represent one of the best examples in the world for the study the primary depositional features of these extreme environments, such as the giant crystals up to more than 1 m tall, showing unique examples of bacteria fossilization in gypsum.

(Stefano Lugli)

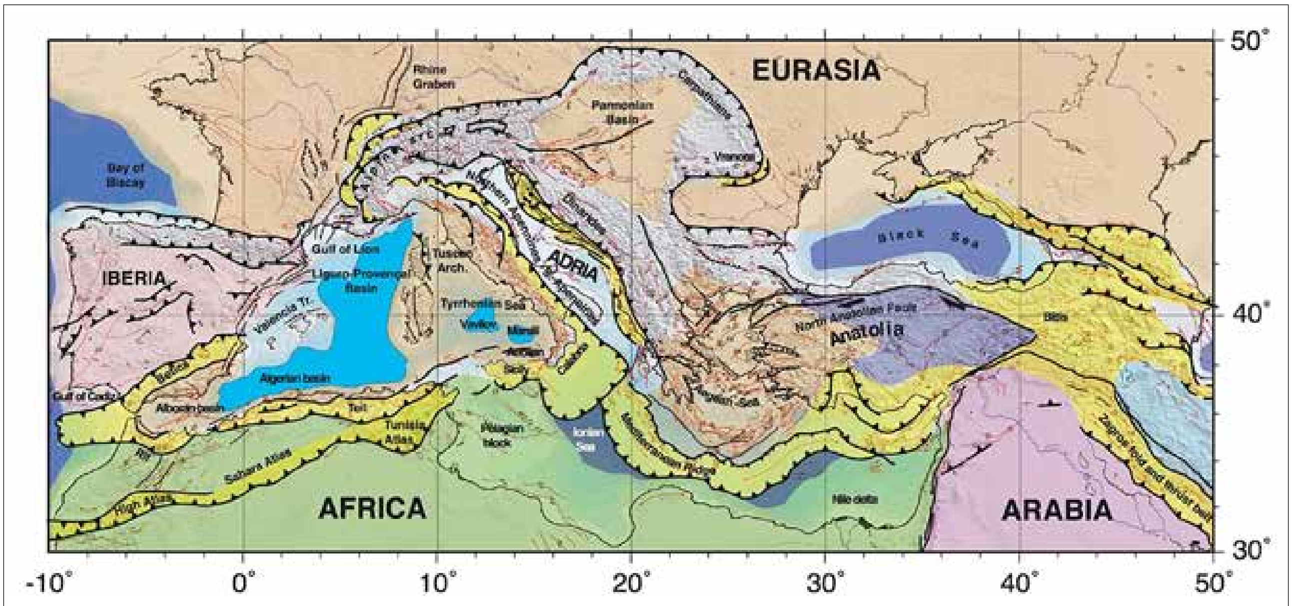
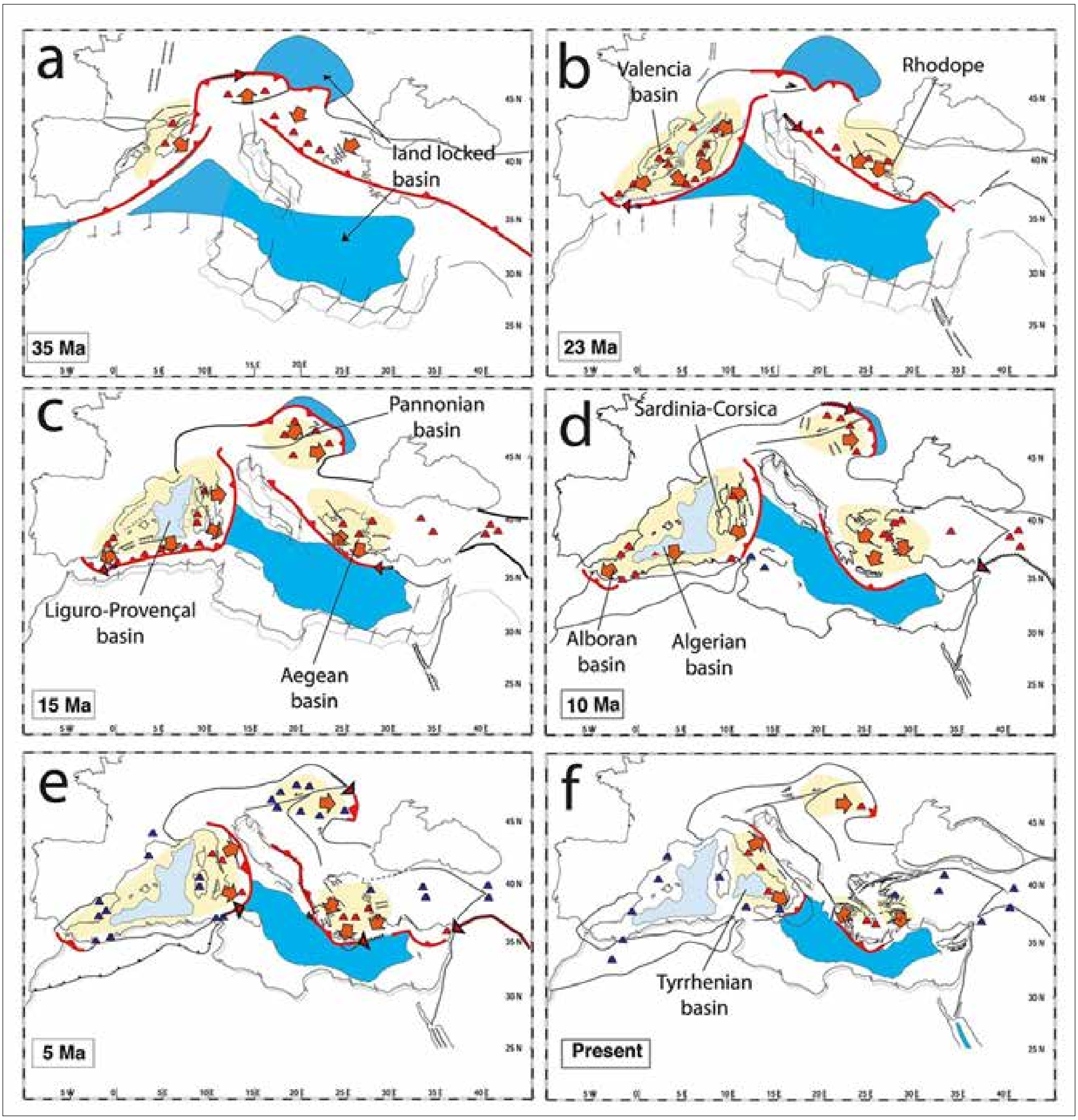
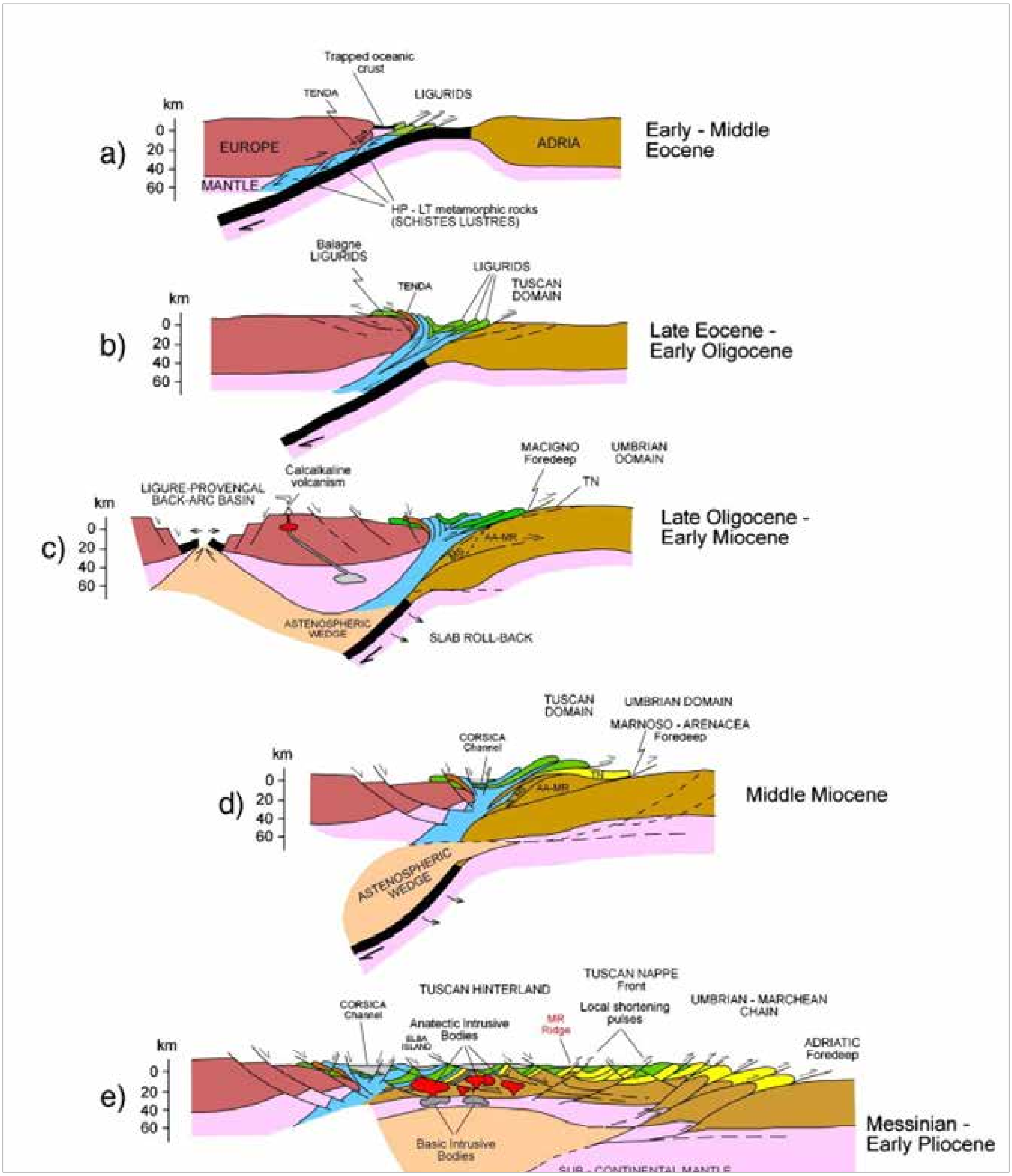


Plate tectonic setting of the Mediterranean basin (Faccenna et al., 2014).



Evolution of the Mediterranean region since 35 million years ago (Eocene). Red lines indicate active subduction. Red and blue triangles indicate calcalkaline and anorogenic volcanoes, respectively. Yellow region: extension area, arrows: direction of stretching (Faccenna et al 2014).



Tectonic evolution of the Northern Apennines. The Upper Triassic evaporites lies at the base of the Tuscan Nappe (yellow, TN in sketch d). (Balestrieri et al. 2011).

The most abundant sulfate found at the surface is gypsum ($CaSO_4.2H_2O$), whereas the anhydrous mineral anhydrite ($CaSO_4$), although occurring naturally at the surface in certain conditions, is mainly found underground. When anhydrite is brought back to the surface and interacts with meteoric water, it hydrates and transforms into gypsum before it dissolves.

The equilibrium solubility of gypsum in pure water is 2.6 g L^{-1} (at 25 ºC, 1 atm pressure and pH 7), 160 times lower than the solubility of halite, and from 9 to 50 times higher than the solubility of calcite at different PCO_2 values.

The solubility of gypsum may increase substantially in waters with other dissolved ions (foreign ion or saline effect). Of special significance is the presence of dissolved NaCl, as in the Secchia Valley where gypsum and halite rocks are associated in the evaporite succession. At 35 °C, gypsum solubility reaches a maximum of 7.3 g L^{-1} at 139 g L^{-1} of dissolved NaCl, then it decreases but remains above the solubility in pure water. Other chemical reactions such as sulfate reduction or dedolomitization may contribute to enhance or maintain gypsum dissolution by reducing the concentration of SO_4^{2-} or Ca^{2+} in the solution.

The dissolution of gypsum at microscopic scale is influenced by its crystalline structure, comprising layers of Ca and SO_4 units, linked by layers of H_2O through weak hydrogen bonding. This layered structure allows the development of perfect cleavage planes, and dissolution also occurs through a layer-by-layer process.

Under similar conditions, solutional denudation rates in gypsum are much higher than in carbonate rocks due to the greater solubility of the former. In fact, rates are commonly reported using mm yr^{-1} rather than mm kyr^{-1}. A cumulative rainfall of 100, 500, and 1000 mm would cause a surface lowering of 0.26, 0.56 and 0.93 mm, respectively.

Where gypsum outcrops the typical karst surface landforms develop readily, from the minor landforms (such as microrills, rillenkarren, and rinnenkarren) to the larger ones (dolines and poljes). The smaller forms might be influenced by the size of the gypsum crystals, the microcrystalline gypsum varieties being those that allow the best development of all types of karren assemblages. Dolines in gypsum are generally funnel-shaped, and can form much faster than in limestones. There is a negative feedback between sinkhole growth (i.e. its increasing capacity of accumulating insoluble materials) and its growth rate, which decreases (both in depth and in diameter) over time. Soil erosion on the slopes and interfluves causes an increase of dissolution in these higher doline area, ultimately leading to landscape inversion phenomena that cause sinkhole floors to become topographic highs and vice versa. A good example of this is the paleo-sinkhole of Cava a Filo near Bologna, where the former sinking point of the bottom of a doline is now located near the top of the hill.

Bare gypsum outcrops often also display weathering crusts with characteristic landforms (not known for carbonate karsts) related to dissolution and re-precipitation processes. One of such landforms are hollow subcircular domes known as gypsum tumuli, generated by local expansion and bulging of the weathering crust. The domes are commonly several decimeters in diameter and height and the upwarped layer may be up to 50 cm thick. Bulging in these particular areas is related to dissolution and re-precipitation processes acting in a surficial weathering zone. The fresh meteoric water that infiltrates in outcrops of macrocrystalline gypsum fills the pores in the upper zone of the rock mass causing dissolution. Subsequently, evaporation and the associated capillary rise of the interstitial water lead to migration of the solution towards the surface, its progressive saturation and gypsum re-precipitation in the outer weathered zone. The volume increase caused by secondary gypsum precipitation together with crystallization pressure cause the local detachment and bulging of the gypsum crust. As the domes grow, the weight of the uplifted crust may exceed its mechanical strength, with the consequent development of concentric and radial cracks. The mechanical strength of the uplifted crust may also be weakened by dissolution. Eventually, the top of the tumulus collapses producing crater-like depressions. The development of gypsum tumuli is favored by the number of wetting and drying cycles, as well as semiarid climates in which evapotranspiration potential exceeds precipitation. Often the surface gypsum beds are fractured forming different adjacent slabs forming a polygonal pattern. The expansion of these polygons causes the formation pressure ridges.

When water penetrates underground, caves can form rather rapidly in gypsum under favorable hydrological and hydrochemical conditions (decennia, centuries) due to its high solubility. Of special interest from the speleogenetic perspective is the solubility and dissolution kinetics of gypsum in shallow (epigenic) conditions, the latter being slower than that occurring in carbonates. Carbonate dissolution at normal pH conditions is mainly controlled by the relative slow reaction at the rock-water interface, which is the rate-controlling factor rather than the more rapid transfer of ions to the bulk solution through the diffusion boundary layer (surface-controlled kinetics). In contrast, gypsum is characterized by a mixed kinetics, in which the rate-limiting step varies depending on the saturation state of the solution. Gypsum rapidly dissociates into the water and the rate-limiting factor is diffusional transport through the boundary layer (transport-controlled kinetics). However, close to equilibrium (saturation ratio ~0.9), the surface-reaction becomes slower than diffusional transport and the regime changes from transport- to surface-controlled. In the transport-controlled stage, which is responsible for most of the solutional work, the thickness of the diffusion boundary layer is an important factor; the thinner it becomes the faster gypsum is dissolved. The thickness of the boundary layer mainly depends on flow velocity and regime, with a linear dependence between dissolution rate and flow velocity in laminar flow conditions, and a disruption of the boundary layer in turbulent flow conditions, accompanied by a significant increase in dissolution rate. As a consequence, caves in gypsum preferably form where conditions allow water to flow fast, as occurs in presence of steep hydraulic gradients, relatively large initial fissure widths, and limited production of insoluble material that tends to clog solutional openings.

In epigenic settings, the linear relationship between flow velocity and dissolution rate causes selection of more favorable flow paths to be much more pronounced in gypsum than in limestones. Initially, larger flow paths enlarge much faster than the tinier ones, reaching breakthrough very rapidly, and once it is achieved this positive feedback becomes even more pronounced. Therefore, in epigenic gypsum karst settings, where flow velocities can be high, gypsum caves tend to be characterized by simple (linear) cave patterns connecting recharge points (sinking streams, large dolines) to discharge points (springs). Most dissolution occurs where the water initially comes in contact with the gypsum. In the vadose (percolation) zone, water entering the few open vertical fissures rapidly enlarges them forming vertical shafts. The transmission of water flow to the base level (e.g., the spring in the nearest valley) mostly occurs close to the water table, since this is where flow reaches the greatest flow velocities. This explains why phreatic loops are very rare, and if they occur they are typically very shallow and related to local structural conditions. At the water table, most conduit enlargement occurs during high flow events (i.e., floods) through a combination of dissolution by rapidly flowing floodwaters that can maintain undersaturated conditions over longer distances, and mechanical erosion boosted by entrained sediment particles and favored by the high erodibility of the gypsum. The dimensions of the few ‘victor’ conduits generally reflect the maximum discharge of the flood events that created them, but other processes such as collapses do not allow these conduits to survive for long times.

(Jo De Waele)

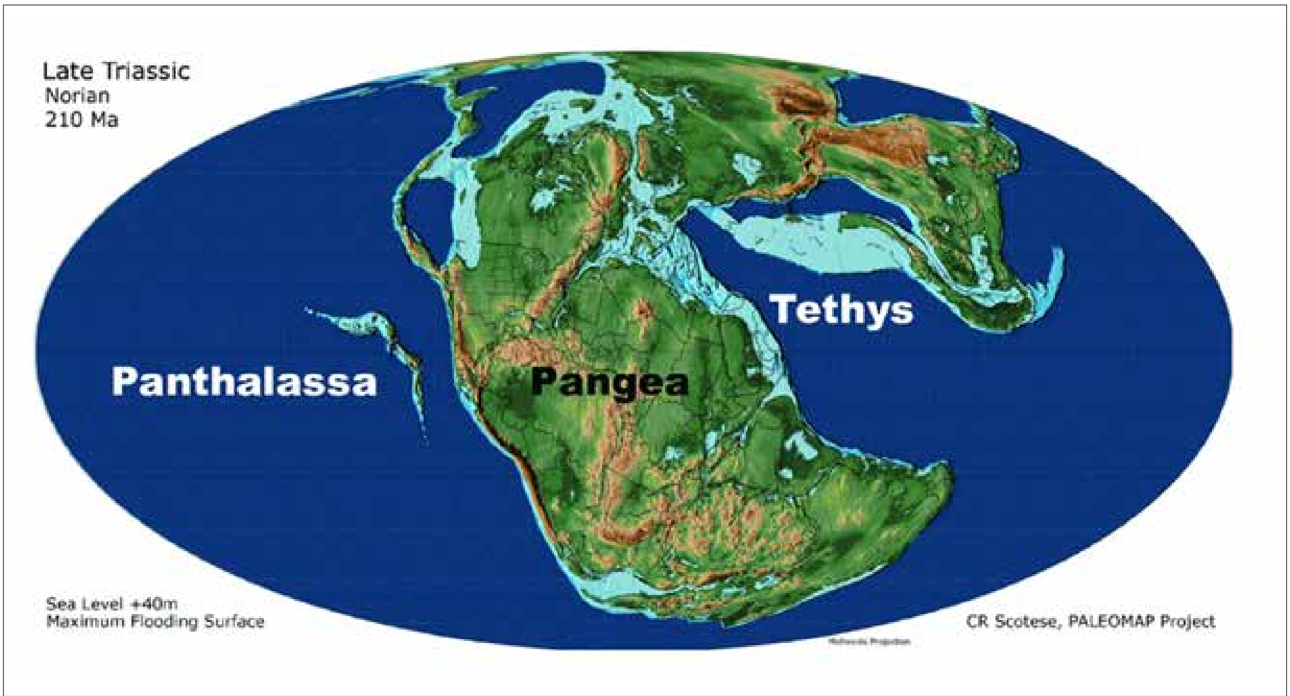
Karst features (rillekarren) on the Triassic gypsum (photo S. Lugli).

Day 1

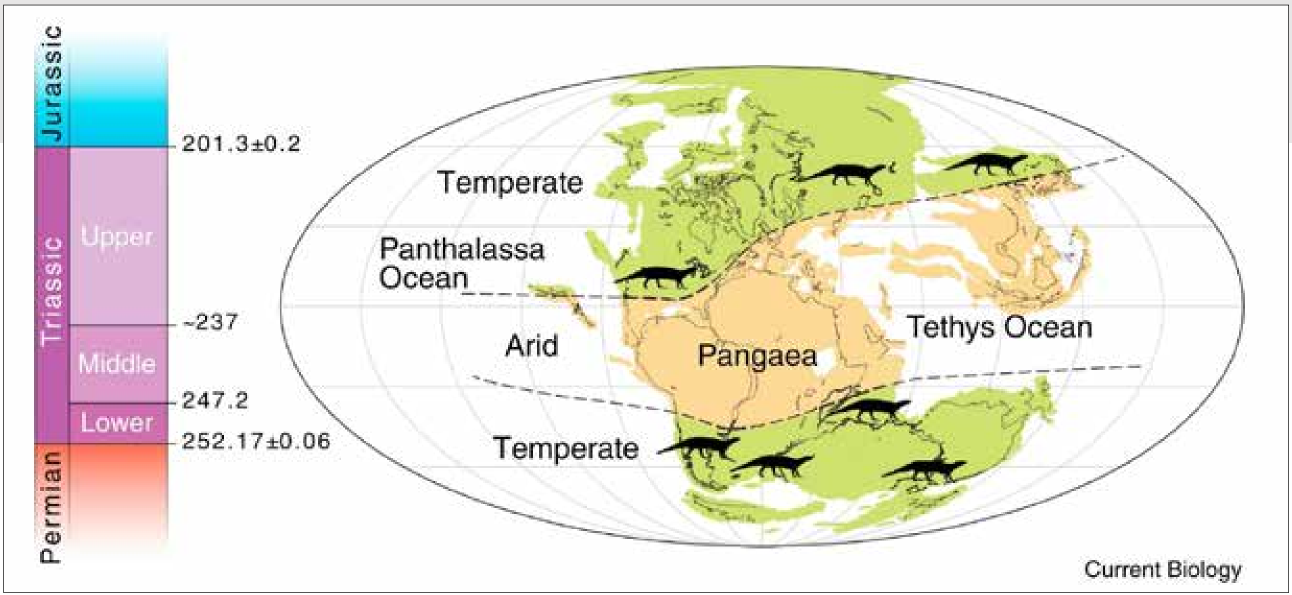
Triassic Gypsum: Alta Val Secchia (CS1)

Geological setting

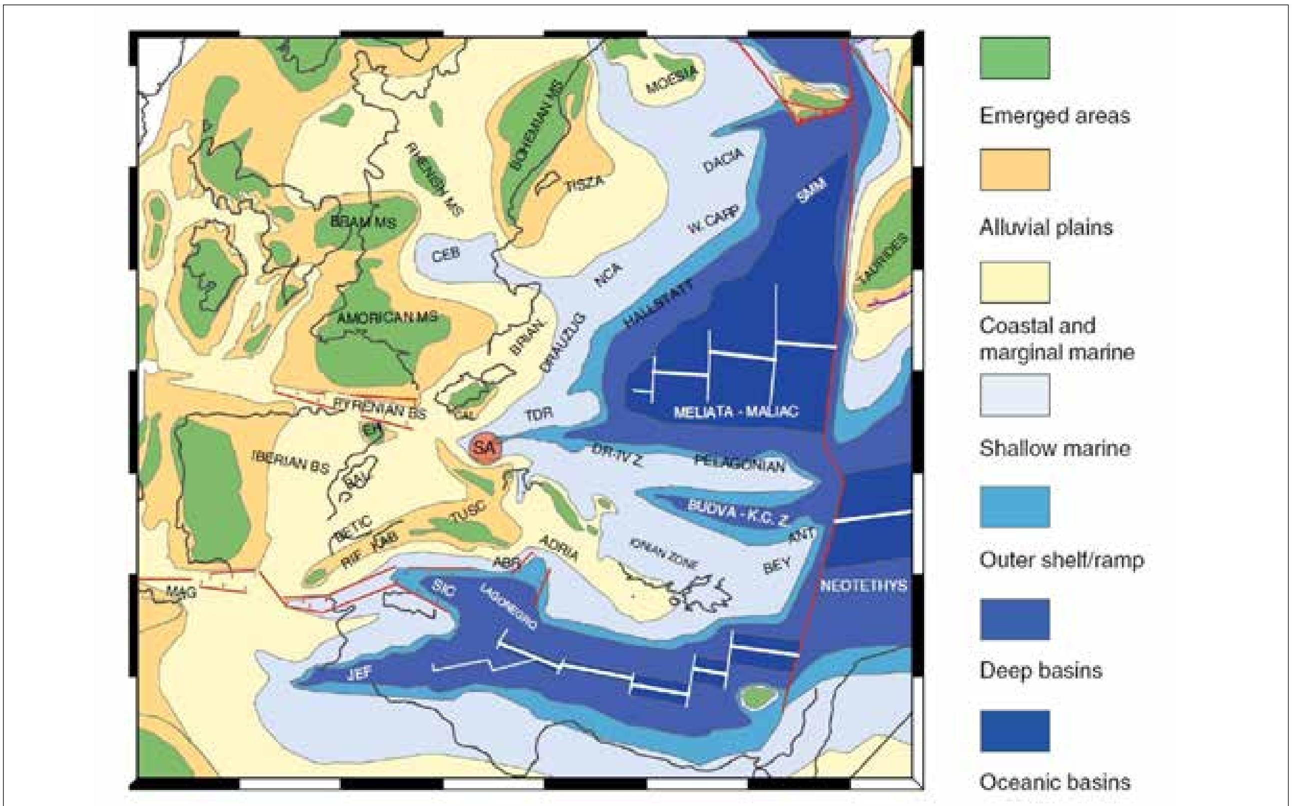
The evaporite unit of the Secchia River Valley is mainly composed of alternations of gypsum-anhydrite rocks (white and gray colored) and dolostones (dark colored) with minor halite at depth. The inferred total thickness reaches 2200 m in the northernmost zone (Colombetti and Zerilli, 1987). In Tuscany the evaporites lie at the base of a more than 2 km-thick carbonate-clastic Mesozoic sequence, the Tuscan Succession or Nappe, deposited during the ingression of the Tethys Sea along the rift system cutting the Variscan orogen and its European foreland. At that time all the continents were assembled together forming the supercontinent Pangea, surrounded by the global ocean Pantalassa. The breaking up of the Pangea and the development of rift basins migrating westward along the arid-climate belt created an "evaporite wave" in the restricted to shallow marine environments along the coastal systems. As a consequence, the first evaporite deposition happened in Greece in the Permian, moved across today's Croatia, Italy, France, Spain, and terminated during the Cretaceous in the Gulf of Mexico, between North America and Africa.



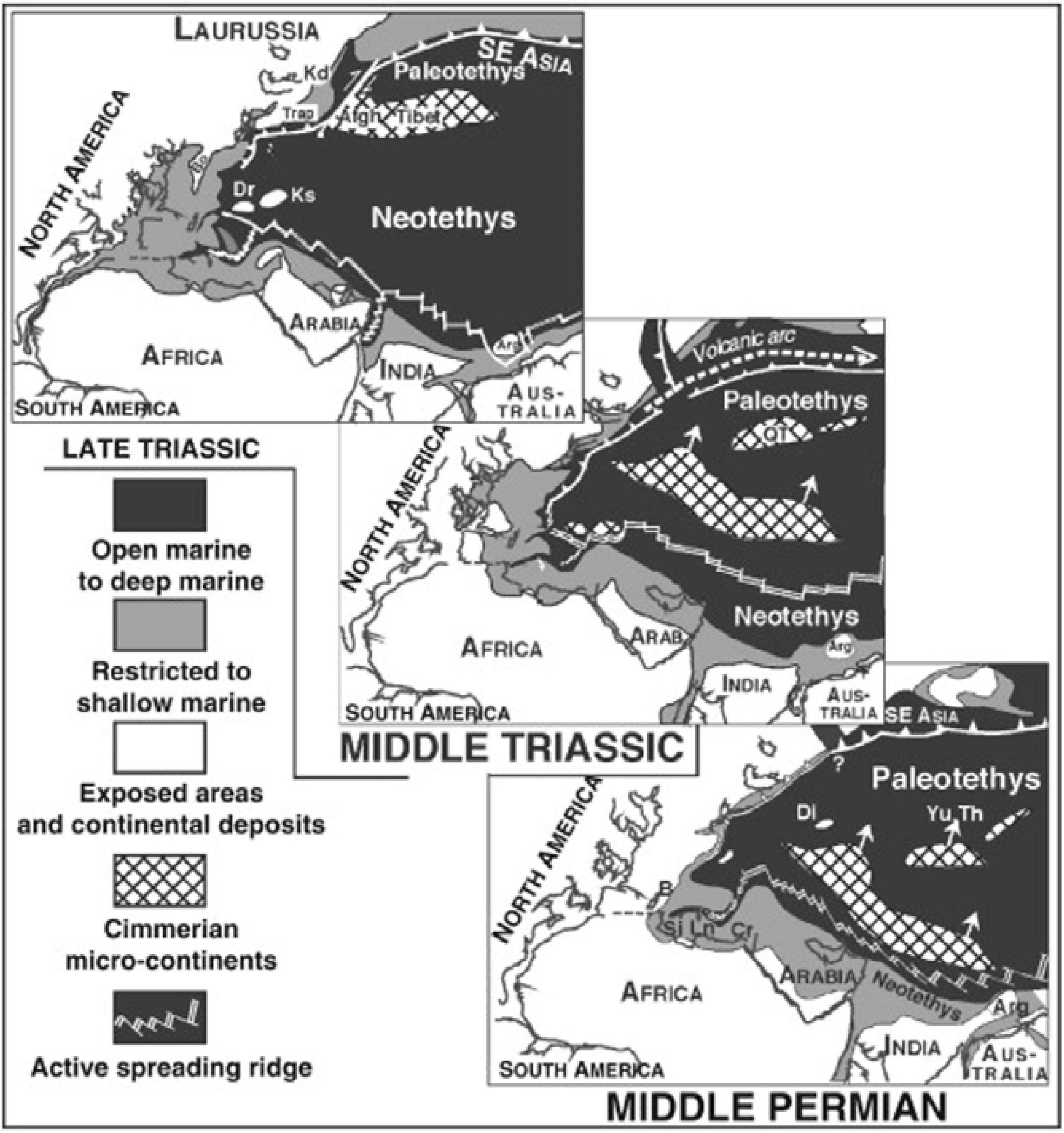
Paleogeographic map of the Upper Triassic at 210 million years ago. The Burano evaporite Formation was deposited at the westernmost edge of the Tethys Sea (Scotese 2001).



The Triassic time scale spans some 50 Myr, separated by mass extinctions at the beginning and end. Palaeogeographic map of the world in the Triassic, showing the major climatic belts, and the extent of the arid-climate 'dead zone' (beige) of the Early Triassic, most organisms such as dinosaurs are found in the temperate zones (green). The arid-climate area was prone for evaporite deposition in the shallow lagunal systems of the western Tethys Ocean. From Benton 2016.



Early-late Carnian (Late Triassic) palaeogeographic map of Western Europe showing land, sea, and main tectonic blocks. The Upper Triassic evaporites formed in the lagoons created by the westward migration of the Neotethys rift system in the coastal, marginal and shallow marine settings. (BS: Basin; MS: Massif): ABR: Lazio-Abruzzi platform; ANT: Antalya; BAL: Balearic Islands; BEY: Beydaglari autochtonous; BRAB: Brabham Massif; BRIAN: Brianconnaise; CAL: Calabria; CARP Carpatian; DR-IV: Drina-Ivanica Zone; EH: Ebro High; JEF: Jeffara rift; K.C.Z.: Krasta-Cukali Zone; MAG: Maghrebian rift; NCA: Northern Calcareous Alps; RIFKAB: Rif-Kabylies nappe; SA: Southern Alps; SMM: Serbo-Macedonian Massif; TDR: Transdanubian Range; TUSC: Tuscany). Bernardi et al., 2018.



The "evaporite wave" in the restricted to shallow marine environments (gray) created by the breaking up of the Pangea and the development of rift basins migrating westward (De Graciansky and Roberts 2011). The first evaporite deposition happened in Greece in the Permian and moved westward between North America and Africa until the Cretaceous.

The Burano Formation was the main decollément horizon for the Tuscan Nappe during the NE directed build-up of the Northern Apennines chain.

In the study area, the Burano sequence is exposed along the Secchia River Valley structure, which has been interpreted as a transpressional system running transverse to the major tectonic features of the Northern Apennines. The evaporite unit is disrupted into thrust slices, which are tectonically included into younger allocthonous units. The evaporite thrust slices were detached from the base of the Tuscan Nappe by formation of mega-tension gashes. These thrust slices were then incorporated into the migrating overlaying Ligurian units during a post-Burdigalian-Langhian deformation phase (Chicchi and Plesi, 1991).

The Burano evaporites were affected by thermal events related to the development of the greenschist facies Alpi Apuane metamorphic complex, located to the SW of the Secchia Valley.

The carbonate rocks are mainly massive dolomitic mudstone, which commonly appear as mega-boudins within a sulfate groundmass. The dolostones have been affected by Mg-metasomatic replacement by magnesite induced by hydrothermal circulation. Total homogenization temperatures of fluid inclusions in hydrothermal magnesite range from 275 to 310° C.

The anhydrite rocks are characterized by flow structures such as centimeter-scale pseudo-lamination composed of aligned prismatic crystals with transposed isoclinal folds outlined by dolostones fragments. Homogenization temperatures of fluid inclusions in authigenic quartz incorporated into sulfate rocks range from 260 to 305° C. The gypsum rocks show the same general structures as the anhydrite rocks and formed at their expenses by late migration of sharp hydration fronts propagating from fractures and strata boundaries.

Although minor halite is only sparsely distributed at depth, as suggested by boreholes and salt springs, widespread and thick caprock-like sulfate megabreccias suggest the former presence of thick salt deposits in the northernmost zone.

The role of the Burano Evaporites during the Apennines tectogenesis can be depicted as follows:

a) prevalent deposition of gypsum in the Upper Triassic;

b) gypsum dehydration at burial conditions to form anhydrite (Cretaceous?);

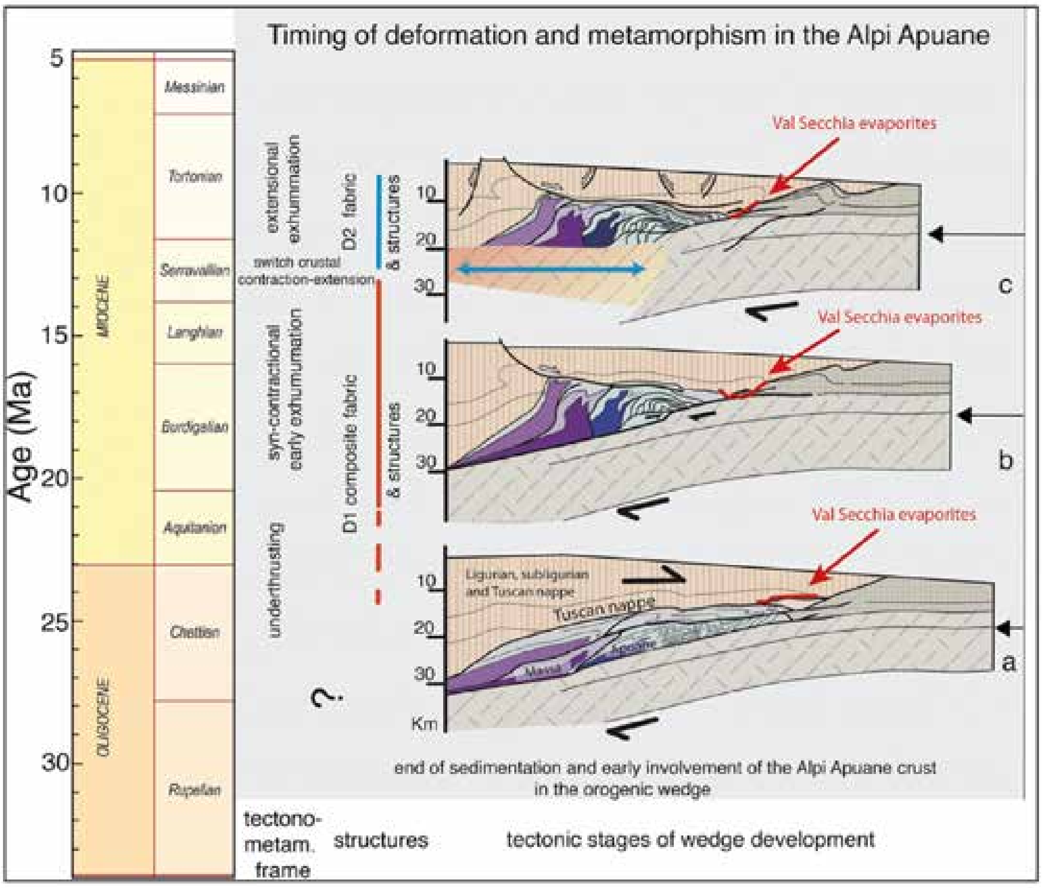
c) syn-tectonic flow of anhydrite rocks, brecciation of dolostones; syn-tectonic growth stage of quartz euhedra at deep burial conditions possibly related to the development of the Oligocene-Miocene greenschist facies Apuane metamorphic complex;

d) hydrothermal deposition of sparry magnesite and partial Mg-metasomatic replacement of dolostones by magnesite;

e) sub-surface dissolution of halite to form thick matrix-supported residual caprock-like anhydrite megabreccias;

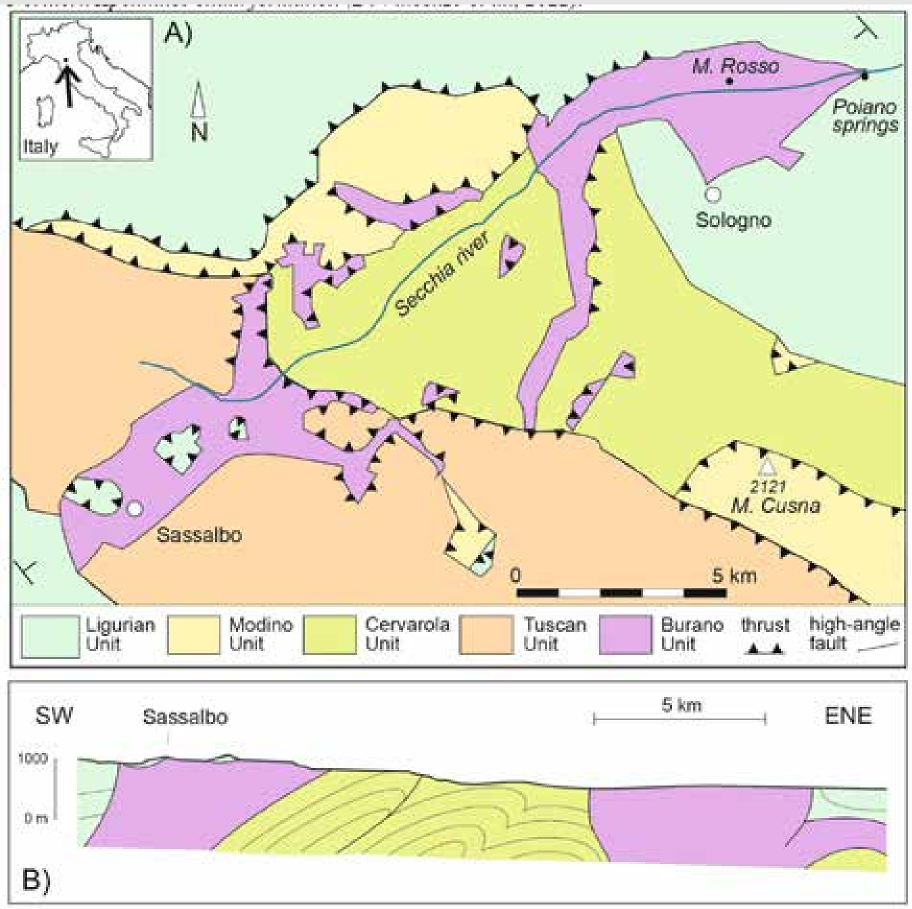
f) complete gypsification of anhydrite at sub-surface conditions; g) evaporite dissolution at surface exposure producing dolostone breccias with partial calcitization and removal of most clasts (*Calcare cavernoso*).

(Stefano Lugli)

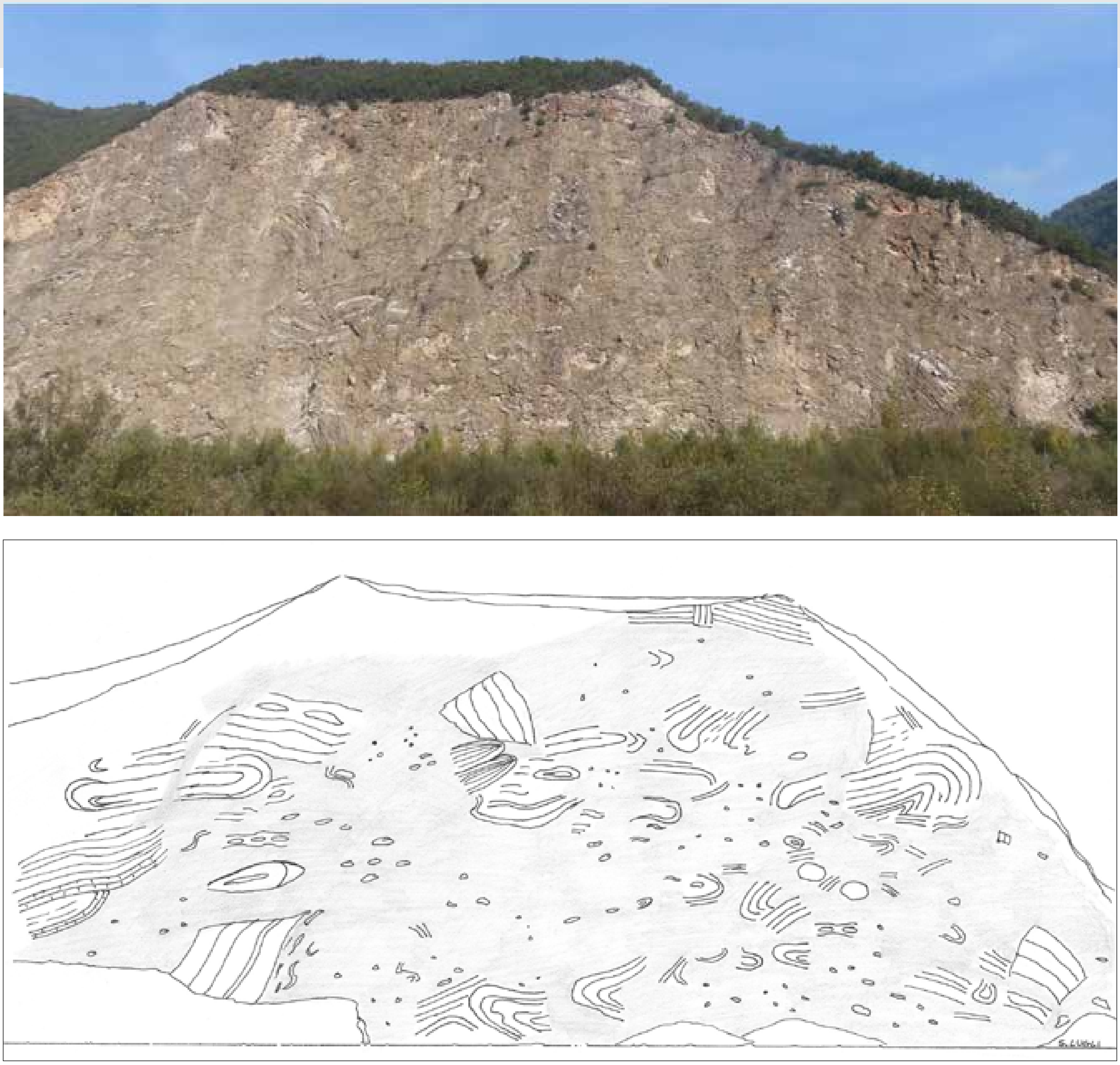


The complex burial, deformation and thermal history of the Burano evaporites during the Northern Apennines chain formation (Di Vincenzo et al., 2022).

The Secchia River valley cutting through the Triassic gypsum outcrops with the rock prism of the Pietra di Bismantova in the background (photo P. Lucci).



Geological map of the Upper Triassic evaporite unit (Burano unit) in the Secchia River Valley and in Northern Tuscany (modified after Lugli et al 2002).



Reconstruction of the M. Rosso scarp structure. The cliff consist of fragments of strongly deformed and disrupted evaporite layers floating in a gypsrudite groundmass. The section is 270 m tall and has been created by erosion and dissoution at its base by the Secchia river. It is often affected by rockfalls, testified by whitish dust deposits covering the vertical cliff. Photo and diagram S. Lugli.

A unique, dramatically fast, evolution

Karst caves are formed because some rocks dissolve in water. Gypsum is a more soluble mineral than calcite and therefore caves in gypsum evolve faster than those in limestone. But in the Secchia Valley they do it even faster. The reason is that here the caves do not evolve only by dissolution, but also by collapse.

The Triassic evaporite rock is highly unstable because it was deeply deformed and dismembered by complex geological processes. Deposited in the ancient Tethys Sea, over 200 million years ago by evaporation in a series of lagoons and then buried at several kilometers of depth, during the formation of the Apennine chain it functioned as a sort of level of weakness, along which enormous strata tectonically overlapped on top of each other. After the intense tectonic deformations, the dissolution of the rock salt in the subsoil further disrupted the geological formation in enormous juxtaposing blocks leaning against each other. Anhydrite prevails at depth, but it is not stable at surface conditions and hydrates, transforming into gypsum. The phenomenon occurs with a significant increase in volume, further fragmenting the rocks in the most superficial part of the outcrops. These particular mineralogical whims influence the development of karst with the formation of the hypogean bends, which exist only here. The streams that are swallowed up in the mountains do not cross the core of the gypsum reliefs, as for example happens for the Messinian gypsum, but follow an underground path that remains in the outermost rim of the mountains, where gypsum dominates and not anhydrite, which is less soluble and practically impermeable.

There are no other karst rocks in the world that present such a complex and dramatically fast evolution as in the Secchia Valley.

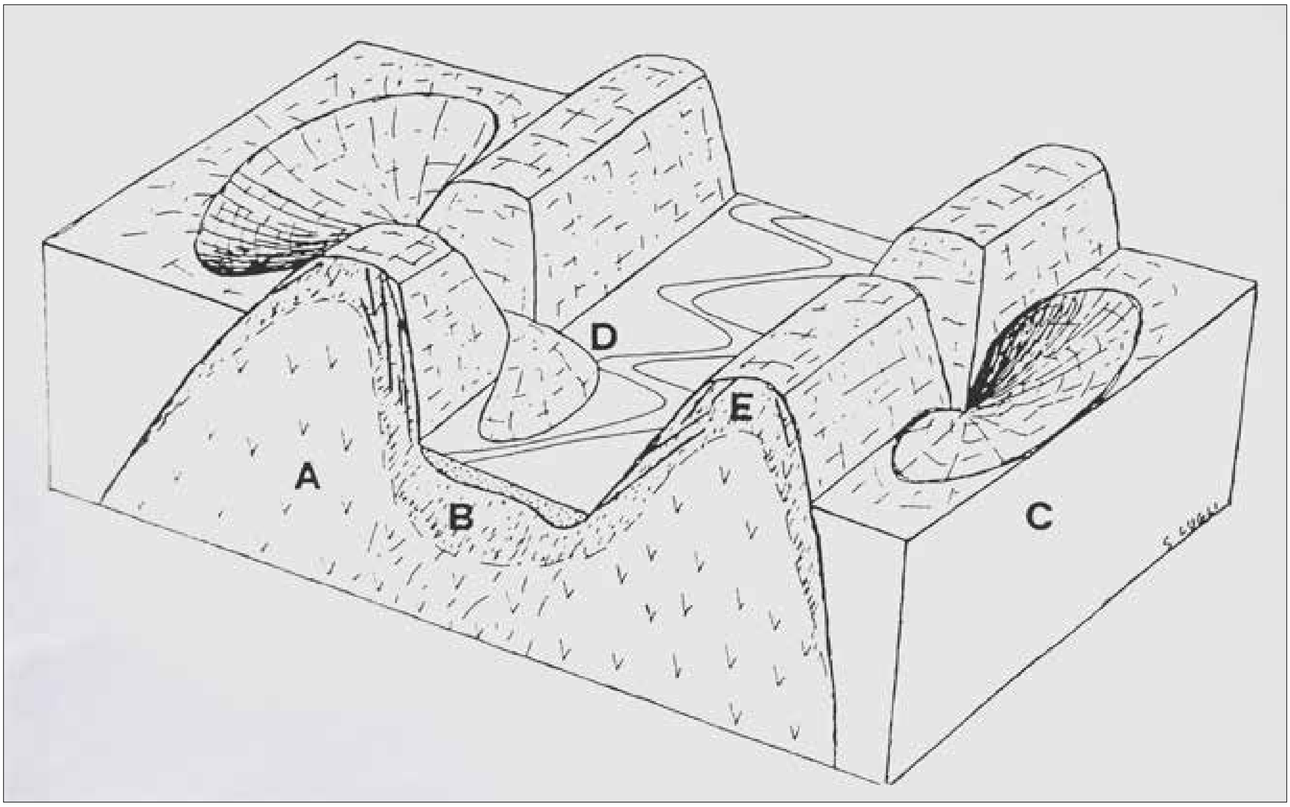
The tormented, multicolored, evaporite rocks in the Tanone grande della Gacciolina cave (photo P. Lucci).

Once an underground stream has opened its way in the rock, large blocks detach from the walls and ceiling of the conduits and the stream quickly dissolves them away, leaving room for new collapses. A spectacular collapse room in the Tanoni karst system is 100 m long, 28 m wide and 18 m high (M. Bertolani room).

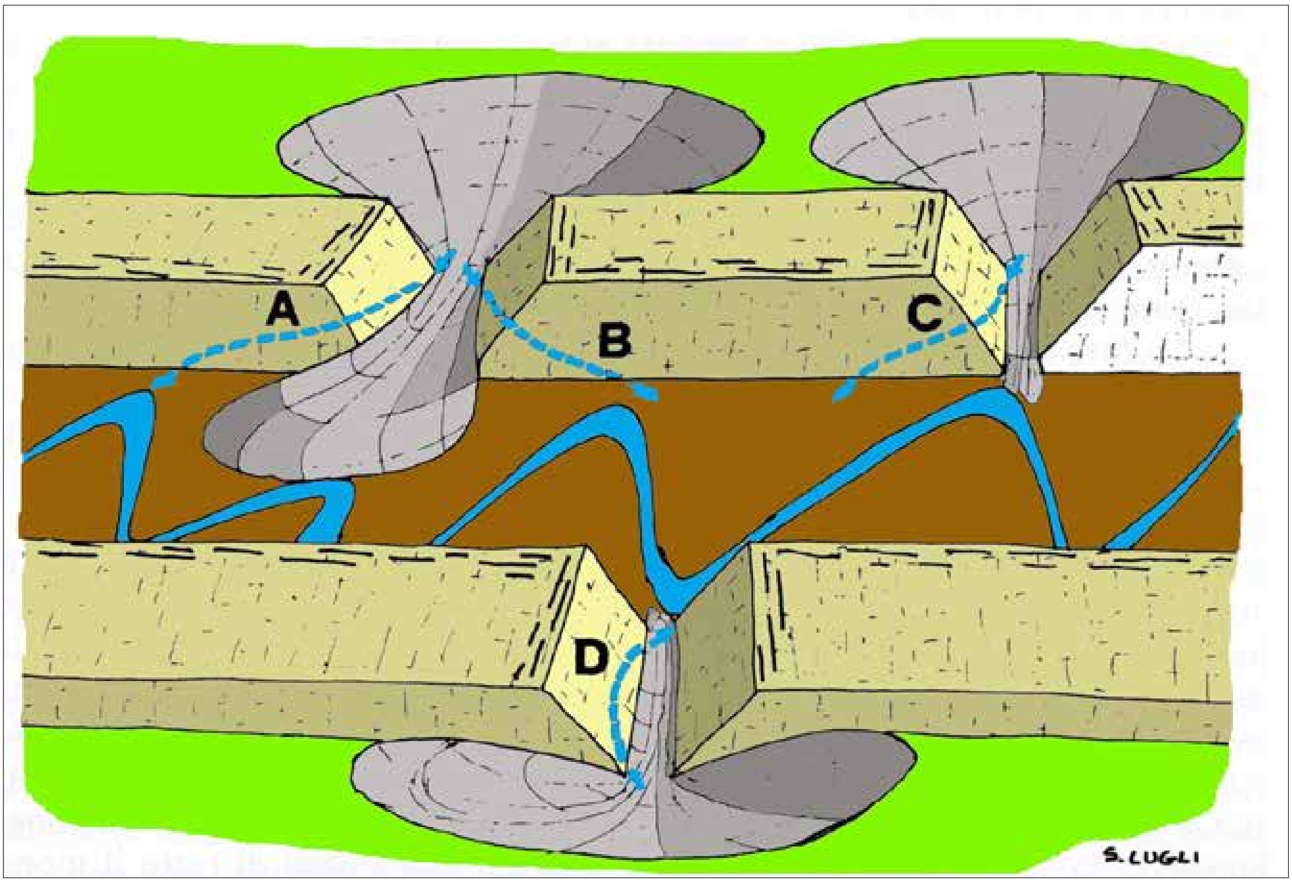
Some caves disappeared, such as the Tanone di Secchia: "in 1938 the cave opened at the base of the vertical wall, at full level, with a wide mouth […], it measured a width of almost 6 m with a height of at least 4. In 1945 […] the entrance appeared almost completely blocked by a huge block […]. In August 1948, after further landslides of mostly minute materials, a poorly traversable hole remained. Today perhaps the cave is already closed or in the process of closing completely". The cave is officially extinct, and this is the fate that will touch in a more or less distant future even at the suggestive entrance of the Tanone Grande della Gacciolina, modified by recent collapses (winter 2022), that we will visit.

In the same way, new caves open and then close again, like the cave above the Poiano springs revealed in 1942 by a large rockfall, which also modified the two easternmost mouths of the salt springs. This cave also went extinct. Just a few days ago a new collapse modified again the springs area (2 October 2022).

The effects of climate change are now adding to the rapid processes linked to geological factors. The frequency and intensity of extreme precipitation events have already increased and may increase in the future by concentrating in short periods. This means that we will see an increase in the collapses of the rock walls inside the caves, but also outside, along the spectacular gypsum slopes along the valley, often revealed by streaks of dust left by recent rockfalls.



The main features influencing the karst evolution of the Secchia River Valley. A) anhydrite core, B) gypsified rim, C) shale formations generating mudflows, D) mudflow deposit, E) slope-parallel fractures (Lugli 1993).



The hypogean bends controlled by mudflow deposits in the Secchia River Valley. Composite systems: A) Talada karst system, B) Melli system, C) Rio dei Tramonti e Cà delle Ghiaie systems, simple systems: D) Dorgola and Rio Vei systems (Lugli 1993).

The hypogean bends (anse ipogee)

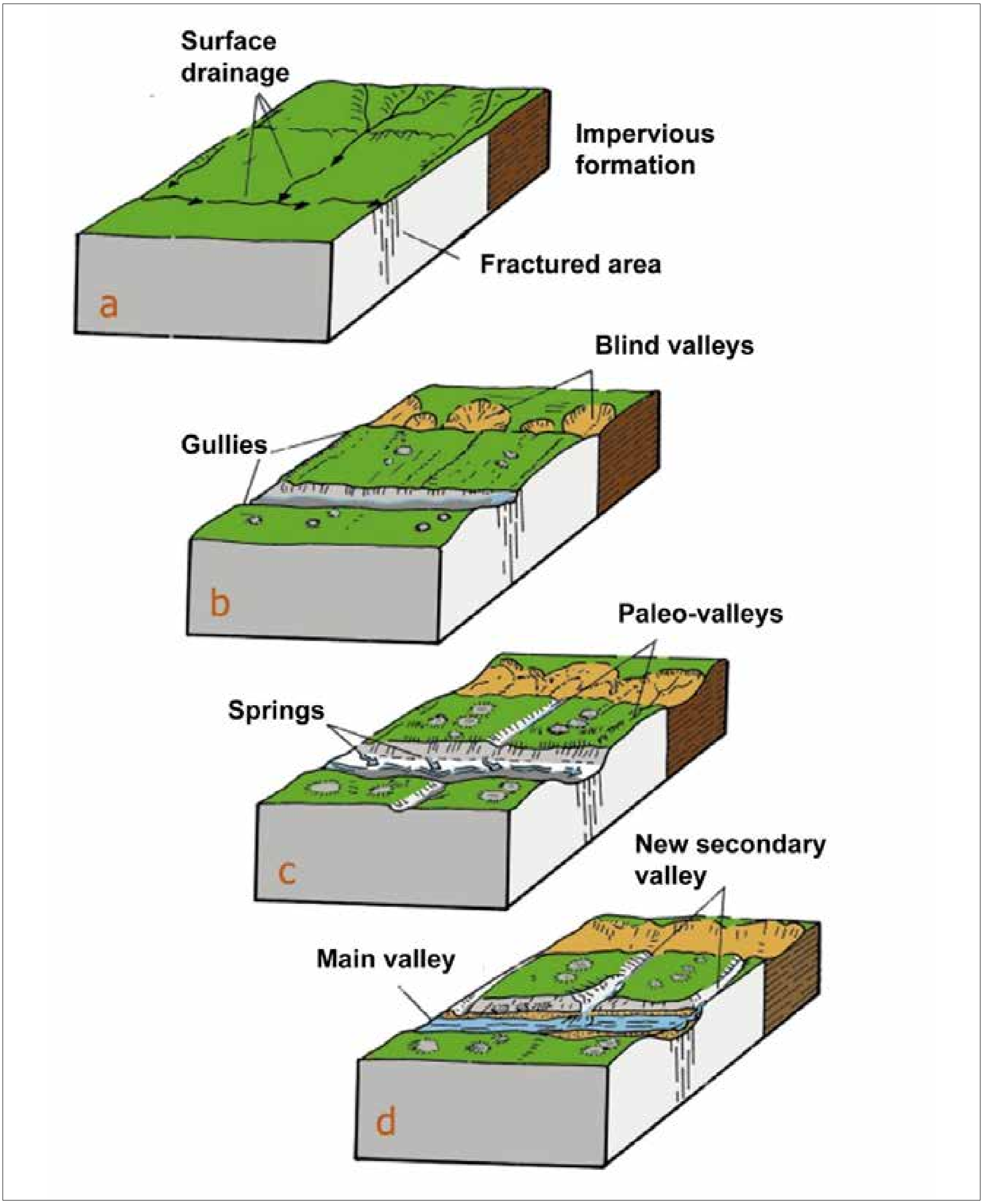
The hypogean bends are complex karst systems crossing the outcrops of the upper Secchia River Valley. They are fed by the superficial streams and run just few tens of meters from the rock-wall along directions strictly parallel to the external fluvial valleys. The streams rise back to the valleys after a variable hypogean pathway, which is controlled by:

- vertical tension fractures cutting the slopes of the evaporite outcrops. They are due to the rapid deepening of the evaporite valleys by fluvial erosion and dissolution;

- superficial anhydrite to gypsum hydration mechanisms preventing the conduits to penetrate the core of the outcrops;

- alluvial terraces and fan-shaped mudflows originated from the shale formations surrounding the evaporite ridges. They may act as impediment to the resurgence of the conduits by sealing some of the fracture systems.

The hypogean bends can be classified as: 1) simple, when the water rises back to the same valley where sinking takes place; 2) composite, when the resurgence occurs in a different valley due to presence of alluvial or mudflow deposits causing the capture of the water flow into another orthogonal fracture systems.
(Stefano Lugli)



Evaporite karst evolution in the Secchia River Valley: a) initial stage; b) blind valleys formation; [c] fluvial valley development; [d] new secondary valleys evolution (Forti and Francavilla 1990).

The woodland formations are dominated by *Quercus pubescens, Ostrya carpinifolia*, *Fraxinus ornus*; these species are associated with *Acer campestre, Sorbus domestica, Sorbus torminalis, Quercus cerris*.

Gypsum outcrops and peculiar morphologies lead to the colonization of species of colder and more humid climates, of warmer climates or of colder and dry climates.

The Flora is particularly rich in biodiversity: here there are 550 species; the habitats of Rete Natura 2000 surveyed are 21: the spring and resurgent, the rupicolous, scree and cave environments stand out.

The conservation status can be considered good. These habitats of Directive 92/43/EEC best characterize the property:

• *Sparse thermo-xerophilous vegetation of southfacing cliffs* (6110* "Rupicolous calcareous or basophilic grasslands of the Alysso-Sedion albi");

• *Marsh vegetation in the Poiano spring* (7210* Calcareous fens with Cladium mariscus and species of the Caricion davallianae");

• *Chasmophytic vegetation of rocks exposed to the north and near the entrances of the caves* 8210 "Calcareous rocky slopes with chasmophytic vegetation");

• *Caves* (8310 "Caves not open to the public");

The area of the Fonti di Poiano was the subject in 2014 of an important naturalistic restoration carried out successfully, for the restoration of the hydraulic and environmental conditions in order to increase biodiversity that was once much more significant (LIFE GYPSUM Project).

On the right side of the valley, the gypsum slopes are less arid with the with the presence of rupicolous species such as *Campanula rotundifolia, Rhamnus saxatilis*, and especially the very rare *Saxifraga callosa*. On the opposite side, the major slope, lower stability and the different exposure, allow the presence of rupicolous species of warm and arid environments with real excellences such as *Helianthemum oleandicum subsp. italicum, Ononis rotundifolia* and the very rare *Artemisia pedemontana*, species alpine, which is the only Apennine station here.

In the less steep areas we find typical habitats with a prevalence of species with an annual cycle; especially crassulaceae mainly of the genus *Sedum* or *Petrosedum*.

There are also deposits of chalky debris, rare and protected species such as *Asplenium scolopendrium*.

The fauna is homogeneous if compared to the one in the rest of the territory of the Park (ungulates, birds of prey, wolves); *Osmoderma eremita* and *Euplagia quadripunctaria* are present among insects.

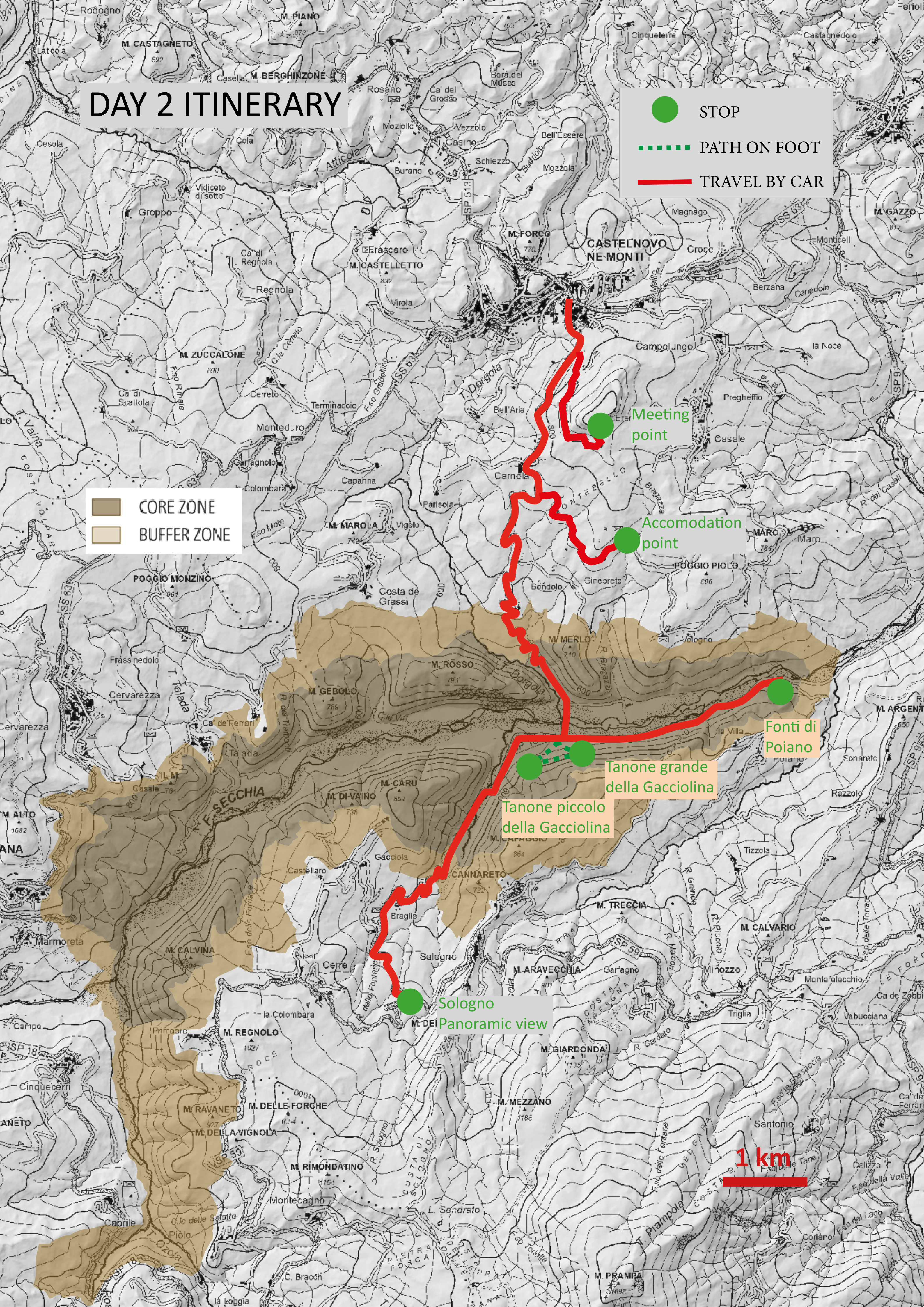
There are amphibians *Speleomantes italicus* and *Triturus carnifex*.

The fauna of the groundwater includes significant amount of species, called stygobias - and 7 were found here for the first time, some of ancient marine origin.

Niphargus poianoi, a small crustacean and *Duvalius guareschi,* a beetle, are endemic of this area.

In the caves we find important colonies of bats; there are 16 species, 7 of which are Community interest, some of which in reproductive or hibernation colonies, as *Rhinolophus ferrumequinum, R. hipposideros*, *Myotis myotis, Myotis blythii, Barbastella barbastellus, Myotis bechsteinii.*

(Alessandra Curotti, Massimiliano Costa)


DAY 2 ITINERARY
STOP
PATH ON FOOT
TRAVEL BY CAR
CORE ZONE
BUFFER ZONE
Meeting point
Accomodation point
Fonti di Poiano
Tanone grande della Gacciolina
Tanone piccolo della Gacciolina
Sologno Panoramic view
1 km
CASTELNOVO NE'MONTI
F. SECCHIA

Day 2

Sologno panoramic view

From this observation point we see one of the most iconic panorama of the entire Apennine chain. Several outstanding geological features are visible from here.

The Sologno viewpoint, one of the most iconic view of the entire Apennine chain (photo S. Lugli).

<u>A huge rock prism: the Pietra di Bismantova</u>

The spectacular rock prism of the Pietra di Bismantova (Bismantova Stone) appears to float on a sea of shale sediments. It has a thickness of about 120 m and reaches an altitude of 1047 m above sea level. Originally the sediments covered also the adjacent areas, but the dismembering of the platform and the strong erosion phenomena, combined with the sliding of the underlying shales, isolated the rock prism with high vertical slopes.

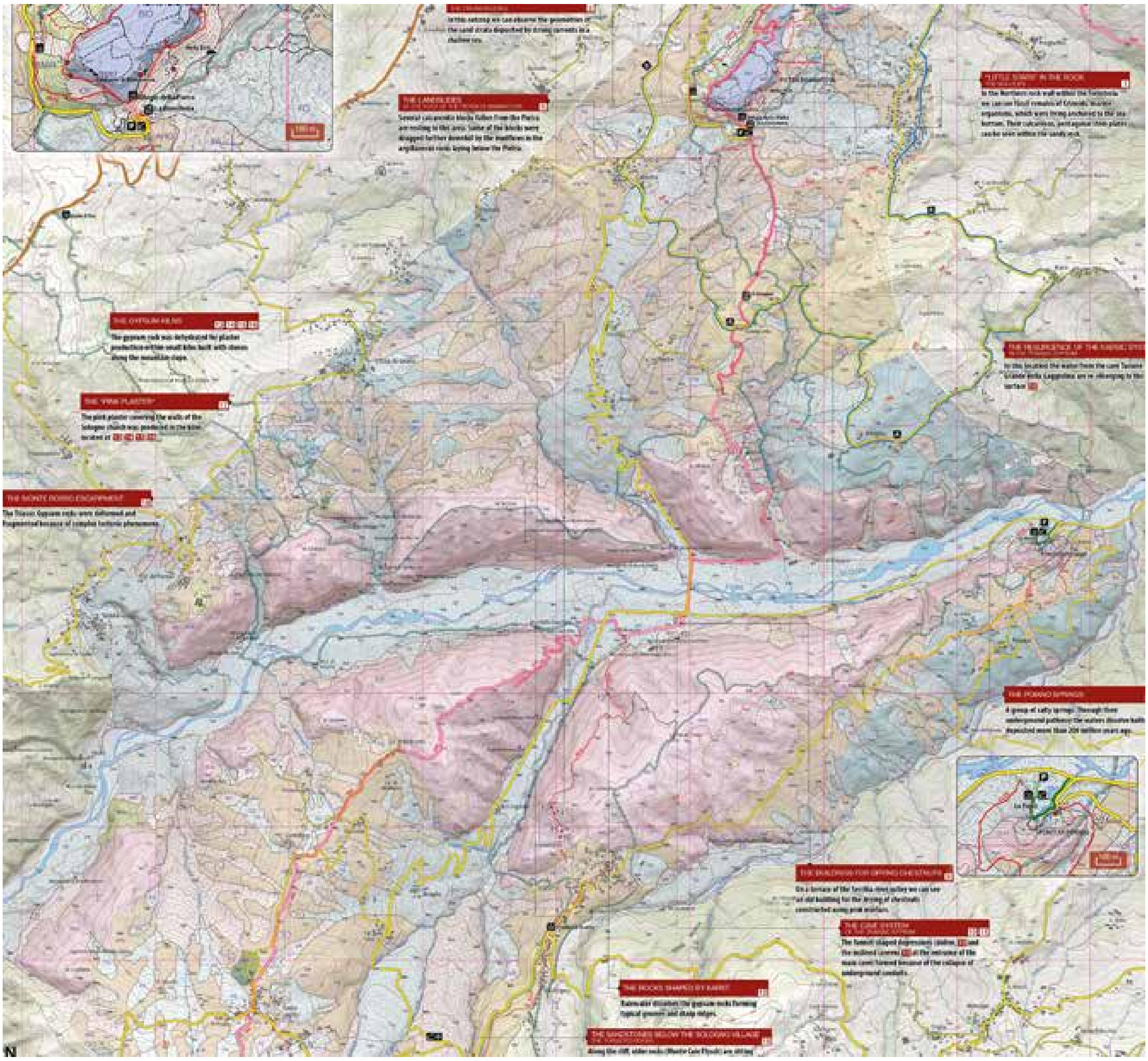
The rock is a biocalcarenite, a sandstone (-arenite) made out of carbonate sand grains (-calc-), which are fragments of marine organisms (bio-). The grains of the sand are mainly fragments of shells of marine organisms: mollusks, echinoids (sea urchins) together with Crinoids (sea lilies), bryozoa, coralline algae, foraminifera and fish teeth, especially sharks. The sand was deposition at the bottom of a shallow temperate sea, 20-40 m deep, on a carbonate platform.

Geological Formation: Pantano Fm. (Bismantova Group)

Age: Burdigalian (Miocene), 16-20 million years ago.

<u>A geological twisting: the Monte Rosso escarpment</u>

Today the evaporite strata appear strongly deformed and fragmented because they were buried below a thick pile of sediments and because of the intense strain phenomena related to the collision between the European and the African plates. The evaporite rocks are easily deformable and acted as the main detachment horizon along which huge rocks masses were thrusted into stacks so that one lies on top of the other forming the uplifting Apennine chain.



Geologic map of the Secchia River Valley.

The result of the complex tectonic phenomena in visible in the Monte Rosso vertical wall in front of us, which shows a chaotic juxtaposition of deformed strata fragmented by the dissolution and removal of former halite layer.

Halite is more soluble than gypsum and is present intermixed with the gypsum, but today it remains only underground at depth, where it is actively dissolved by the meteoric waters infiltrating the gypsum rocks. This is the reason why the waters of the Poiano Springs (located a few kilometers at our right) are salty.

<u>The hydrogeological instability: large landslides in the clay formations</u>

We are now standing on a very large landslide (mudflow), which was re-activated in 1996 by rainfalls. The movement reached up to 1.5 m per day and came to an end after about 2 months. The sliding exposed the ancient white fir trunk dating back to 2.400 years ago (radiocarbon dating). Other wood fragments were recovered from drillcores: the oldest one was found at 24 m depth and dates back to 5200 years ago, evidence that multiple landslides accumulated in different times, burying the forest growing at the surface.

Emilia Romagna is among the most landslide-prone area in Italy: over 20% of the hilly-mountainous territory is affected by more than 70,000 landslides. This situation inevitably affects the urban and infrastructural systems of the local communities, causing widespread damage, but fortunately few victims, due to the slow kinematics of landslides.

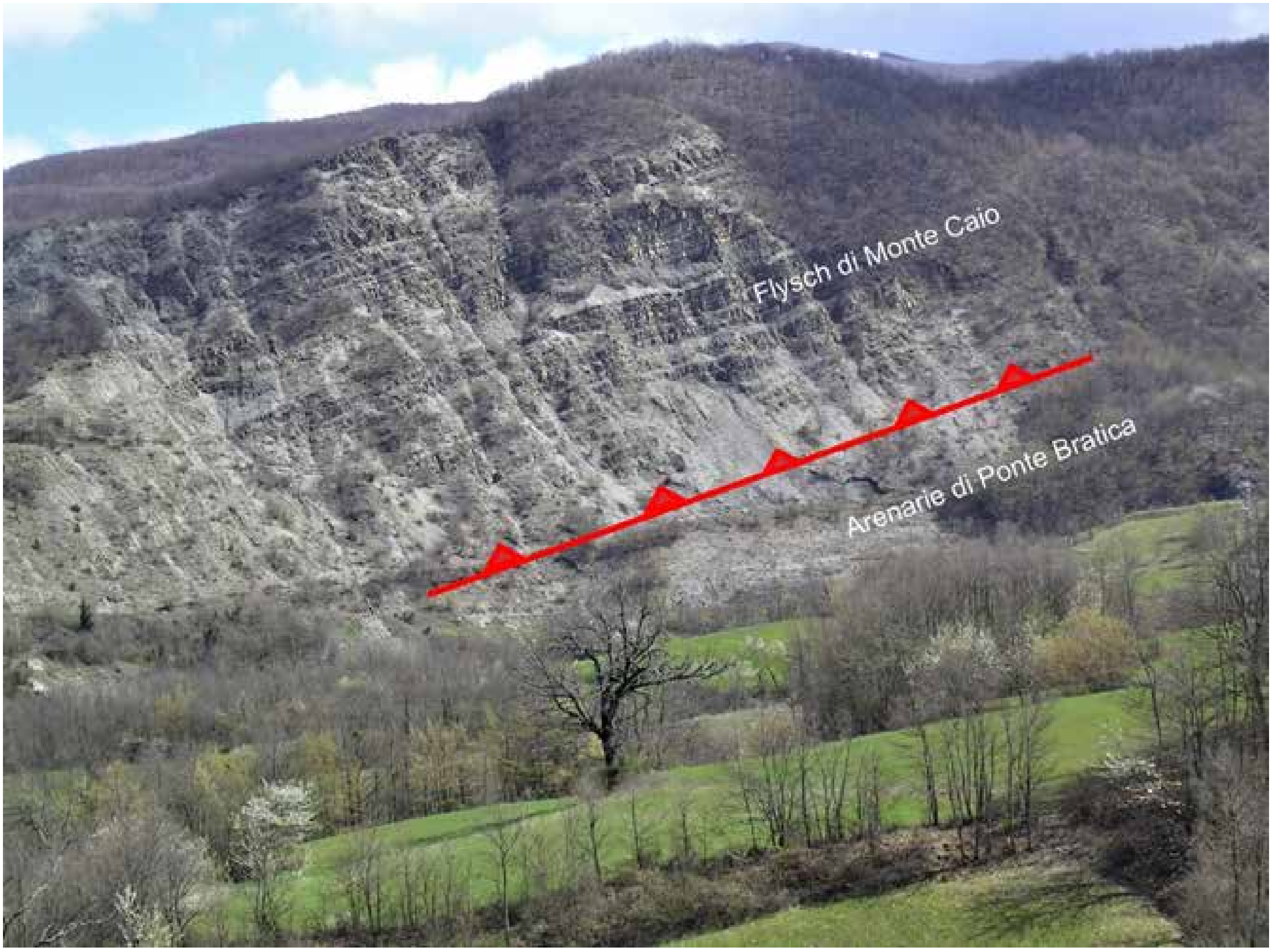
<u>Thrusting rocks: the sandstones below the Sologno village</u>

In the escarpment under the village of Sologno we can observe the contact between the Arenarie di Ponte Bratica (below) and the Flysch di Monte Caio (above).

The Ponte Bratica sandstones crop out at the base of the escarpment and are formed by layers of sandstone alternating with pelites (fine-grained sediments) of turbiditic origin, ie, generated by submarine landslides in the upper Oligocene (28-23 million years ago). The Flysch of Monte Caio consists of calcareous-marly and arenaceous turbidites deposited at the end of the Cretaceous (84-66 million years ago).

The presence of ancient rocks above younger rocks indicates that the contact between the two formations is tectonic: the oldest formation did override the most recent ones due to the complex phenomena related to the collision between the African and the European plates.

(Stefano Lugli)



The rock thrusting below the Sologno village (photo S. Lugli).

Gypsum is soluble in water and meteoric and stream waters flowing into fractures enlarge them progressively by dissolution. The results are karst features such as bowl-shaped depressions called doline and karst caves: tane, tanoni (lairs) and pozzi (shafts).

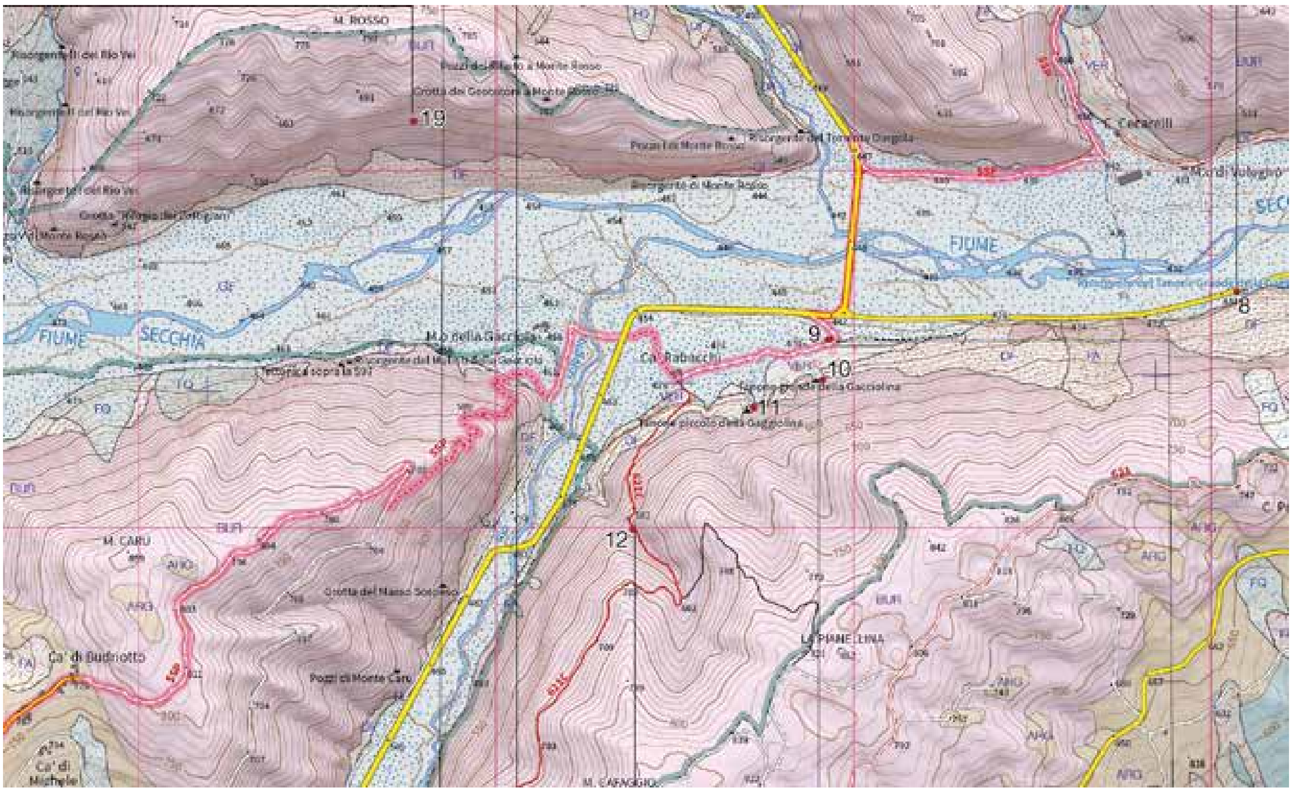
The waters of the Sologno stream, enter the gypsum hill in a location called sinkhole, forming the Tanone Grande and Tanone Piccolo della Gacciolina karst system, a very large hypogean bend. For this reason, the streambed section downstream of the sinkhole is commonly dry. The underground waters reach back the surface a few kilometers downstream, forming a resurgence, and flow into the Secchia river.

A few kilometers to the west of the map is located the Monte Caldina karst system, which is the deepest gypsum cave in the world, reaching the record depth of 265 m.

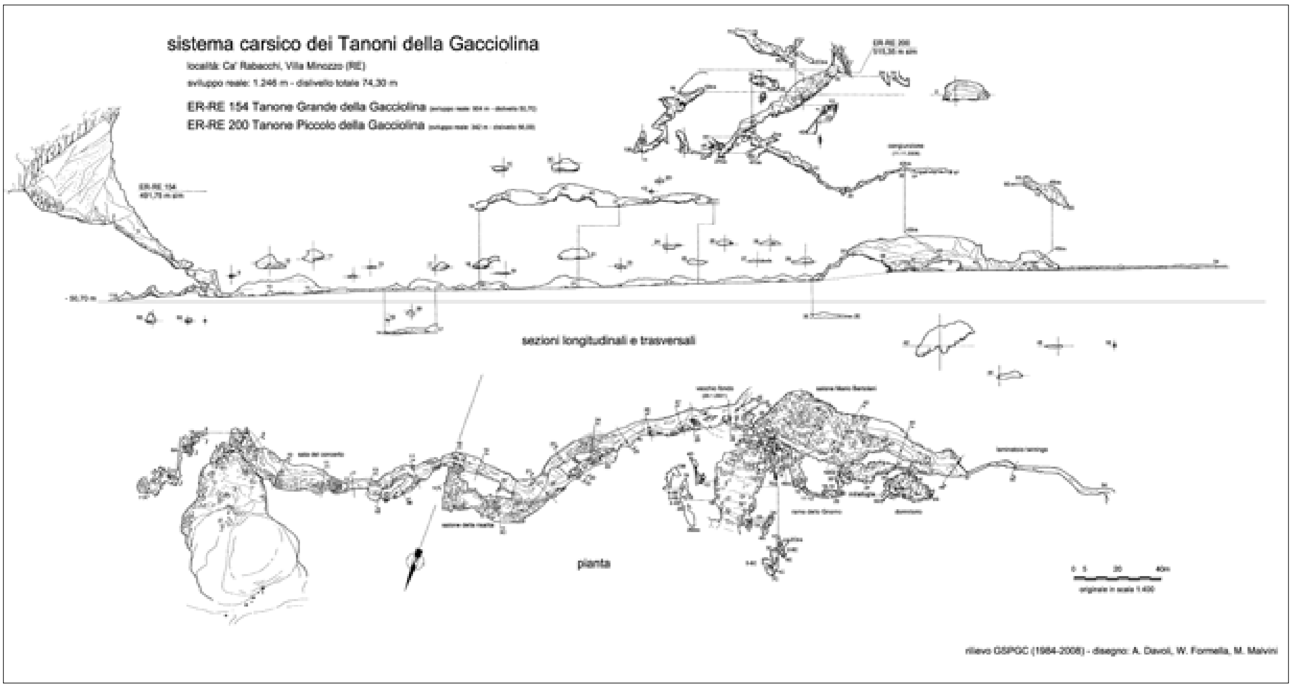
The Tanoni karst system: spectacular cave entrances

The complex karst system is in communication with the outside through a spectacular funnel-shaped depression (doline) formed by the partial collapse of some sections of the cave (10). Collapses are common in gypsum walls, the most recent dates back to the beginning of 2022.

(Stefano Lugli)



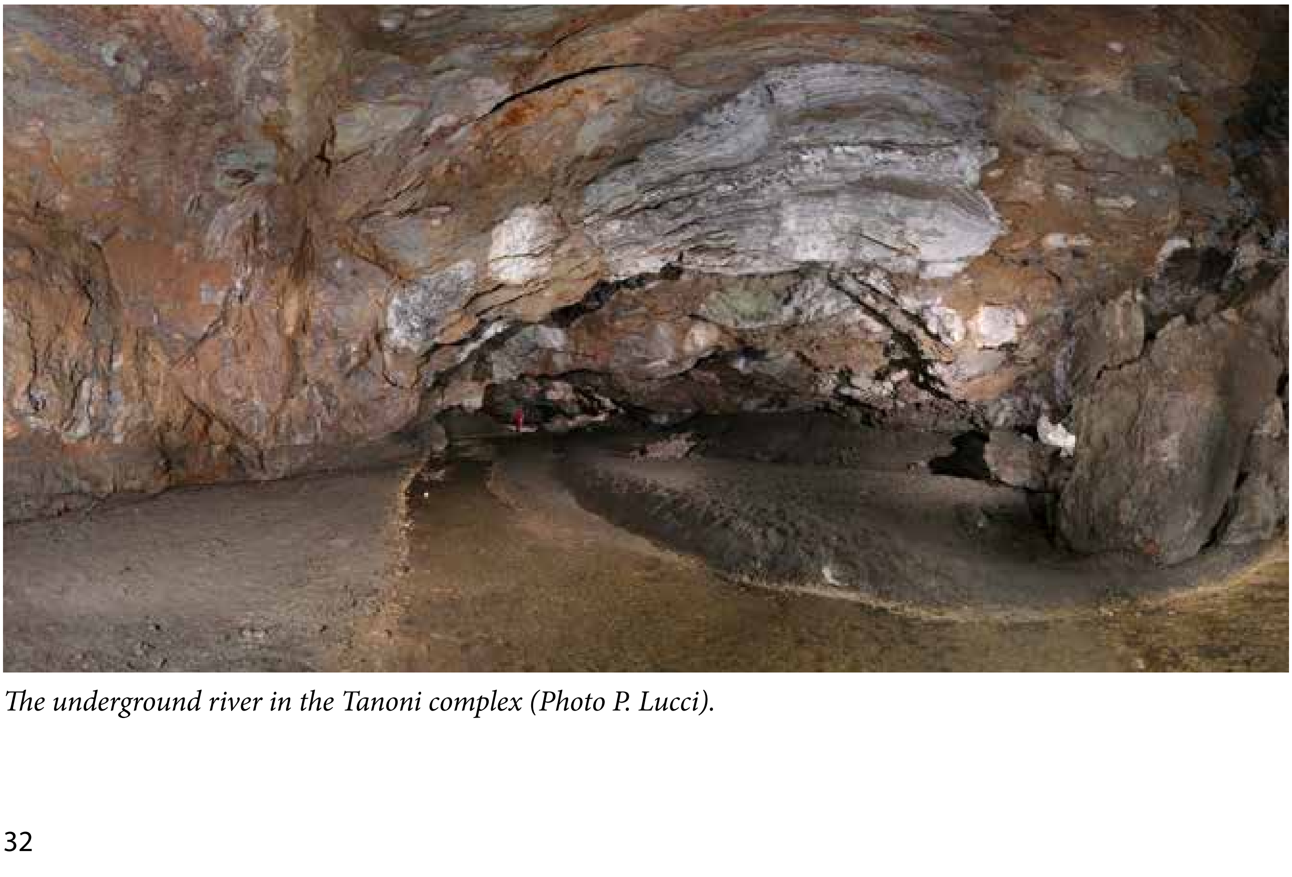
Location of the Tanone grande and Tanone piccolo della Gacciolina karst system (points 10 and 11).



Map and section of the Tanone grande and Tanone piccolo della Gacciolina karst system.

The entrance of the Tanone piccolo della Gacciolina cave (photo P. Lucci).

The largest collapse room of the Tanone piccolo della Gacciolina karst system (photo P. Lucci).



The underground river in the Tanoni complex (Photo P. Lucci).

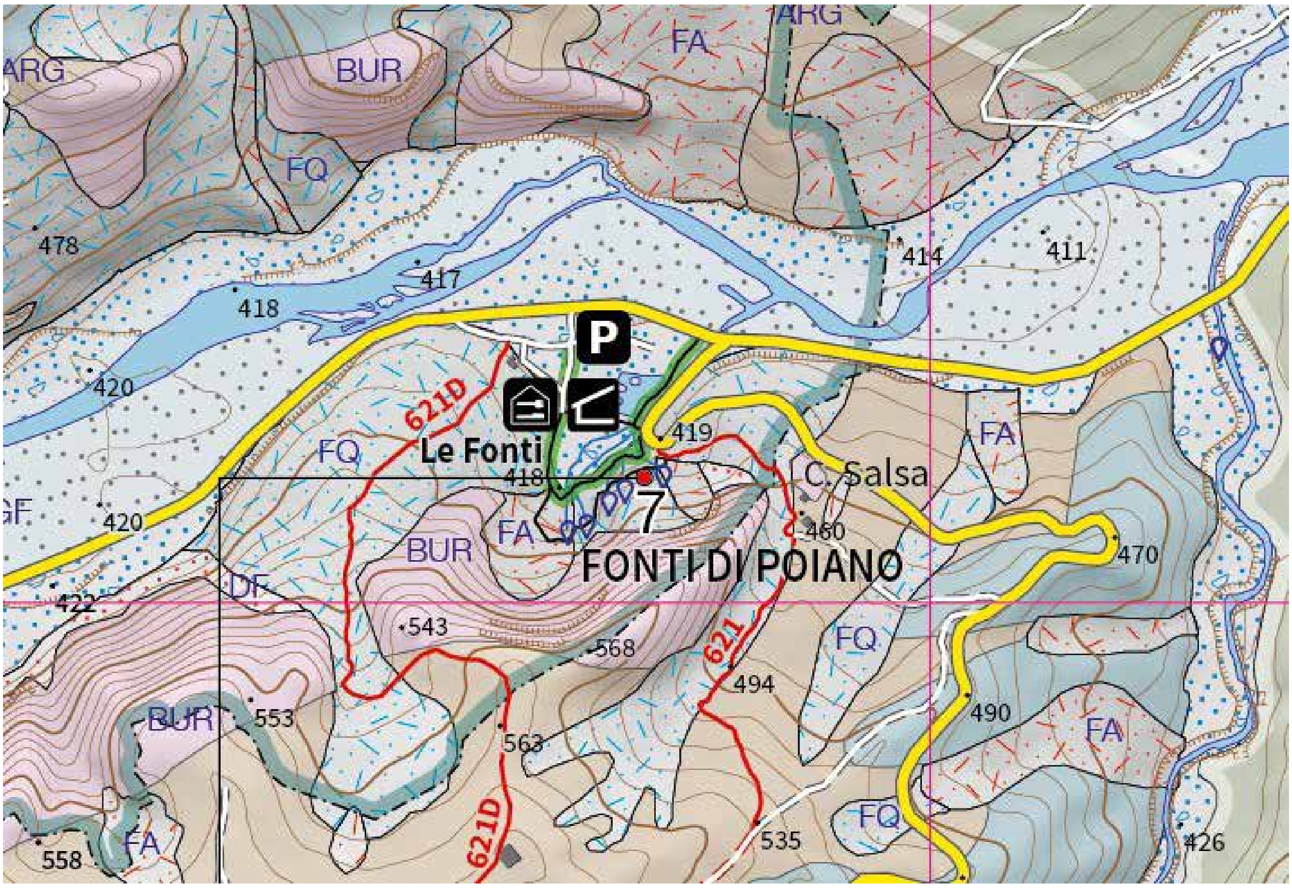
The entrance of the Tanone grande della Gacciolina cave (photo P. Lucci).

Poiano springs: salt from a vanished ocean

The waters infiltrating into the karstic mountains are forced to come up to the surface in the lowest segment of the valley where the gypsum rocks terminate and only impermeable shale sediments are present. In this location several springs discharge into the Secchia river an average 400 liters per second of water containing about 6 grams per liter of salt and 3 grams per liter of gypsum. The salt that makes the salt springs was deposed over 200 million years ago in the ancient Tethys Sea, which has now disappeared due to the collision between the African and the European plates. Halite is more soluble than gypsum and is present today only underground at depth, where it is actively dissolved by the meteoric waters infiltrating the gypsum rocks. This is the reason why the waters of the Poiano Springs are salty.

This is also another spot where the rapid evolution of the karst landscape is dramatically evident. The scars left by the 1942 rockfall are still clearly visible at the eastern side of the outcrop. The most recent rockfall happened the 2nd of October 2022.

(Stefano Lugli)



The Poiano springs area.

Aerial view of the Poiano salt sprigs. The scar left by the 1942 rockfall are visible at center. The springs area is also surrounded by fan-shaped muflow deposits.

One of the springs of the Poiano karst area (photo P. Lucci).

The Triassic gypsum outcrop, located in the higher Apennines and far away from the Aemilian way and the urban areas of the Emilia-Romagna region, experienced, through the centuries, a low level of human pressure and anthropization, conserving the original wilderness. Human activities here focused on the exploitation of gypsum as building material and plaster, using traditional, and not industrial, approaches to the quarrying. Agriculture, breeding and chestnut-growing, fully integrated in the rural landscape, were the other activities attested. Currently, because of the process of mountain depopulation inset in particular since the 1950s, the residents here are few; among them, the old age index is high.

(Stefano Piastra)

Firing of the Triassic gypsum using a traditional kiln to produce pink mortar and plaster for the restoration of historic buildings of the Sologno village (Photo S. Lugli).

The pink mortars and plasters

Gypsum is a useful material for construction. Dehydrated into kilns, gypsum turns into a powder (scagliola), which mixed with water hardens and can be used to produce mortars and plasters. The gypsum of the Secchia valley was traditionally burned in small cylindrical kilns (fornelle) built with blocks of stone leaning against the mountain slopes. Italy and Spain boast the greatest historical tradition in the use of plaster and share another unusual record. The fired gypsum produced in the villages of Sologno (Reggio Emilia) and Albarracín (Teruel) has completely exceptional characteristics, unique in the world. The mortars and plasters produced here, traditionally for local use, do not show the typical white appearance, but are pink in color. This phenomenon is due to variable quantities of iron minerals inclusions of the gypsum stone, which ensure chromatic nuances ranging from pale pink to bright pink. The ancient gypsum stone, evidently impure, also contains other spectacular inclusions. These are perfectly formed bi-terminated quartz crystals that can reach a few centimeters in length. In the Secchia valley the crystals are black, while in Albarracín they are predominantly red. The plasters and mortars of these places therefore, in addition to having unique chromatic characteristics, are naturally embellished with beautiful crystals, embedded like precious stones in the buildings walls. On our way to visit the entrance of the Tanone Grande della Gacciolina karst system, over a terrace of the Secchia river, we will see the remains of an old building for the drying of chestnuts constructed using pink mortars. Pink plaster covers also the walls of the old buildings of the Sologno village, including the church.

In recent years, the local community revisited the traditional production techniques of pink mortars and plasters to be used for the restoration of historic buildings.
(Stefano Lugli)

Large bi-terminated black quartz crystal (1 cm across) embedded like a precious stone in the pink plaster covering a house dating from last century in the Sologno village (Lugli 2019).

Messinian Gypsum:

Bassa collina reggiana (CS2), Gessi di Zola Predosa (CS3), Gessi bolognesi (CS4), Vena del Gesso romagnola (CS5), Evaporiti di San Leo (CS6), Gessi di Onferno (CS7)

Geological setting

The Messinian salinity crisis

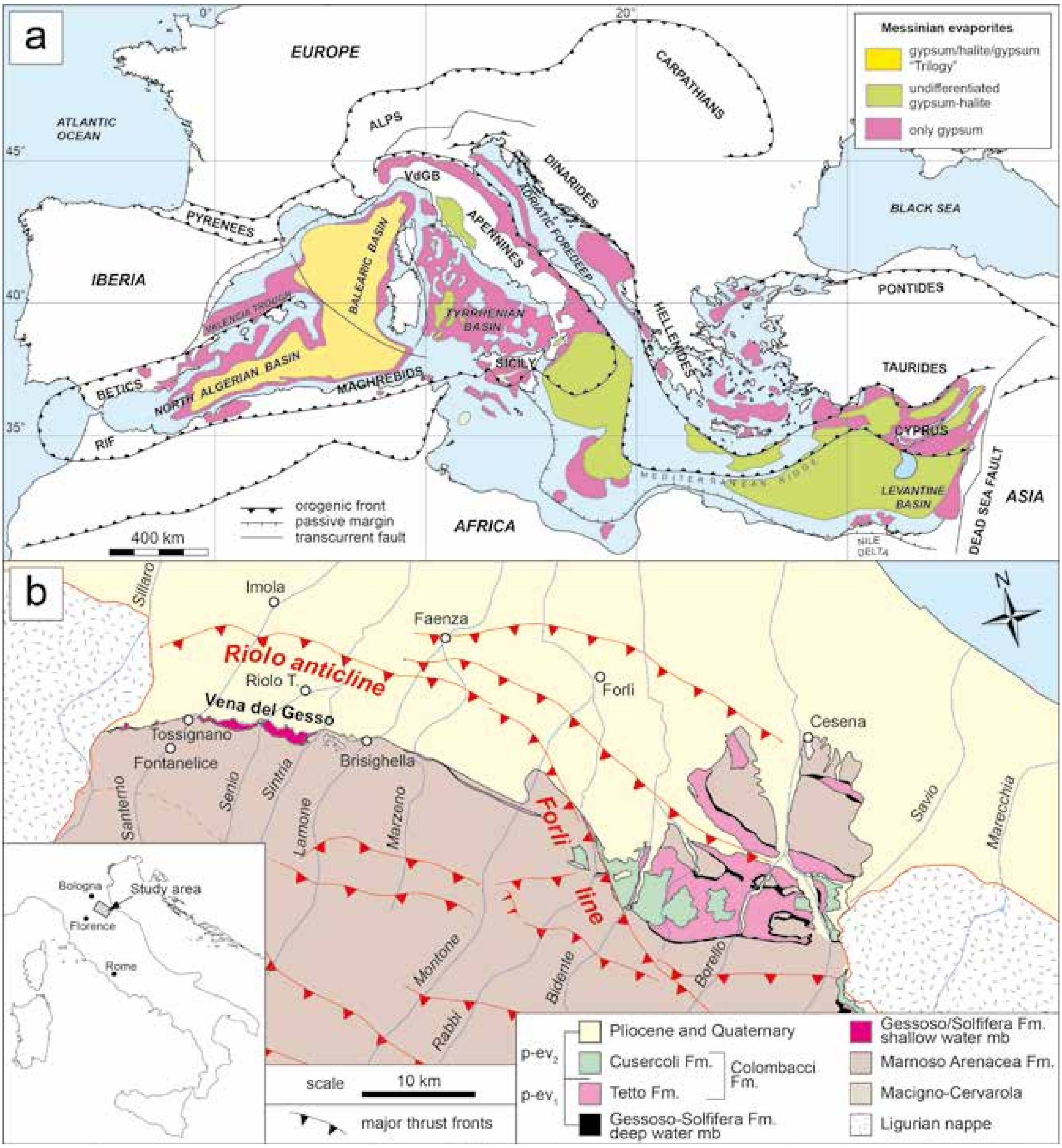
The younger gypsum of the nominated property belongs to the Gessoso-solfifera Formation of Messinian age (Latest Miocene). Also called Primary Lower Gypsum (PLG), it was deposited during the first stage of the salinity crisis. The Messinian salinity crisis is the most dramatic event in the history of the Mediterranean Sea. It was an ecological catastrophe that caused the disappearance of almost all forms of life from our sea. Between 5.97 and 5.60 million years ago (Messinian, Upper Miocene) the Mediterranean turned into a huge salina. The movement of the African plate towards the Europen one caused the reduction in size of the Strait of Gibraltar and the negative water balance, which still characterizes our sea due to intense evaporation, was no longer compensated by the inflow from the Atlantic Ocean. Salinity increased dramatically until the evaporitic minerals crystallized. Between 5.55 and 5.33 million years ago the extremely salty waters were then replaced by fresh and brackish waters and our sea became a Lago mare (sea lake). The extraordinary anomalous conditions of the salinity crisis lasted for about 640 thousand years and determined the formation of over one million cubic kilometers of gypsum and salt in the marginal areas and in the deepest basins.

Gypsum accumulated in shallow (<200 m depth) and semi-closed marginal basins of the Mediterranean, driven by astronomically-controlled climatic oscillations.

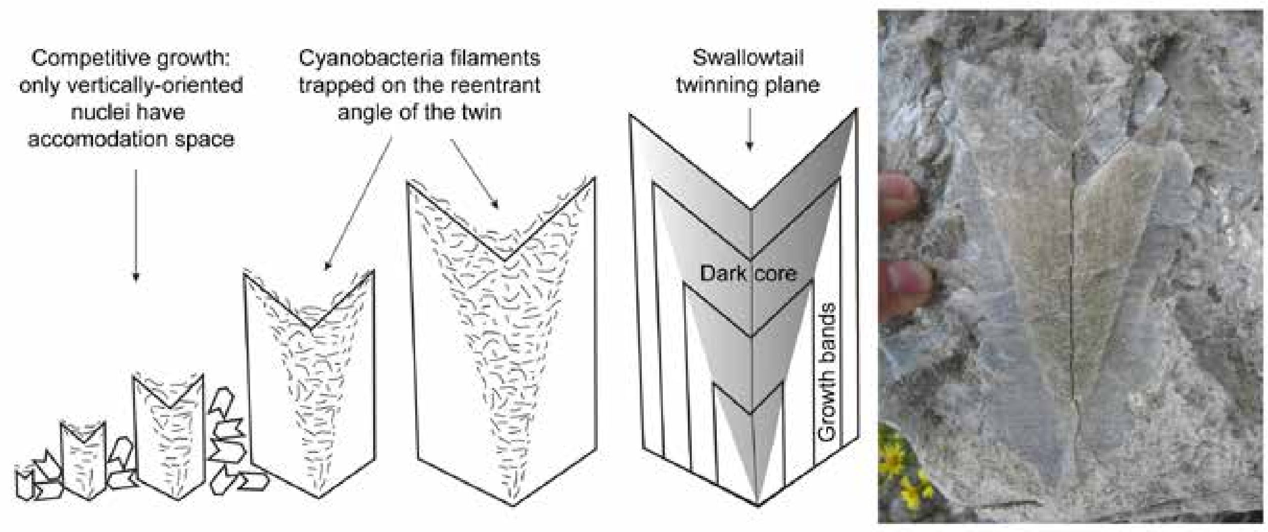
The gypsum crystals

The gypsum crystals, also called selenite, present numerous extraordinary aspects. First among these is the considerable size of the crystals that may exceeds one meter. The second is the presence of e filaments inside them with shape recalling that of spaghetti. The selenite crystals are semi-transparent but the central area is cloudy, full of filaments of organisms that lived at the bottom of the basin and were trapped during growth. This is an exceptional case of cyanobacteria and/or sulphide-oxidizing bacteria fossilization in gypsum. The excellent state of preservation of organic matter made it possible to analyze the genetic material of cyanobacteria, the oldest example ever recorded to date. Only these microorganisms and a few others were able to survive the high salinities of the Mediterranean during the salinity crisis about six million years ago.

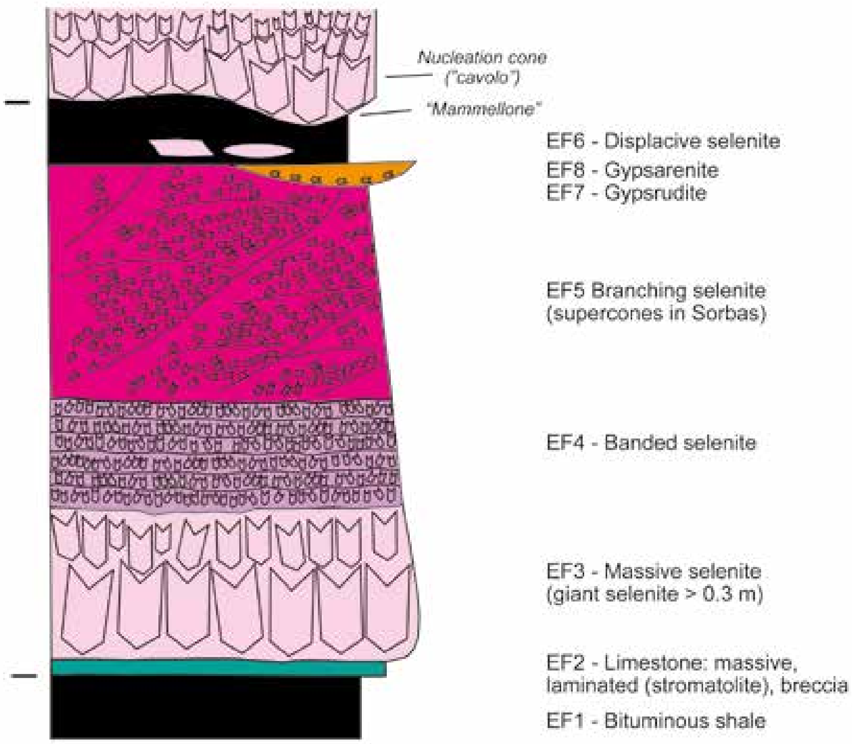
The gypsum crystals of the Vena del Gesso are also famous for their crystalline habit, which conists of “arrow head” or “swallow tail” twins. One of the most striking features of the selenite layers is that the crystals are vertically oriented with the re-entrant angle of the twin pointing upward and the tip downward. This peculiar vertical arrangement can be explained by the competition for the space of the crystals which only favored the growth of the nuclei oriented upwards, the only possible free space from the bottom of the basin. All other randomly oriented crystals terminated their growing against those oriented vertically, which were therefore the “winners” of the competition.



The Messinian evaporites in the Mediterranean basin (a) and in the Romagna area (b) from Lugli et al., 2010.



Competitive growth of gypsum crystals (Lugli et al., 2010).



Schematic stratigraphic column of the various types of selenite in Vena del Gesso layers. The inclined crystals of branching selenite indicate the presence of sea currents. The lower gypsum crystals sank into the underlying clay forming structures called cavoli (cabbages) or mamelons (Lugli et al., 2010).

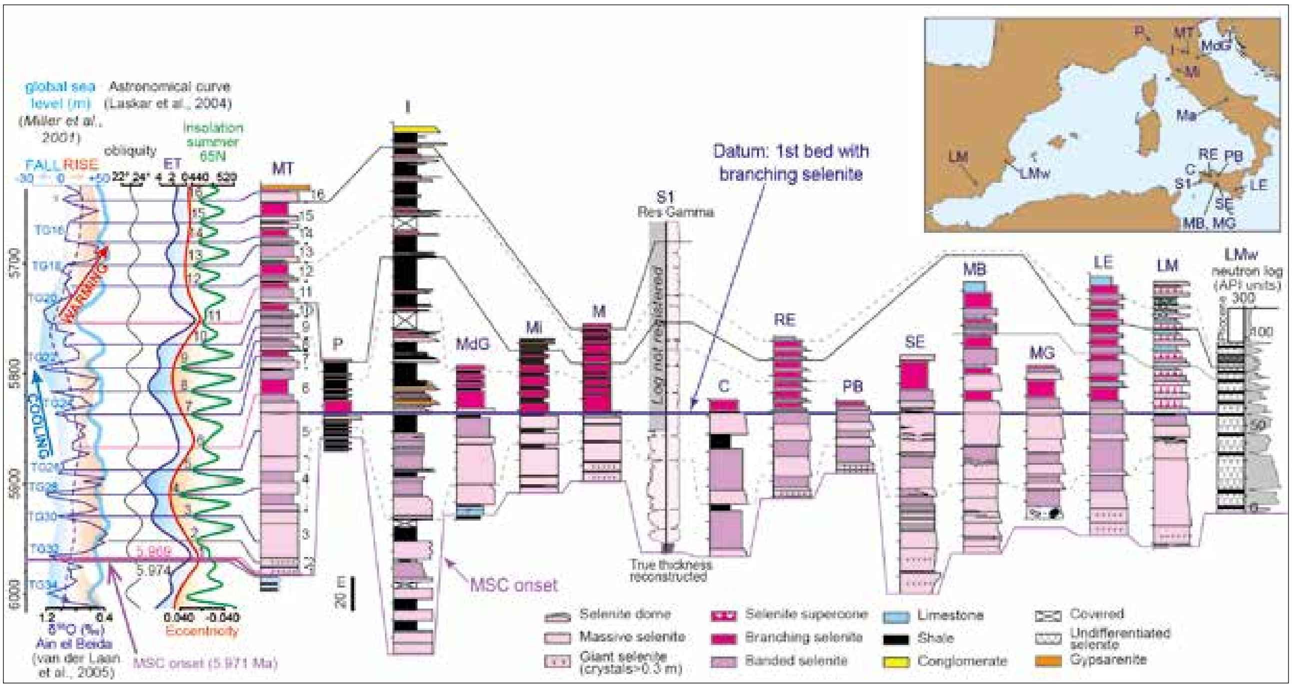
The gypsum layers

The layers display an arrangement of the gypsum crystals related to the gradual increase of seawater salinity during evaporation. At the base of the layer, we always find the largest crystals (massive selenite), but continuing upwards the crystals become smaller (banded selenite). In the upper part, the crystals are no longer vertical but are inclined and are grouped together like the branches of trees (branching selenite). The crystals grew at an angle due to effect of brine currents. These ramified structures appear only from the sixth cycle onwards.

Gypsum astrochronology

One of the aspects immediately catching the eye when observing the gypsum cliffs is the organization in thick layers separated by thin veneers of clay. Up to 16 layers of gypsum make up the Vena del Gesso and the Gessi Bolognesi, the first two, rarely visible are the thinnest, while the third, fourth, fifth and sixth are the thickest. The gypsum formed in the arid climatic phases of the salinity crisis, when the strong evaporation of sea water allowed the crystallization of evaporitic minerals. The clay that separates the gypsum layers was instead deposited in the humid climatic phases, when intense rains caused the runoff of the emerged areas and the transport of the finest particles into the basin. During the wet phases, the gypsum could not form because evaporation was not intense enough. It is one of the most spectacular and best studied cases in the world of sedimentation influenced by natural climatic variations caused by astronomical causes. The perturbations of the orbital parameters of our planet caused by the interference of other celestial bodies change the intensity of the solar energy (insolation) that reaches the surface the Earth over time. These climatic cycles, the so-called Milankovitch cycles, are generated by the perturbations of the eccentricity of the orbit (frequency of 400,000 and 100,000 years), of the inclination of the earth's axis (41,000 years) and the precession of the equinoxes (about 21,000 years). The climatic precession regulated the deposition of gypsum and clays. In the Mediterranean the alternation of arid/humid climatic phases are directly related to the variation of solar insolation governed by the precession of the equinoxes. Each pair of layers consisting of gypsum and clay that we see in the therefore records the deposition that took place over a period of about 21,000 years. The 16 layers of the Gessoso-solfifera Formation, which reaches a thickness of over 200 m in the Vena del Gesso, were deposited in about 340,000 years.

(Stefano Lugli)



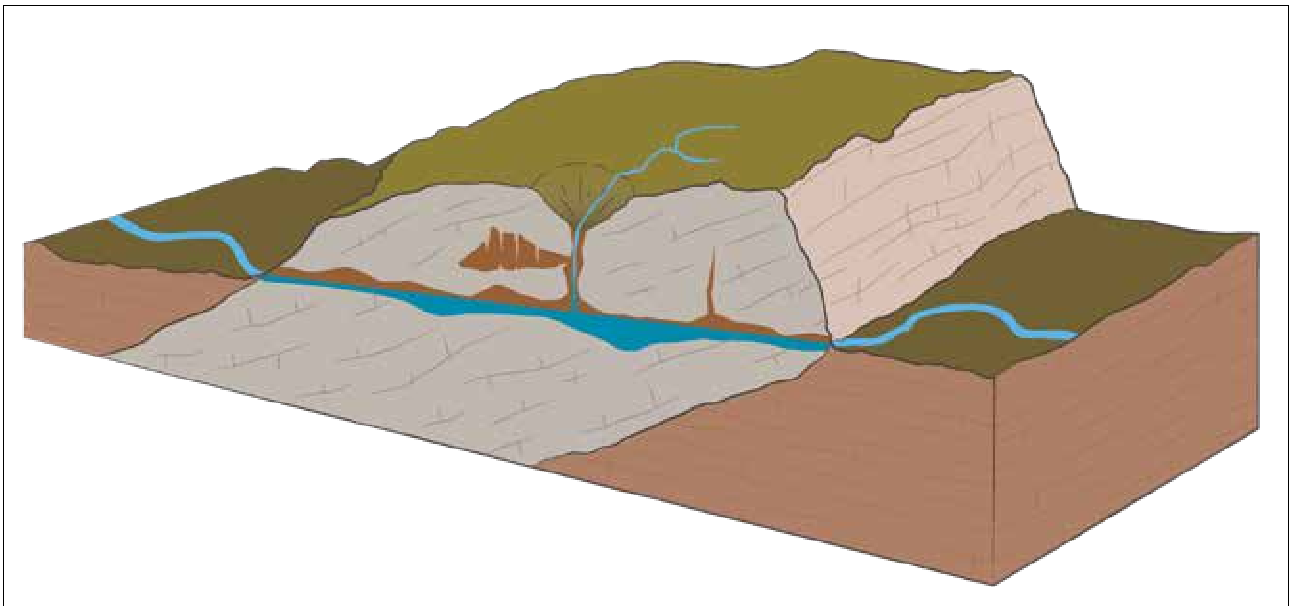
Astrochronology of the Primary Lower Gypsum in the Mediterranean basin (Lugli et al., 2010).

In the Messinian gypsum karstification can occur in a single phase in many epigenic gypsum cave systems, with water entering the soluble evaporite rock, reaching base level quickly, and exiting at the spring. These through-flow systems are sometimes characterized by an underground river flowing on an insoluble (or less soluble) and less permeable underlying unit (e.g., carbonates, marls, shales). These caves generally show a rather simple plan view, with linear and poorly branching patterns often strongly influenced by stratigraphic and/or structural elements (i.e., bedding planes or major fractures). Many large epigenic cave systems are known from the Messinian gypsum areas of Emilia Romagna region. The longest of these is the Acquafredda-Spipola cave system (ca. 11.5 km, Bologna, northern Italy), carved in steeply dipping gypsum beds and following the strike of the strata, with some sections following down-dip or along NW-SE-oriented joints. This cave can be explored from the upstream sink (Acquafredda), almost to the spring, and has a river flowing through it.

The fast evolution of gypsum caves allows them to rapidly adjust to changing climate- or tectonically controlled base level changes. In many of the gypsum caves in Emilia Romagna Region up to five horizontal storeys can be recognized, corresponding to ancient base levels that controlled the position of the underground river. An excellent example of such cave systems is Re Tiberio in the Vena del Gesso Regional Park (northern Apennines), carved during the last 130 kyr, with cave level formation mainly occurring at the end of cold periods, and very limited speleogenesis and some deposition of calcite speleothems during warmer episodes. This climate-controlled cave evolution, coupled with episodic fluvial entrenchment, river terrace formation, and paragenetic episodes in the previously carved cave levels has contributed to the understanding of landscape evolution in this region of the Apennines.

Sulfate rocks are more ductile than other rocks such as limestone, causing the fractures to be more widely spaced. Fracture density also decreases rapidly with depth, explaining why caves in gypsum are often not very deep, barely exceeding 200 m in depth. The deepest known cave is Monte Caldina in the Triassic gypsum outcrops of the Upper Secchia Valley, 265 m deep. Because of the lower tensile strength and more ductile rheology of gypsum, chamber roofs can reach much larger spans in limestones, given equal bed thickness. Because of the large bed thickness in some areas of Emilia Romagna, gypsum cave rooms can reach considerable sizes, such as the Giordani Room in Spipola Cave, probably one of the largest epigenic gypsum cave rooms in the world.

(Jo De Waele, Paolo Forti)



Tipical blind valley, crossing and resurgence system in the Vena del Gesso area.

The fossil resurgence of the Tanaccia cave (photo P. Lucci).

Pendants and sedimentary filling in the Tanaccia cave (photo P. Lucci).

Gypsum crystals growing on carbonate concretions at the Risorgente del Rio Basino cave. (photo P. Lucci).

Stream bend at the resurgence of Rio Basino cave (photo P. Lucci).

Man and gypsum

The Messinian gypsum outcrops of the Emilia-Romagna Region had a strong impact, through the centuries, on the human settlement, economic activities and land use.
The steep morphologies of the slopes, the high incidence of the landslides, the poor fertility of the soils, the presence of subaerial and hypogean karst phenomena, constituted a limiting factor for the local communities, pushing them to adopt specific strategies of adaptation to this peculiar environment. This is the case, for example, of the historical development of non-irrigated cultivations, as there was no subaerial hydrographical network in gypsum areas; moreover, agriculture developed, in particular, in the base of the dolines, where the cultivation was easier and the degree of fertility of the soil relatively higher.
But the most significant dynamics regarded waters: water supply played here a key-role. The fact that the waters of the gypsum karst springs, because of the high content in sulphates, are undrinkable, brought the local population to exploit, for drinkable water, rainwater collected in cisterns. Cisterns were systematically built for rural house located on gypsum bedrock; in the case of entire villages built on Messinian gypsum, we have even, since the Middle Ages, collective cisterns for urban population, where rainwater was considered Commons, as in the case of Tossignano (Vena del Gesso romagnola). This practice, geographically centred in the Mediterranean environment, is very unusual for a region as the Emilia-Romagna on the border between Mediterranean and Continental biomes, where most of the Apennines, made up of sedimentary rocks, are rich in drinkable waters.
Currently, the historical adaptations above discussed, developed in a long-term perspective in the broader context of man-environment interactions, experienced a cultural reconsideration: not only relics of the daily life of the past, but cultural heritage.
If, in most of the cases, gypsum bedrock was limiting for human activities, one of the few economic potentials of these rocks was quarrying: from Roman times to the present day the excavation became one of the cores of the local economy, and the selenite became the basis for a local type of rural architecture, entirely made up of gypsum blocks, mortar and plaster.
Regarding the last decades, the Messinian outcrops of the lower Apennines of Reggio Emilia, the Vena del Gesso romagnola and Gessi Bolognesi, closer, if compared to Triassic gypsum, to the Aemilian way and to the largest cities of the region, experienced, in the last 70 years, an impressive depopulation process, inset by the so-called 'Italian economic miracle' (1950s-1960s): rural population abandoned the primary sector and the mountains, to move to the Po plain and join the industrialization of the region. The gypsum areas, because of the natural limits above discussed, were among the first of the lower Apennines to be abandoned. A direct consequence of this trend was, in recent years, an intense phase of renaturation of the area, which involved both flora and fauna. Currently, most of the Northern slopes of the Messinian gypsum outcrops, originally barren, are covered by dense coppice woods. Gypsum quarries were closed mainly between the 1970s and the 1980s, except for one, Mt. Tondo quarry (Vena del Gesso romagnola), still in activity, identified as the only quarrying site in the region for gypsum.

(Stefano Piastra)

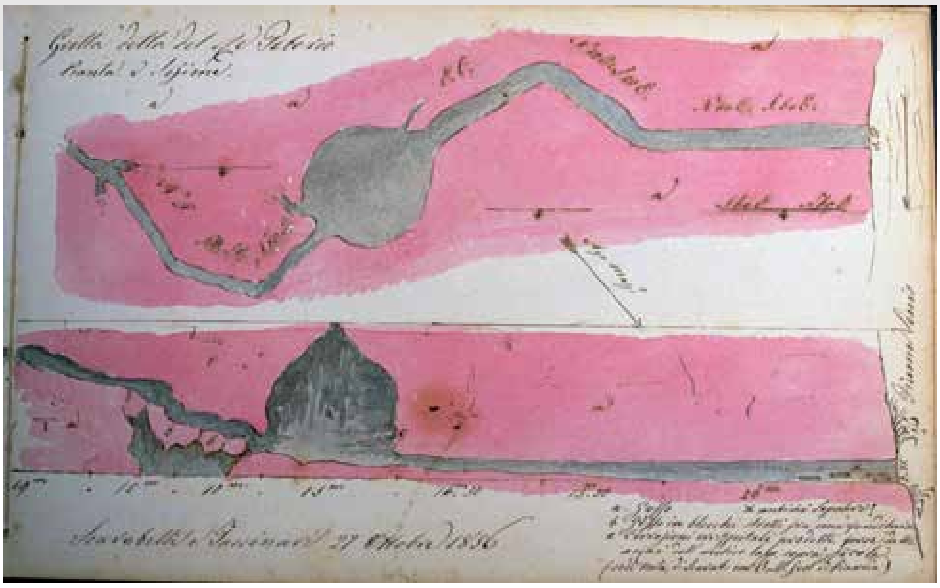
Urban cistern for rainwater, dating back to Medieval times, in Tossignano (Vena del Gesso romagnola) (photo P. Lucci).

The Messinian gypsum outcrop of the Vena del Gesso romagnola in 1944 (aerial war photo by RAF): most of the Northern slopes are barren.

Present-day view of the same area: because of depopulation, the slopes are now covered by coppice woods.

As discussed above, in the Emilia-Romagna region the local communities adapted, in a long-term perspective, to gypsum karst environment.
This meant, for pre-historical period and Roman and Middle Ages, a series of sites, located in Messinian gypsum, significant for man-gypsum interactions.
In particular, between the Copper Age and the Early Bronze Age, the natural cavities, in particular large fossil karst springs, were mainly used as burial sites of the communities living in the neighborhood. These are the cases of Mussina cave (Messinian gypsum outcrop of Reggio Emilia province), Farneto cave (Gessi Bolognesi) and Tanaccia and Re Tiberio caves (Vena del Gesso romagnola). Mussina, Farneto and Re Tiberio caves were among the very first gypsum cavities to be investigated in a scientific perspective at the dawn of the Italian Prehistoric archaeology by a generation of scientists of high-level: Giuseppe Scarabelli (1820-1905), in particular, surveyed extensively Re Tiberio cave and made here, in 1870, one of the very first stratigraphic excavations in the history of Italian archaeology.
In the Emilia-Romagna region, a new phase of human use of the gypsum caves took place during the Iron Age: the Tanaccia and, especially, Re Tiberio Caves (Vena del Gesso romagnola) became natural sanctuaries connected to sacred waters; artificial shelves were excavated in the walls of the caves to host miniaturist pottery, bronze rings and small anthropomorphous statues in bronze, as donations to the deities. Centuries later, during the Middle Ages, the anthropomorphous statues dating to the Iron Age were frequently remelted by counterfeiters to obtain counterfeit coins.
During the Roman Age, the Messinian gypsum areas were located far away from the economic and political focuses of *Regio VIII Aemilia*, whose borders were quite similar to the ones of the present-day Emilia-Romagna Region. In this phase, although geographically marginalized, the Gypsum outcrops of Gessi Reggiani, Gessi Bolognesi and Vena del Gesso romagnola started to be exploited: large quarries were opened to produce blocks as building materials (one has been discovered in Borzano, Gessi Reggiani); thin cleavage fragments of secondary gypsum, known in Latin as *lapis specularis* and used in windows as glass substitute, were quarried in open air and underground sites. In particular, in the last 20 years ca. several caves of the Vena del Gesso romagnola, such as Lucerna cave and Ca' Toresina cave, have been identified as Roman Age underground quarries of *lapis specularis*: their walls were almost entirely excavated to exploit secondary gypsum, and later partially occluded by processing waste of the excavation (grinded gypsum, broken gypsum slabs, clay, etc.).
In the Early Middle Ages, the general crisis (economic, environmental, demographic) which affected Italy had obvious reflections also on the study-areas, where the human presence decreased significantly.
It was during the Late Middle Ages that the situation changed, and human communities returned to settle and to exploit the gypsum zones. As the Middle Ages were a period of general political instability for Italy, the top of the gypsum outcrops, whose morphologies are significantly towering because of the different resistance to erosion and suited to defending, hosted a number of Medieval castles, usually built on gypsum, with gypsum as building material.
(Stefano Piastra)

Small bronze statue, dating back to the Iron Age, found by Giuseppe Scarabelli during his excavations in Re Tiberio Cave in the 19th century. It should be interpreted as a donation to the deities of the cave.



Survey of Re Tiberio Cave by Giuseppe Scarabelli and Giacomo Tassinari, 1856.

Civic Museum of Imola. Medieval crucibles from Re Tiberio Cave, used by counterfeiters to melt the bronze statues of the Iron Age in order to obtain counterfeit coins. The crucibles were found in the framework of the archaeological excavations by Giuseppe Scarabelli.

A plate of secondary gypsum ('Lapis specularis'*), cropped during the Roman Age, from Ca' Toresina Cave (Vena del Gesso romagnola) (photo P. Lucci).*

In the Northern Apennines the most common and widespread woodland formations are dominated by three species: *Quercus pubescens* (dominant in the sunniest slopes), *Ostrya carpinifolia* (dominant on the north side) and *Fraxinus ornus*; these species are associated with *Acer campestre*, *Sorbus domestica*, *Sorbus torminalis*, *Quercus cerris*.

In the messinian gypsum the presence of evaporitic soils and the peculiar morphologies associated to them lead to the development of three unique habitats. Gypsum outcrops in fact develop morphologies very different from the surrounding areas and they can both amplify or mitigate extreme microclimatic conditions, leading to the colonization of species of colder and more humid climates (microthermal, sub-Atlantic, orophytic), of warmer climates (macrotherm, Mediterranean), or of colder and dry climates (para-steppic conditions).

The second habitat is the bottom of the sinkholes, which open in the northern slopes and, due to the phenomenon of thermal inversion that stratifies the cold air in the bottom, they present a vegetation and a fauna of cold climates, at very low altitudes: ferns, mosses, liverworts, molluscs, insects and amphibians. The north-facing cliffs present various species of moss (among whom *Tortula revolvens* living only on gypsum rocks) and lichens, associated with many ferns, including the common *Asplenium ceterach*, *Polypodium vulgare*, *P. cambricum*, *Asplenium trichomanes*, the rare *Asplenium scolopendrium* and the very rare *Asplenium sagittatum* and *Polystichum lonchitis*; in these stations grows also the rare *Staphylea pinnata*. In some cases, in particularly fresh and deep dolines and ravines, there are small woods typically of mountain (on hill elevation); in these habitats there are herbaceous species always linked to fresh and humid microclimates, such as *Galanthus nivalis* threatened by climate change and global warming, because here the extreme peaks of heat and aridity are almost totally mitigated by the influence of the air and the humidity of the subsoil. The northern hillsides are home of *Isopyrum thalictroides*, *Scilla bifolia*, *Mercurialis perennis*, *Cystopteris fragilis*, *Asplenium scolopendrium*, *Allium ursinum*, *Convallaria majalis*. In some cases, on the northern slopes, the woods have been replaced by fruit chestnut trees, with centuries-old arboreal specimens rich in cavities and, therefore, very important from an ecological point of view.

The third habitat are the rocky cliffs, exposed to the south, hosting a particular flora, composed of Mediterranean species and loving gypsum substrate, such as the moss *Tortula revolvens* (exclusive of gypsum rock). On the most inaccessible cliffs live, directly clinging to the gypsum rock, many species adapted to these extreme, arid and inhospitable environments; among them there is the botanical emblem of the Vena del Gesso, the very rare *Allosorus persicus* (the messinian gypsum component site Vena del Gesso is the only Italian site, at the extreme West distribution limit; it is a distinctly gypsophilous species in Italy); moreover, different species of *Sedum*; *Alyssum alyssoides*; *Helichrysum italicum*; *Helianthemum apenninum*; *Onosma echioides; Onosma helvetica; Fumana procumbens; Thymus striatus*; *Ruta graveolens*; *Artemisia alba*. Where a thin layer of soil is formed, thanks to the lower slope, the typical Mediterranean garigue is asserted, with evergreen shrubs alternating with dry meadows, partly constituted by the same species present on the cliffs, together with *Brachypodium rupestre* and some orchids as *Anacamptis morio* (NT); among the shrubs there are many Mediterranean species, such as *Pistacia terebinthus*, *Rhamnus alaternus*, *Viburnum tinus*, *Phillyrea latifolia*, *Juniperus oxycedrus*, *Quercus ilex*.

At the foot of the cliffs there are *Quercus pubescens* forests or shrubs, with *Juniperus communis*, *Rosa canina*, *Prunus spinosa* and, where the soils are even more arid and poor, compact spots of *Spartium junceum*. In the meadows and at the edges of the vineyards extending beyond the foot of the cliffs, there are the rare and endemic *Bellevalia webbiana* (EN), *Himantoglossum adriaticum* protected by the European Union, and many other species of orchids.

There are more than 1.200 species of plants, some of them linked to the karst habitats, such as the ferns (22 species); there are more than 35 species of orchids.

The fauna of the candidate property is of extraordinary interest, due to the great environmental and microclimatic diversity, but also to the presence of an ancient, stable and rare ecosystem of great scientific and conservation importance in the caves in gypsum. The fauna of the caves presents organisms of ancient marine origin, witnesses to the evolutionary history of the planet, trapped in these underground environments protected for millions of years. In the caves there are troglobite, troglophile and troglossene species: the first are of greatest interest, strictly and inextricably linked to the underground cavities. Over 150 invertebrate species are known within the caves of the Emilia-Romagna gypsum areas, about half of which are troglophile species, ¼ troglossene species and as many troglobite species (about 35 species).

Among the molluscs the most interesting species is *Islamina piristoma* (Gastropoda, Hydrobiidae), endemism of the northern Apennines which lives exclusively in Vena del Gesso messinian gypsum.

Among the arachnids, several species of mites are very interesting, such as *Medioppis melisi* (endemic of Vena del Gesso and Gessi Bolognesi), *Ramusella caporiacci* (endemic of Vena del Gesso), *Trichouropoda schreiberi* (discovered and described in the Vena del Gesso and Gessi Bolognesi) or *Parasitus loricatus*, *Uroobovella rackei*, *Trichouropoda schreiberi*. There are also many troglobitic and endemic crustaceans, such as the amphipods *Niphargus* gr. *longicaudatus* and *Niphargus* gr. *speziae* (both Italic) and other more widespread such as the isopod *Androniscus dentiger* or the copepod *Diacyclops paolae*. Some interesting hexapods are first of all two springtails

*Persian fern (*Cheilanthes persica*) has in Monte Mauro the only Italian site and the most western in the World distribution, going from the Himalayan chain to the Vena del Gesso, through the mountains of the Caucasus and the Balkans.*

(Collembola): one new for science and now in the nomenclature phase *Deuterophorura* sp. (endemic of Vena del Gesso) and the more widespread *Mesachorutes quadriocellatus*; moreover, some insects, such as the rove beetle (Staphylinidae) *Lathrobium maginii* subsp. *mingazzinii* (endemic of Vena del Gesso), the round fungus beetles (Leiodidae) *Choleva garganona* (Italic) are known from the evaporitic areas. Very interesting is also the abundant presence of an endemic Italian orthopteran, typical of the caves: the beautiful *Dolichopoda laetitiae*.

In the caves of the messinian Vena del Gesso and Gessi del Riminese there is also an endemic amphibian of the Apennines, *Speleomantes italicus* (NT).

But, most of all, in the caves we find very important colonies of bats (Chiroptera). There are 23 species in the candidate property, some of which in large reproductive or hibernation colonies. Among the reproductive species in caves there are three species of horse-shoe bats (Rhinolophidae): *Rhinolophus euryale* (NT) with 550-750 females (in the Lucerna cave, Monte Tondo galleries and Onferno cave), *R. ferrumequinum*, *R. hipposideros*; moreover, some Vespertilionidae such as *Myotis myotis*, *Myotis blythii*, *Myotis nattereri* and a Miniopteridae: *Miniopterus schreibersii* (VU), with about 3.500 female in the Onferno cave. They are all also present during hibernation and, in particular, *Miniopterus schreibersii* is present with over 27,000 individuals (18,000 at Monte Tondo, 7.000 at Onferno cave and 2,000 at the Croara cave). There are also interesting wood bats, such as *Barbastella barbastellus* (NT) and *Myotis bechsteinii* (NT), besides all the more common anthropophilous species.

The resurgence streams are home to some rare insect species, including, in particular, the damselfly *Coenagrion mercuriale* ssp. *castellanii* (NT) which has in Romagna one of the most important populations in Italy. Moreover, there are some endemic Amphibians: *Triturus carnifex*, *Bombina pachypus* (EN), *Rana italica* and one endemic fish resistant to sulphurous waters and rich in dissolved salts: *Rutilus rubilio* (NT).

Many other endemic or sub-endemic fish are, most of all, in the Santerno and Senio rivers: *Barbus plebejus*, *Barbus meridionalis* (NT), *Protochondrostoma genei*, *Padogobius bonell, Cobitis bilineata*; there is also a very rare freshwater crayfish: *Austropotamobius pallipes* (EN).

The southern cliffs have many Mediterranean animals, such as the rare cricket *Saga pedo* (VU), the beautiful butterflies *Phengaris arion* (NT) and *Iolana iolas* (NT). Among the vertebrates, the snake *Coronilla girondica*, some passerines, such as *Sylvia moltonii* and the rare *Sylvia undata* (NT) and mammals such as *Hystrix cristata*.

On the rocky cliffs two birds of prey are nesting: *Falco peregrinus* (6 pairs in Vena del Gesso) and *Bubo bubo* (1 pair in Vena del Gesso); there are also many other nesting raptors, among which *Pernis apivorus*, *Circus pygargus, Circaetus gallicus*. Altogether, over 150 species of birds are known, of which almost 100 are nesting. Other interesting nesting birds are *Streptopelia turtur* (VU), *Caprimulgus europaeus*, *Lullula arborea*, *Anthus campestris*, *Sylvia hortensis*, *Certhia brachydactyla*, *Lanius collurio*, *Passer italiae* (VU), *Emberiza hortulana*. There are two species often wintering at the entrance of the caves: *Strix aluco* and *Tichodroma muraria*.

In general, in the forests there are all the large and medium mammals of the Apennines, with some important species such as *Canis lupus* (about 5-6 family herds), *Felis silvestris* (only in Vena del Gesso), *Martes martes* (only in Vena del Gesso), *Mustela putorius*. Among the small mammals there are other interesting species, such as the endemic *Sorex samniticus* and the rare *Eliomys quercinus* (NT).

(Massimiliano Costa)

Day 3

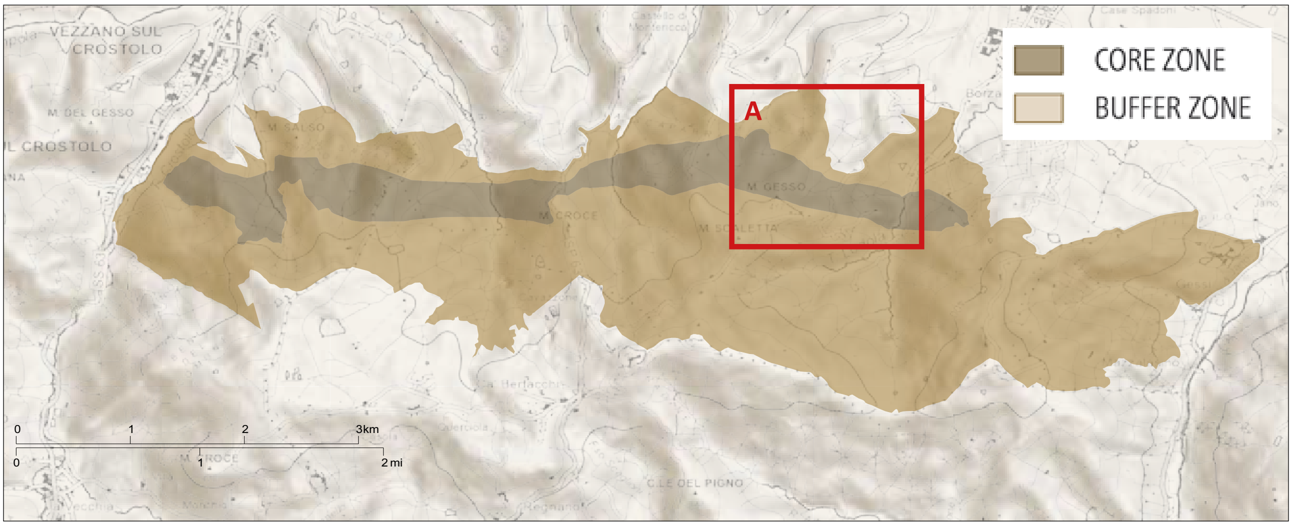
Ca' Speranza-Borzano gypsum and Tana della Mussina cave (CS2 Bassa collina reggiana)

The Messinian gypsum outcropping in the Reggio Emilia lower hill area consists of a series of discontinuous gypsum blocks forming a thin ridge in a northwest-southeast Apennine direction. From the karst area we will have a superb view of the transition from the Northern Apennines to the Po alluvial plain. The gypsum blocks here show a vertical orientation, as we can see from the swallowtail crystal twins, and are surrounded by clay formations. The gypsum layers rarely emerge from the profile of the foothills, so only along the streams incisions the presence of gypsum can be perceived on a large scale. In the Reggio Emilia area, therefore, we can not distinguish a "gypsum vein" in the landscape as we will see in Romagna. However, with a close look we can clearly outline the woodland cover of the gypsum areas following a pattern ultimately emphasizing the modest elevation of the blocks. Spectacular exception is the Borzano block, with its castle on top, which proudly sticks out from the surrounding landscape.

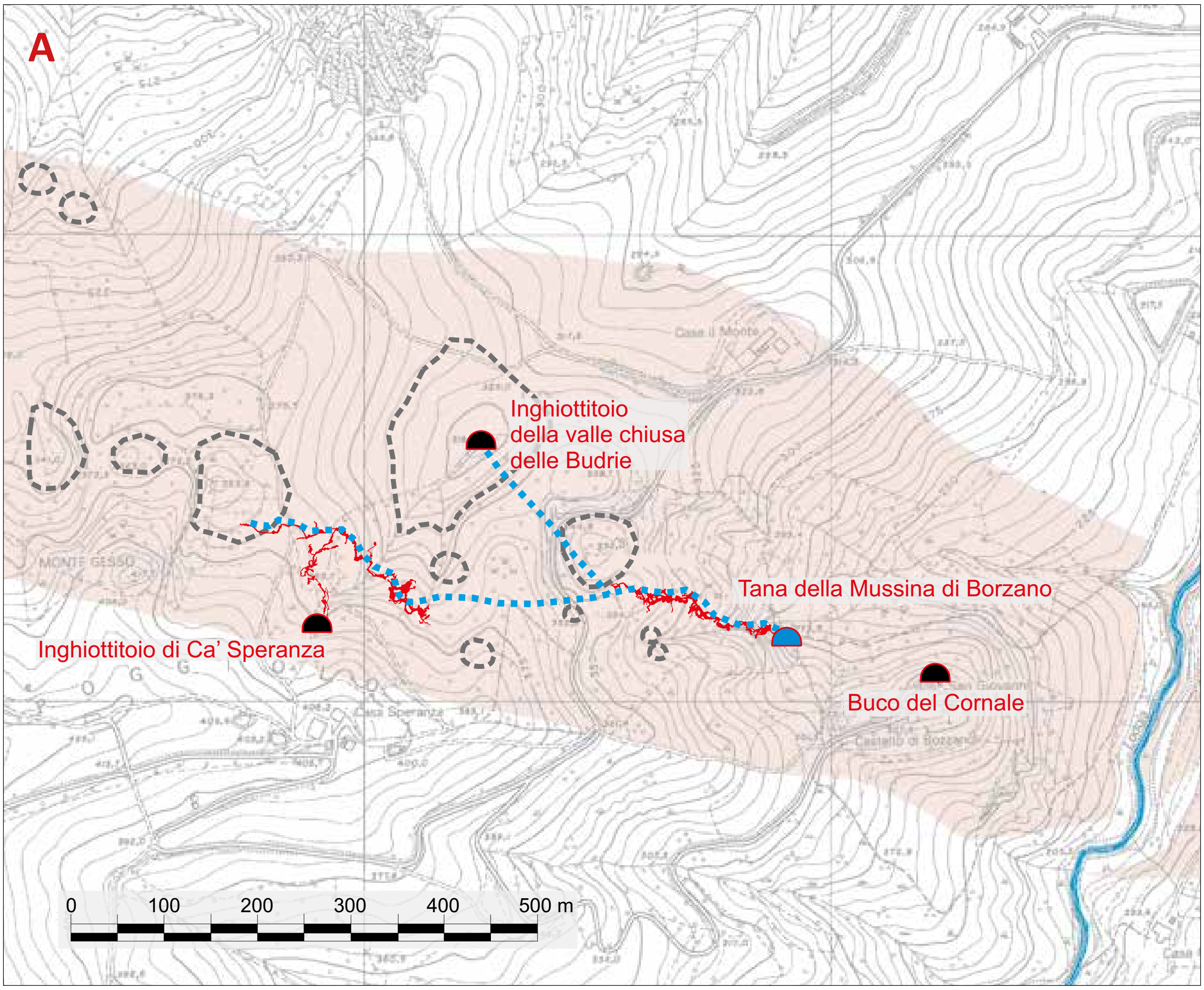
Sinkholes are widespread at the bottom of the numerous dolines; they are almost always occluded by mudslides, which drain the surface waters and feed small and medium-sized karst systems generally arranged parallel to the gypsum ridge. This is again in contrast with the Vena del Gesso, where most karst systems run perpendicular to the gypsum ridge. The most important karst is the Ca' Speranza-Mussina system, which collects most of the water from the area to the northwest of the Borzano castle. The waters rise at the Tana della Mussina, a cave famous for the excavations of its Copper Age burial site carried out in 1872 by Gaetano Chierici, a pioneer of palaeoethnology in Italy.

The area is also one of the cradles for the use of gypsum as ornamental stone and plaster-stucco production, with the famous *scagliola carpigiana*, created as imitation of semi-precious stone panels for church altars starting from the 17th century.
(Stefano Lugli)

The entrance of the Tana della Mussina cave (photo P. Lucci).



VEZZANO SUL CROSTOLO
M. DEL GESSO
CROSTOLO
M. GESSO
M. CROCE
M. SCALETTA
A
CORE ZONE
BUFFER ZONE
0
1
2
3km
0
1
2 mi
C.LE DEL PIGNO

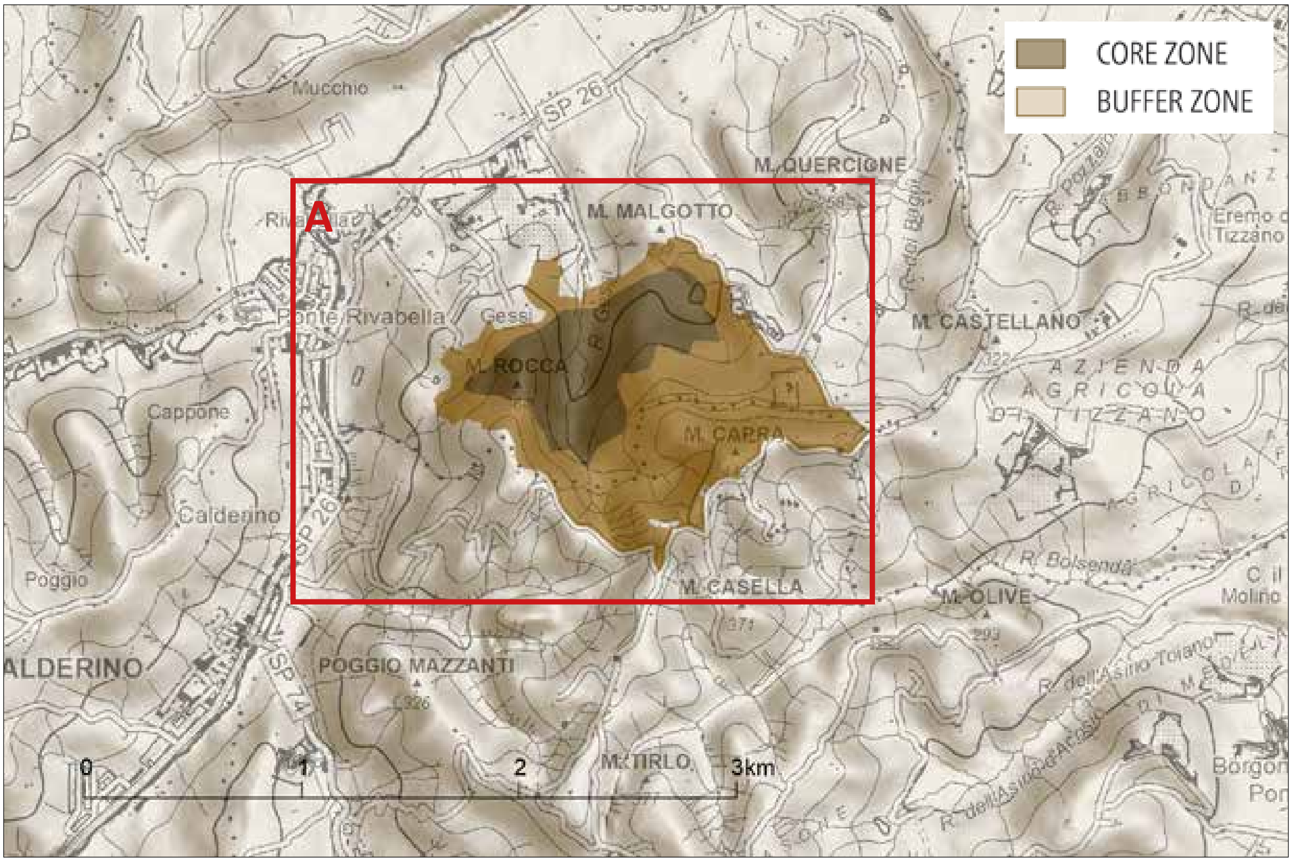


A
Inghiottitoio della valle chiusa delle Budrie
Tana della Mussina di Borzano
Inghiottitoio di Ca' Speranza
Buco del Cornale
MONTE GESSO
Casa Speranza
Castello di Borzano
0
100
200
300
400
500 m

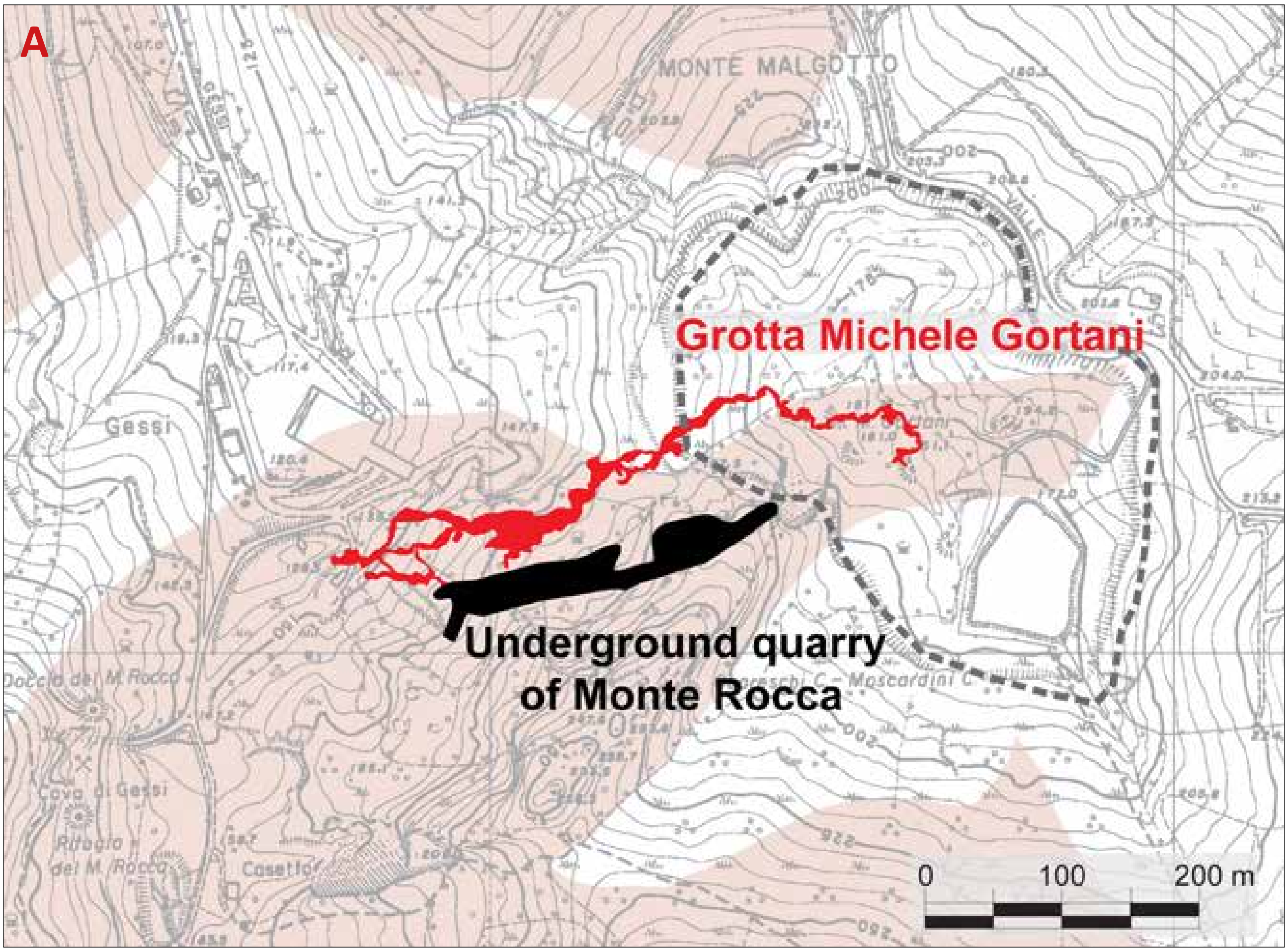
Gessi di Zola Predosa (CS3)

Several fragments of an extensive karst system, named “Monte Rocca Cave”, now entirely filled with finely layered sediments, have been cut by an underground gypsum quarry near Zola Predosa, some km West of Bologna. The total development of the visible filled karst conduits is around 80 metres, but many parts have been destroyed by the quarry, and the real size of the cave must have been several hundreds of metres. The cave sediments are inclined about 43° toward NNW. Close to the western end of the quarry’s tunnel there is a passage with a well-developed post-antigravitative ceiling channel with flat roof, developed during a sedimentation stage of the cave, and its flat roof is now inclined 42° toward the NNW. The gypsum beds measured nearby show an inclination of around 40° in the same direction. Both inclined cave sediments and roof morphologies testify that they formed after the end of the deposition of the Primary Lower Gypsum beds, dated at 5.61 Ma, and before the onset of the intra-Messinian tectonic phase, dated at about 5.55 Ma. After the formation of the cave with its sediments and roof morphologies, the gypsum sequence was tilted by the intra-Messinian and by the Plio-Quaternary tectonic phases, acquiring an inclination of about 40° toward NNW.
It is important to stress that in the gypsum outcrop near Zola Predosa there is also an active vadose cave system, the “Grotta Michele Gortani”, with a length of over 2 kilometres, which develops in an ENE-WSW direction, following the strike of the gypsum strata and paralleling both the quarry’s tunnel and the palaeokarstic cave. At the moment there is no physical connection between this active cave and the fossil one.
This palaeocave, and its sedimentary filling, are the best examples of the intra-Messinian karst cycle near Bologna, and show that this short emersion of the gypsum beds, with its extensive karstification phase, occurred in several, probably isolated patches, of which the Monticino Quarry near Brisighella, and the Zola Predosa paleocave, are the best examples that survived until today.

(Stefano Lugli)



Messininan palaeokarstic phreatic conduit, intercepted in the final part of the Monte Rocca quarry's tunnel (Dalmonte et al., 2012).



Day 4

Vena del Gesso romagnola (CS5)
A spectacular gypsum cliff: Riva di San Biagio

The landscape of the Vena del Gesso seen from Tossignano represent one of the most iconic view of the geological history of the Apennines. Here the Vena del Gesso appears in its most spectacular morphological expression, known all over the world. A ridge bordered by a steep escarpment that highlights thick layers made up of countless glittering gypsum crystals. This "vein" is of worldwide interest in the study of evaporites because it has allowed us to shed light on one of the most dramatic geological upheavals in the history of our planet, the Messinian salinity crisis.

The area is the most spectacular place where the sedimentary evolution of the northern Apennines before, during and after the salinity crisis is clearly exposed. The glance from the viewpoint allows to observe a natural section that embraces all the geological formations below and above the gypsum.

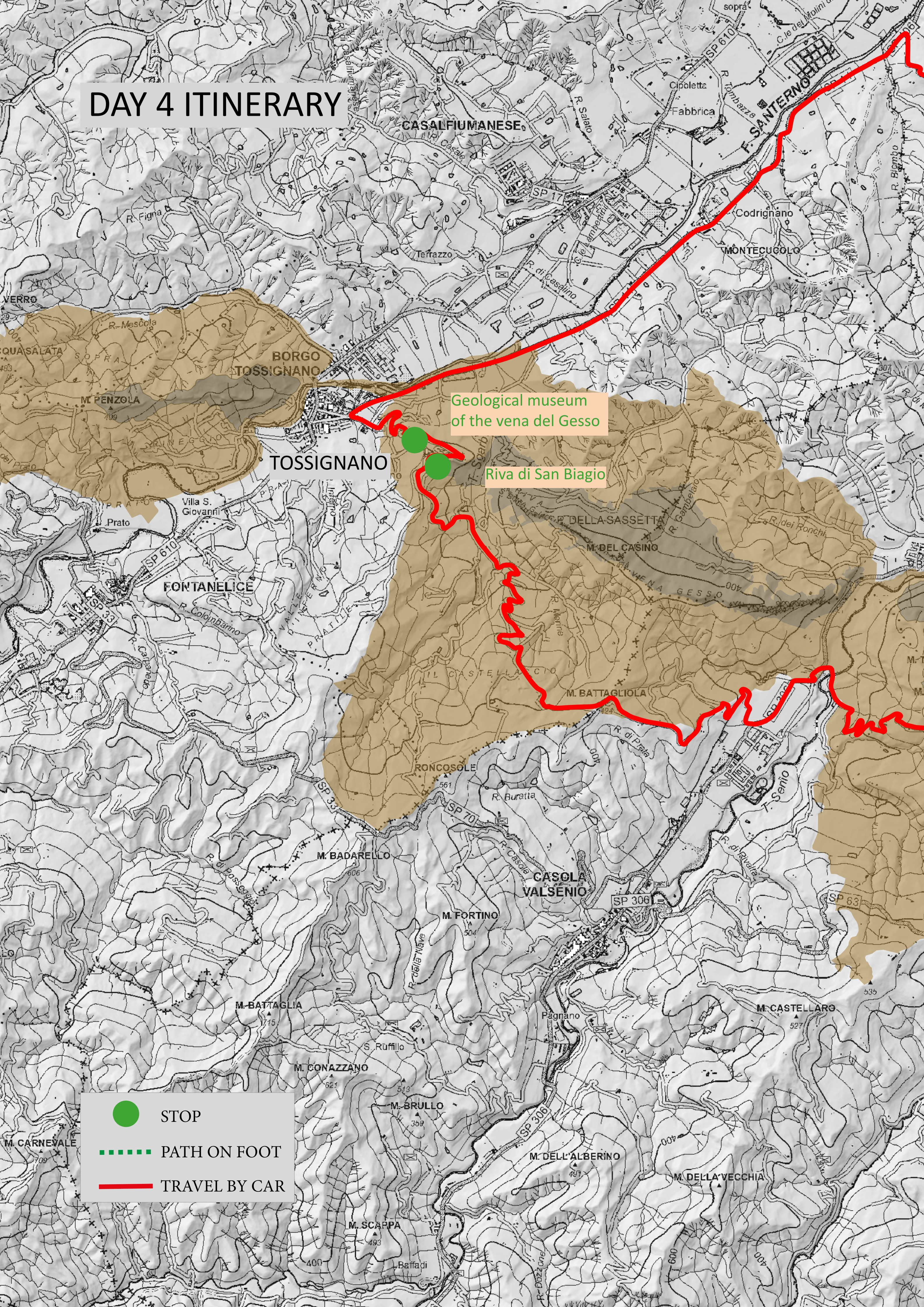
Below the gypsum there are two units, the Marnoso-arenacea Formation (Langhiano-Messinian), consisting of the characteristic alternation of layers of sandstone and clay deposited by turbidites generated by submarine landslides of mostly Alpine origin. The turbidites are followed by a unit some tens of meters thick of clays rich in organic matter, the euxinic clays (Upper Tortonian - Lower Messinian), deposited just before the gypsum.

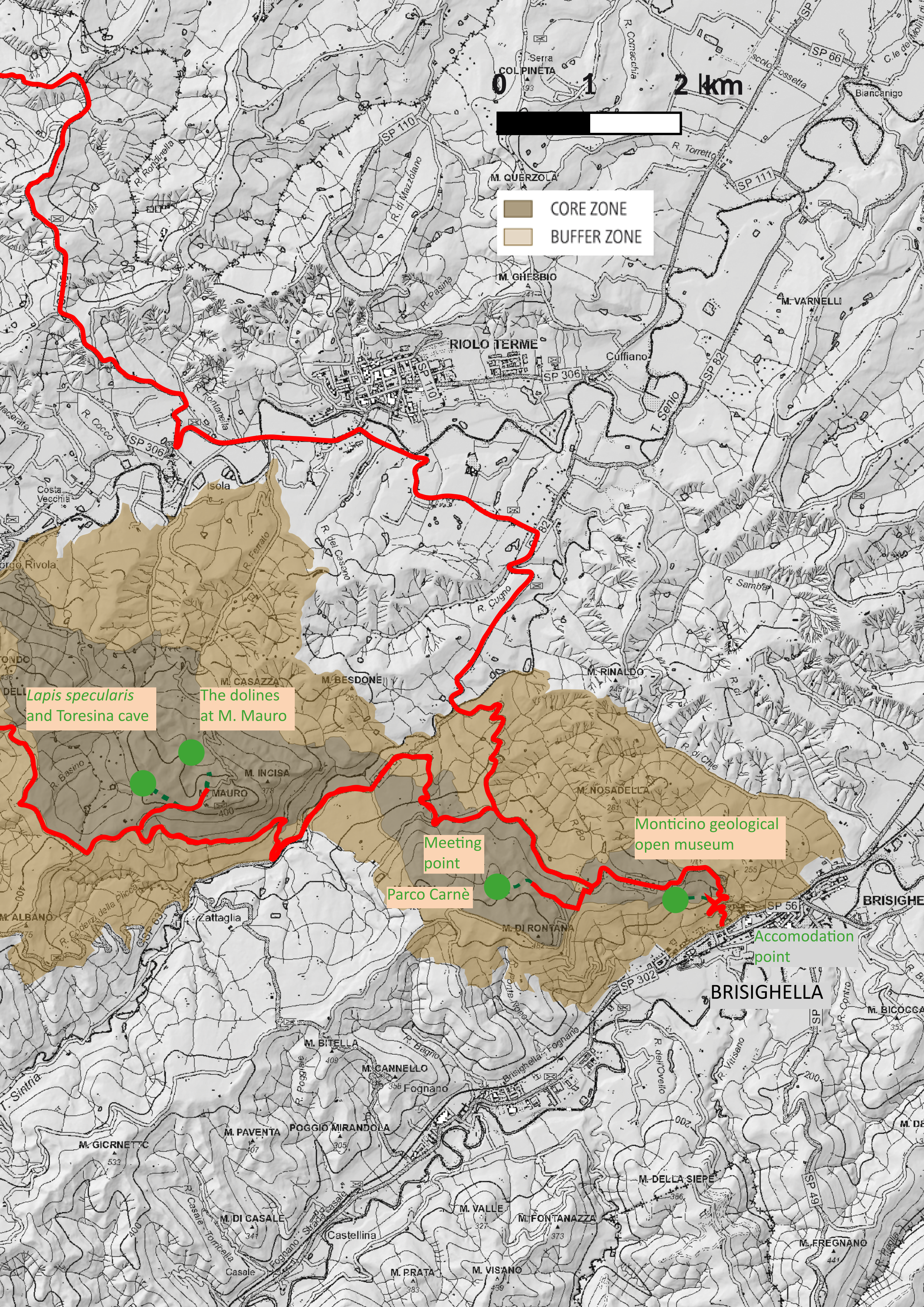
The Vena del Gesso seen from Tossignano (photo P. Lucci).

Above, the Vena del Gesso is sealed by the Colombacci Formation (Upper Messinian), formed by clastic and limestone sediments, deposited in fresh or brackish waters during the final phase of the salinity crisis, the Lago Mare phase. Above the Colombacci Formation we find the Argille Azzure Formation (Lower Pliocene), consisting of relatively deep-sea sediments, whose deposition marks the return to normal marine conditions at the end of the crisis. The the Argille Azzurre are easily recognizable by the extensive badlands characterizing the landscape above the gypsum.

The gypsum ridge is actually the result of the juxtaposition and embrication of large mountain-size blocks, encircled by mud sediments, which are the result of huge submarine mass-waste phenomena triggered by the intra-Messinian tectonic phase.

Another spectacular feature formed as a consequence of the mass-waste phenomena is the graben structure of the Riva di San Biagio section of the "Vena del Gesso". The gypsum ridge is dissected by faults forming an extensional feature, truncated at the top by the Messinian erosional surface.
(Stefano Lugli)


DAY 4 ITINERARY
Geological museum of the vena del Gesso
Riva di San Biagio
TOSSIGNANO
BORGO TOSSIGNANO
CASALFIUMANESE
FONTANELICE
CASOLA VALSENIO
M. PENZOLA
M. DEL CASINO
M. BATTAGLIOLA
RONCOSOLE
M. BADARELLO
M. FORTINO
M. BATTAGLIA
M. CONAZZANO
M. BRULLO
M. CARNEVALE
M. SCAPPA
M. DELL'ALBERINO
M. DELLA VECCHIA
M. CASTELLARO
MONTECUCOLO
Codrignano
F. SANTERNO
T. Senio
SP 610
SP 306
SP 70
STOP
PATH ON FOOT
TRAVEL BY CAR



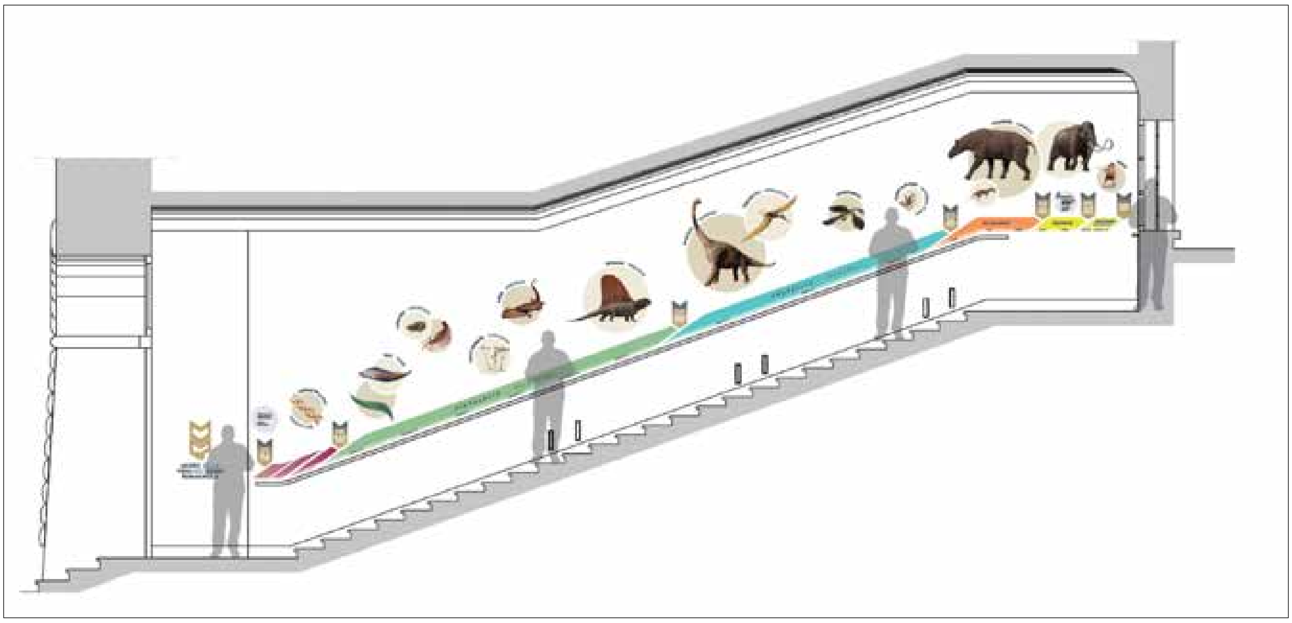
0 1 2 km
CORE ZONE
BUFFER ZONE
Lapis specularis and Toresina cave
The dolines at M. Mauro
Meeting point
Parco Carnè
Monticino geological open museum
Accomodation point
BRISIGHELLA
RIOLO TERME
M. QUERZOLA
M. GHEBBIO
M. VARNELLI
Cuffiano
COL PINETA
Biancanigo
Isola
Costa Vecchia
Borgo Rivola
M. CASAZZA
M. BESDONE
M. RINALDO
M. INCISA
M. MAURO
M. NOSADELLA
M. DI RONTANA
M. ALBANO
Zattaglia
M. BITELLA
M. CANNELLO
Fognano
M. PAVENTA
POGGIO MIRANDOLA
M. GIORNETTO
M. DI CASALE
Castellina
Casale
M. VALLE
M. FONTANAZZA
M. DELLA SIEPE
M. PRATA
M. VISANO
M. FREGNANO
M. BICOCCA
SP 306
SP 110
SP 66
SP 111
SP 82
SP 56
SP 302
SP 49

Panoramic views on the Gessoso-solfifera Formation from Tossignano looking westward (above) and eastward (below).

The new Geological museum of the Vena del Gesso at Tossignano, due to be officially open to the public in a few days, was created to illustrate the complex geological history of the area, highlighting the natural peculiarities of the Park and the local cultural richness. It belongs to the network of the "diffuse territorial museum system" of the Vena del Gesso, which comprises other museums and visitor centers, caves and mountain trails.

The museum boasts interactive videos and games, panels, a large collection of mineral, rock, fossil samples and artifacts. A special section is devoted to laboratory experience for the study of minerals, rocks, fossils and sediments. Microscopes are available to observe thin section of the most common rocks of the park.

Laboratory activities are specifically designed for children, such as: preparation of plaster by dehydrating gypsum crystals and observe the hardening of *scagliola* in moulds, simulating submarine slides and turbidite deposits in water tanks, collecting and classify microfossils from clay samples by wet sieving and many other activities.
(Stefano Lugli)



The time steps at the entrance of the Tossignano Geological Museum.

The area north of the top of Monte Mauro is characterized by the presence of numerous and large dissolution dolines, some of which coalesce forming multiple karst depressions, other having a large doline with smaller ones nested in it. Although most of these dolines are on average 50 metres wide and 30 metres deep, some have diameters that exceed 100 m. The large compound doline south of the ruins of a house at Ca' Castellina is undoubtedly the most spectacular karst depression of the entire Vena del Gesso, being almost 500 m wide (measured along its major axis) and reaching a depth of 80 m. Most dolines in this area are developed along structural weaknesses striking SE-NW, corresponding to bedding planes or, more often, to strike-oriented slip surfaces related to Messinian submarine landslides. These 30-to-50 metres-wide chaotic strips have favored the infiltration of surface water, thus creating these major alignments of dolines. Surprisingly no large cave systems are known in this area, maybe because of the high infiltration rates and the chaotic nature of the gypsum rocks in this area. On the bottom of the Ca' Castellina doline, however, a nice passage has been explored, showing remarkably well-preserved sediments and signs of antigravitative erosion on its beautiful ceiling (flat-roofed ceiling channels, anastomoses, and gypsum pendants). The bottom of most dolines is covered with gypsum boulders fallen from the surrounding walls and floating in fine marly or clayey sediment. The bottom of some dolines has been adapted in the past for agricultural purposes, showing a flattened and partly sealed bottom.

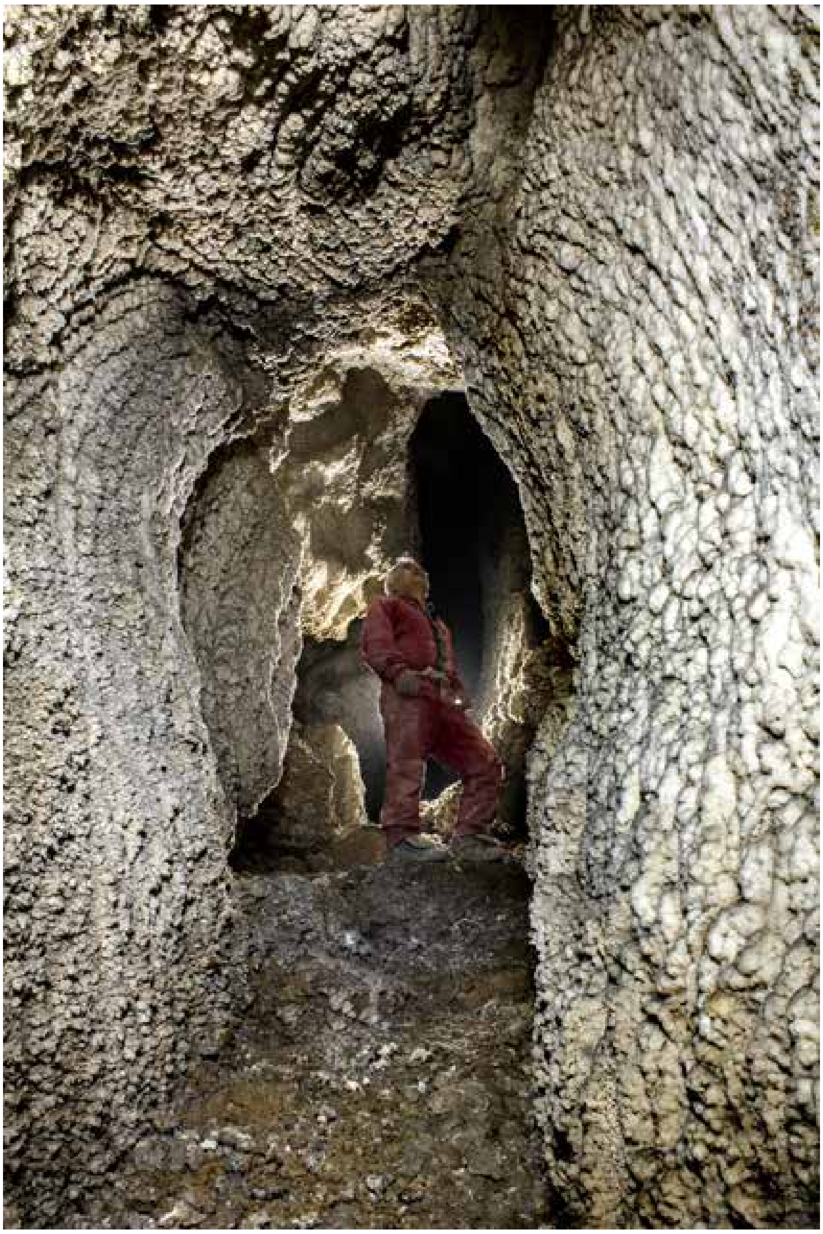
The water infiltrating underground in this area can flow to the NW, reaching the underground river of Rio Stella-Rio Basino cave and its spring, or to SEMPAL spring located 200 metres North of the Basino spring, or flow eastward to the Cassano spring, which waters reach the Sintria River after having flown outside for only some dozens of metres.
(Jo De Waele)

Stunning aerial view of the Vena del Gesso karst landscape dotted with dolines (photo P. Lucci).

Aerial view of the Vena del Gesso karst landscape with large dolines (photo P. Lucci).

The Romans exploited natural caves to collect large and transparent gypsum crystals formed within natural fractures in the gypsum rock. The crystals were carefully removed to obtain thin plates, a few millimetres-thick, to be used in windows panels instead of glass. Those tiny plates were easily separated by taking advantage of the natural gypsum crystal cleavage. The most famous use of *lapis specularis* was for the windows of Pompeii and Herculaneum, the Roman towns buried by the eruption of the Vesuvius in 79 AD, as well as in Rome, where its use also continued thereafter, until the Middle Ages.

Monte Mauro is the gypsum outcrop in the entire Mediterranean basin where the largest number of *lapis specularis* trenches, enlarged karst tunnels and production waste deposits are concentrated outside Spain. The crystals extracted in the Vena del Gesso and Gessi Bolognesi were less valuable in terms of size, transparency and workability than those extracted in Spain and perhaps in Turkey. We know from isotope analyses that the Italian *lapis specularis* was not used in Pompeii and in Rome for the windows of the early Christian basilica of S. Sabina. Their use was probably predominantly local.
(Stefano Lugli)



Grooves left by excavation tools on the walls of the Roman quarry of Ca' Toresina cave at Monte Mauro. The walls were later covered by natural gypsum efflorescence.

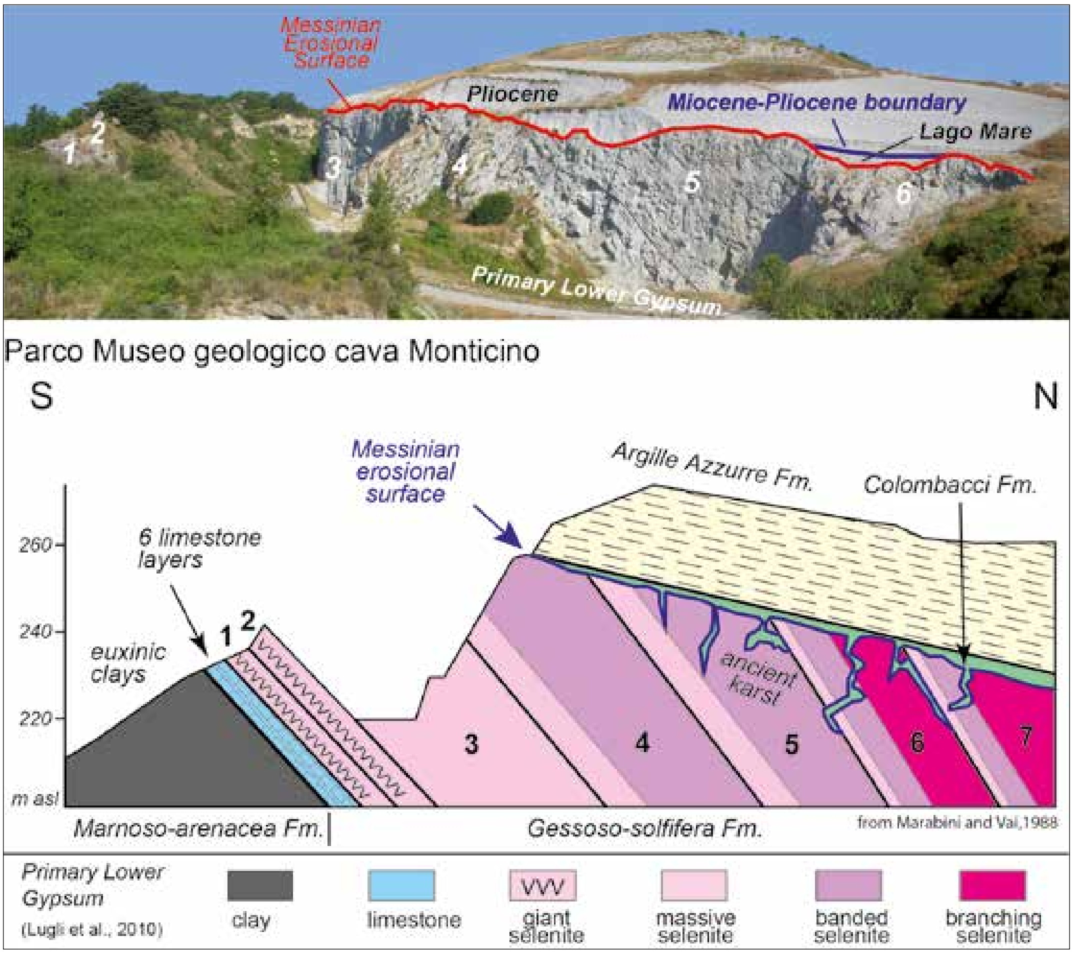
Large lapis specularis *crystal at Rio Basino cave (photo P. Lucci).*

This is one of the best examples in the world where a destructive exploitation activity has turned into a celebrated, easy to access, geo-park with outstanding fossil remains, crystals among the largest in the world and the spectacular exposure of the tectonic history of the Northern Apennine chain.

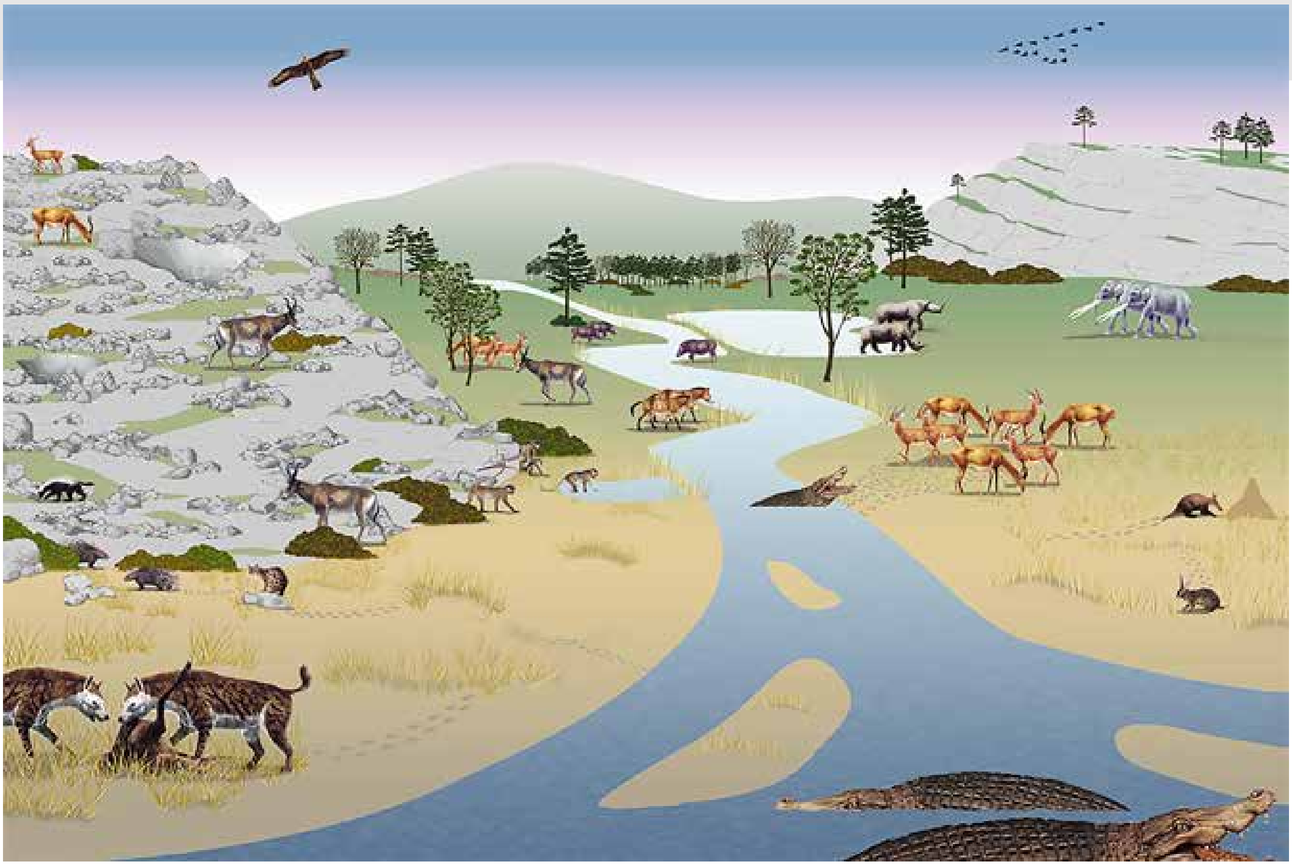
The outstanding mineralogical, geological, speleological and paleontological features that are illustrated along dedicated paths with didactic panels and spectacular dioramas.

The quarry walls are sparkling with million of gypsum crystals, some reaching the stunning length of 1.5 m. The crystals contain easily visible fossilized spaghetti-like bacteria.

A spectacular angular unconformity separates the gypsum layers and the latest Messinian fine-grained sediments (Colombacci Formation) from the Pliocene clays (Argille Azzurre Formation). This is the only place in the entire Mediterranean where evidence of subaerial exposure is present in the gypsum layers and one of the few sites where a macro- and micro-vertebrate fauna can be clearly dated by biostratigraphy, magnetostratigraphy and astrochronology. The subaerial exposure happened at the end of the deposition of the Messinian gypsum sequence and before the Lower Pliocene marine transgression, and this allow to chronologically pinpoint the faunal assemblage between 5,61 and 5,33 million years ago. As a consequence of the exposure to rainwater, fractures in the gypsum were enlarged by karst and birds of prey accumulated food boluses rich in micro-vertebrates, while some of the karst features acted as natural traps for larger vertebrates. The fossil assemblage is very rich and comprises 78 species of continental vertebrates: 34 taxa are amphibians and reptiles (frogs, crocodiles, lizards, snakes, worm lizards), 4 taxa are birds, 40 taxa are mammals (monkeys, aardvarks, equids, rhinoceros, proboscideans, rodents, rabbits, hedgehogs, shrews, bats). Five mammal species are completely new to science:



The spectacular angular unconformity at the Monticino geological park (Modified from Lugli et al., 2010).

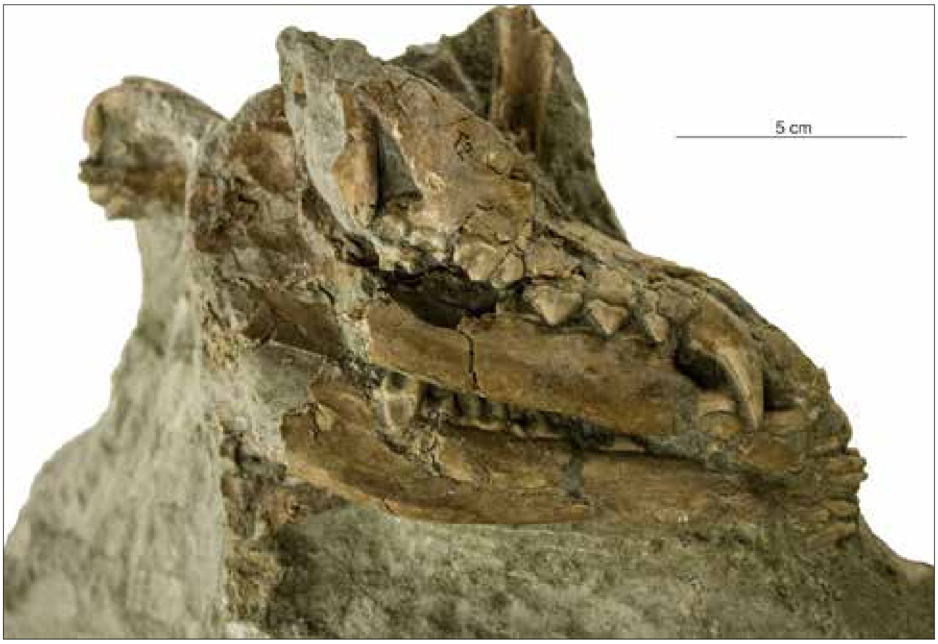


Reconstruction of the Messinian landscape, fauna and flora (sketch by E. Mariani).

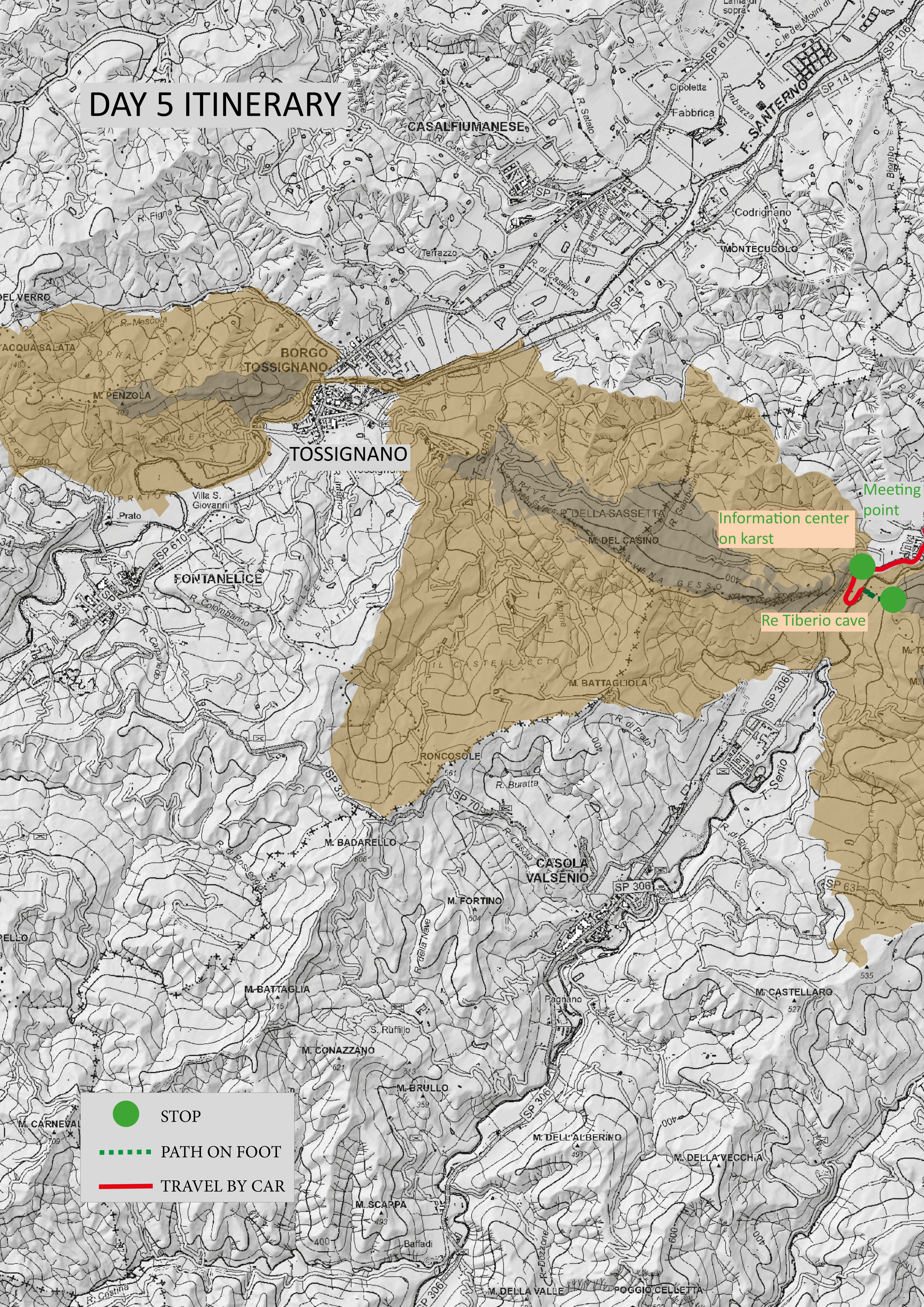
the hyaenid *Plioviverrops faventinus*, the primitive dog *Eucyon monticinensis*, the bovid Oioceros occidentalis, the rodents *Stephanomys debruijni* and *Centralomys benericettii*. The Monticino paleofauna clearly indicates warm-temperate to subtropical climate conditions.

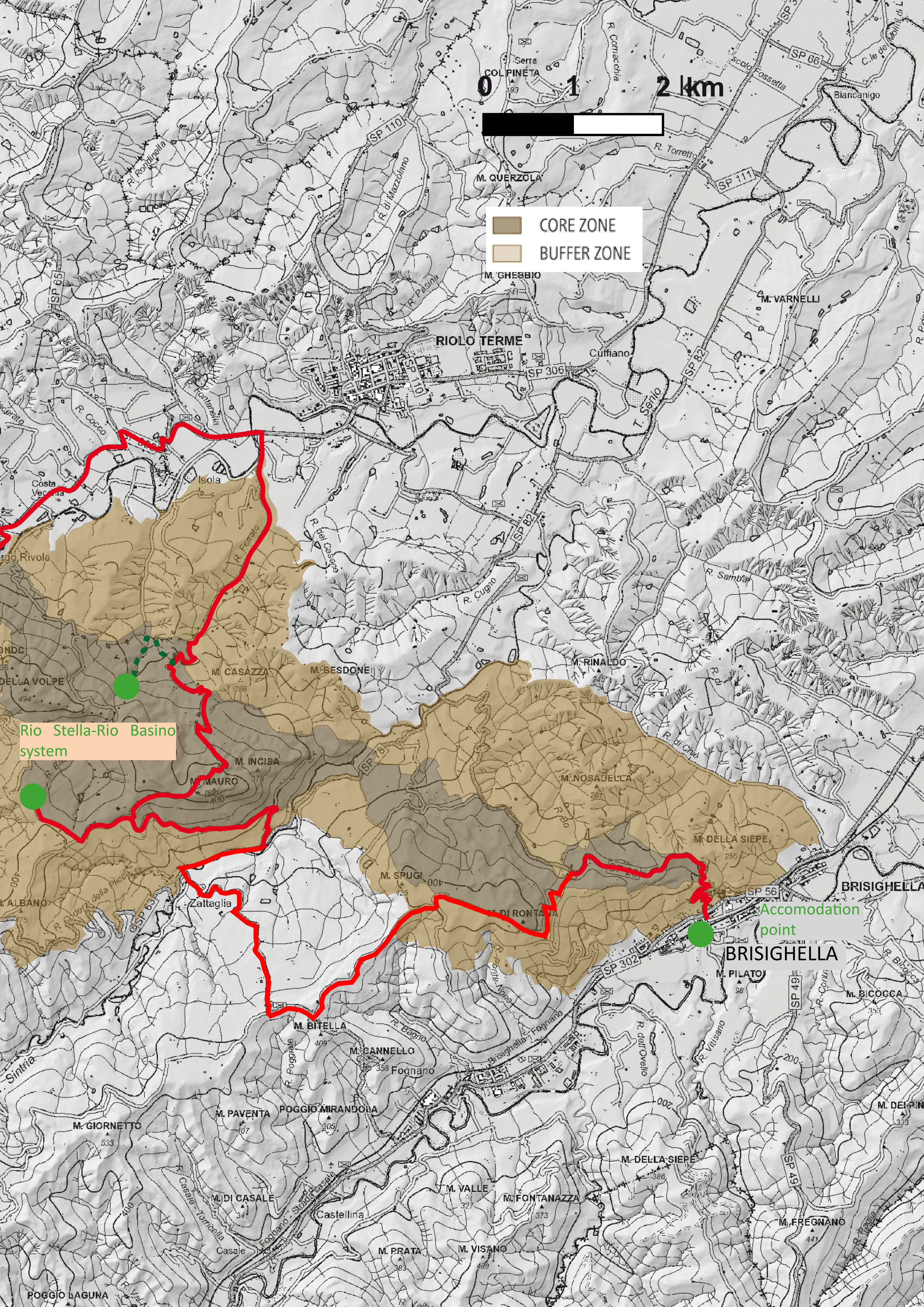
The Monticino mammal fossil community represent one of the first association revealing the existence of an Italian peninsula fully connected with the European continent.

(Stefano Lugli)



The skull of the hyaenid Plioviverrops faventinus *(photo by P. Lucci)*


DAY 5 ITINERARY
Meeting point
Information center on karst
Re Tiberio cave
STOP
PATH ON FOOT
TRAVEL BY CAR
CASALFIUMANESE
BORGO TOSSIGNANO
TOSSIGNANO
FONTANELICE
CASOLA VALSENIO
M. PENZOLA
M. DEL CASINO
M. BATTAGLIOLA
RONCOSOLE
M. BADARELLO
M. FORTINO
M. BATTAGLIA
M. CONAZZANO
M. BRULLO
M. CARNEVALE
M. SCAPPA
M. DELL'ALBERINO
M. DELLA VECCHIA
M. CASTELLARO
M. DELLA VALLE
POGGIO CELLETTA
MONTECUCOLO
Codrignano
F. SANTERNO
T. Senio


0 1 2 km
CORE ZONE
BUFFER ZONE
RIOLO TERME
Rio Stella-Rio Basino system
Accomodation point
BRISIGHELLA
M. QUERZOLA
M. GHEBBIO
M. VARNELLI
Cuffiano
M. CASAZZA
M. BESDONE
M. RINALDO
M. INCISA
M. MAURO
M. NOSADELLA
M. DELLA SIEPE
M. SPUGI
M. DI RONTANA
Zattaglia
M. BITELLA
M. CANNELLO
Fognano
M. PILATO
M. BICOCCA
M. PAVENTA
POGGIO MIRANDOLA
M. GIORNETTO
M. DI CASALE
M. VALLE
M. FONTANAZZA
Castellina
M. PRATA
M. VISANO
M. FREGNANO
POGGIO LAGUNA
Casale
Isola
SP 306
SP 302
SP 56
SP 82
SP 110
SP 111
SP 66
SP 65
SP 49

Day 5

Rio Stella-Rio Basino karst system

The Rio Stella sinking stream and the Rio Basino resurgence cave form the most important traversing cave system which has been crossed, by expert cavers, entirely from upstream to downstream, over an underground distance of 1.5 km (over a straight-line distance of almost 800 metres). Initially, surface waters flowing in the Rio Stella river cross around 1 km of marls and clays of the Marnoso-Arenacea Formation before entering the Messinian evaporite sediments. The swallow point is characterised by a chaotic stack of giant gypsum blocks that fell from the above-towering 70-metres-high almost vertical cliff, along which the gypsum beds are well visible. Looking from the South this layered gypsum wall above the Rio Stella sinking point is clearly "collapsed" into the Vena del Gesso ridge, showing a 200-metre-wide sunken segment bordered by extensional faults. Most of the underground river follows a chaotic maze of narrow passages that find their way through a large and elongated field of boulders that show this area of the Vena del Gesso to be drastically deformed and segmented. The central part of the underground path is made of some large collapse rooms, developed along the cross-cutting of several fractures and faults. Not surprisingly these large chambers are located underneath Ca' Faggia, which is located more or less in the central part of this 200-metre-wide NNE-SSW striking graben-like structure. The underground stream has carved a series of wide meanders with sinuous walls, up to a few meters wide and sometimes tens of meters high, downstream of these larger rooms. More or less 300 metres upstream of the Rio Basino resurgence, the underground river receives water coming from the South. Dye trace experiments have shown these waters to come from the nearby "Abisso Luciano Bentini" (formerly known as "Abisso F10"), one of the most important cave systems in the area draining some dolines located South of Rio Basino-Rio Stella. Bentini Abyss is around 3 km long and 200 metres deep, and almost connects to the Rio Basino underground river: the few tens of metres of distance are entirely developed in unstable and dangerous rocks.

Roughly 100 metres downstream another tributary enters the main stream, this time from the West. The chemical and physical characteristics of these waters (they are warmer and have a rather constant flow rate) point to their origin from slope deposits and some rather superficial drainage pathways collected in a relative large area, probably extending up to the Crivellari settlement.

The cave river resurges at the Rio Basino spring, forming a deep entrenched valley crossing collapsed gypsum boulders, some short underground tracts, short waterfalls and winding meanders. Two-hundred metres downstream of the resurgence Rio Basino receives the waters from SEMPAL resurgence, draining part of the dolines located East, including the Colombaia cave, but with a recharge area possibly extending almost up to the dolines North of Ca' Castellina.

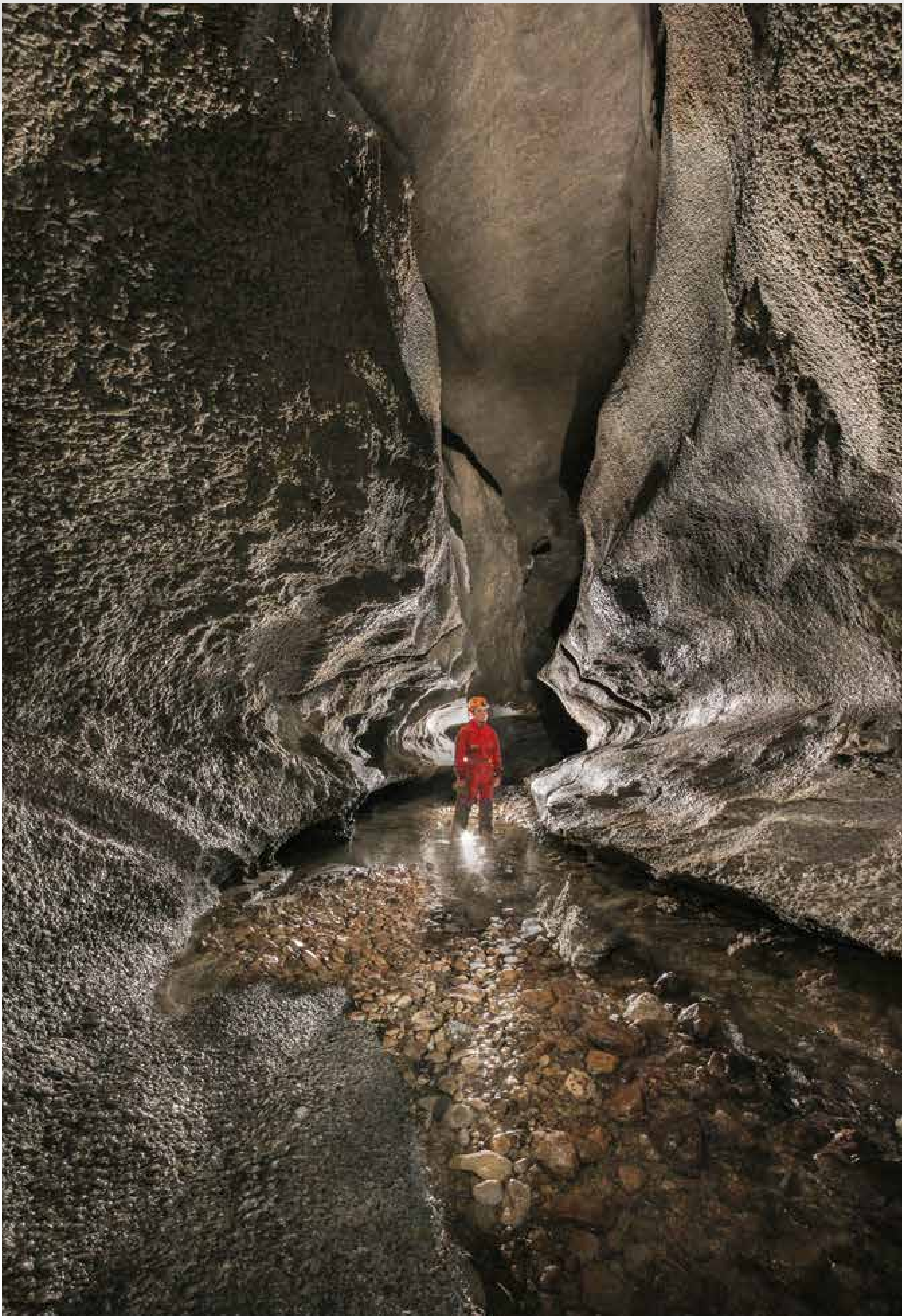
Downstream of this tributary Rio Basino continues for another two kilometres, carving the Argille Azzurre Formation (dark grey and sticky clays) flowing into the Senio River.

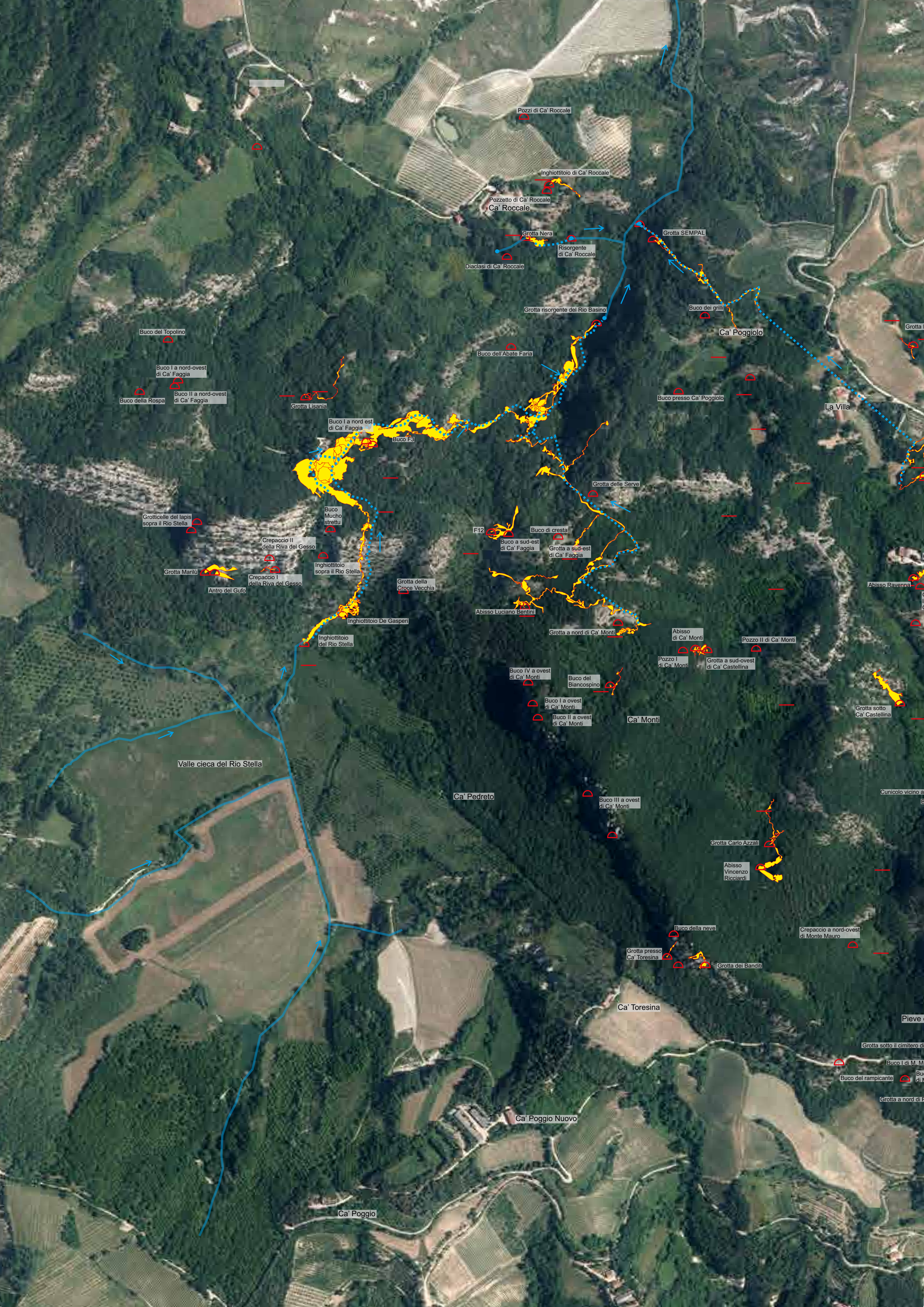
The cave system is remarkable not only for its sheer size and length: some corners are beautifully decorated with fine calcite speleothems (generally yellowish flowstones) and gypsum flowers, among the most beautiful of the region, and rare white cave pearls.

(Jo De Waele)

Next page: Karst morphology at the Rio Stella-Rio Basino karst system (photo P. Lucci).

Following pages: Aerial view of the Vena del Gesso west of Monte Mauro with the cave maps and the underground water circulation.





Pozzi di Ca' Roccale
Inghiottitoio di Ca' Roccale
Pozzetto di Ca' Roccale
Ca' Roccale
Grotta Nera
Risorgente di Ca' Roccale
Diaclasi di Ca' Roccale
Grotta SEMPAL
Grotta risorgente del Rio Basino
Buco dei grilli
Ca' Poggiolo
Buco del Topolino
Buco dell'Abate Faria
Buco I a nord-ovest di Ca' Faggia
Buco della Rospa
Buco II a nord-ovest di Ca' Faggia
Grotta Lisania
Buco presso Ca' Poggiolo
La Villa
Buco I a nord est di Ca' Faggia
Buco F3
Grotta delle Serve
Grotticelle del lapis sopra il Rio Stella
Buco Mucho strettu
Crepaccio II della Riva del Gesso
F12
Buco di cresta
Buco a sud-est di Ca' Faggia
Grotta a sud-est di Ca' Faggia
Grotta Marilù
Inghiottitoio sopra il Rio Stella
Crepaccio I della Riva del Gesso
Antro del Gufo
Grotta della Croce Vecchia
Abisso Ravenna
Abisso Luciano Bentini
Inghiottitoio De Gasperi
Grotta a nord di Ca' Monti
Inghiottitoio del Rio Stella
Abisso di Ca' Monti
Pozzo II di Ca' Monti
Pozzo I di Ca' Monti
Grotta a sud-ovest di Ca' Castellina
Buco IV a ovest di Ca' Monti
Buco del Biancospino
Buco I a ovest di Ca' Monti
Buco II a ovest di Ca' Monti
Ca' Monti
Grotta sotto Ca' Castellina
Valle cieca del Rio Stella
Ca' Pedreto
Buco III a ovest di Ca' Monti
Grotta Carlo Azzali
Abisso Vincenzo Ricciardi
Buco della neve
Crepaccio a nord-ovest di Monte Mauro
Grotta presso Ca' Toresina
Grotta dei Banditi
Ca' Toresina
Buco del rampicante
Ca' Poggio Nuovo
Ca' Poggio

LEGENDA
Ingresso delle grotte
Grotta non accessibile
Planimetria delle grotte
Risorgente
Percorso esterno delle acque
Percorso ipogeo delle acque
Dolina o valle cieca
0
100
200
300
400
500 m
Primo Maggio
Grotta del Pilastrino
Grotta della Colombaia
Castellina
Grotticelle del lapis presso Ca' Castellina
Canovetta
Ca' Virla
Tomba
Ca' Morera
Abisso Babilonia
Buco del vento
Inghiottitoio sopra Babilonia
Cava di lapis specularis a nord di M. Mauro
Pozzo a nord della Chiesa di M. Mauro
di S. Maria in Tiberiaco
Monte Mauro
Buco IV di M. Mauro
Buco III di M. Mauro
Grotta del Pass
Grotta della Palina
Buco a sud di Monte Mauro
Grotta sotto la rocca di Monte Mauro
Cava di lapis specularis a nord est di Pederzeto
Grotta della Lucerna
Grotta a est di Pederzeto
Pederzeto
Cassano
Diaclasi presso la ferrata di Monte Incisa
Fessure di Monte Incisa
Monte Incisa
Ca' Nova
Risorgente di Co' di Sasso
Grotta a nord-ovest di Ca' Co' di Sasso
Pozzo sopra Ca' Co' di Sasso
Ca' Co'di Sasso
Grotta del Monte Incisa
Abisso sopra Ca' Co' di Sasso
Grotta sopra Ca' Co' di Sasso
Buco I a sud-ovest di Ca' Co' di Sasso
Grotta II di Col Vedreto
Pozzo a sud-ovest di Ca' Vedreto
Grotta III di Col Vedreto
Torrente Sintria
Ex cava di calcare di Pietralunga
Pietralunga

Information center on karst

Near Borgo Rivola, overlooking the entrance to the Grotta del Re Tiberio, you can visit one of the very few museums in the world dedicated to karst phenomena in gypsum, with particular regard, of course, to the caves of the Vena del Gesso Romagnola.

The restoration of a disused roadman's house, wanted by the Management Body for Parks and Biodiversity of Romagna and the Regional Park of the Vena del Gesso Romagnola, was completed with the preparation of the museum by the Regional Speleological Federation of Emilia-Romagna.

The museum benefitted from the precious contribution of geologists, karstologists, biologists and geographers of the University of Modena-Reggio Emilia and Bologna, paleontologists from the University of Florence, archaeologists from the Regional Superintendences, with which the Speleological Federation has already been working closely for decades. Fundamental was the iconographic and textual documentation, a result of decades of frequentation of the area, as well as explorations and studies on karst phenomena in gypsum.

The exhibit consciously avoids the merely aesthetic exposure of minerals and fossils not strictly functional to the development of a path, which begins with a room dedicated to geodiversity, illustrating the main geological characteristic of the Vena del Gesso, and ends with a room dedicated to its biodiversity.

And precisely the karst phenomena of the Vena del Gesso offer the multidisciplinary ideas that are developed along the museum itinerary: from the genesis of the Vena del Gesso to then gradually face the evolution of its caves, underground hydrology, fossils and pollens found in underground environments, underground fauna, with particular regard to invertebrates and bats. Large space is dedicated to the anthropic interaction: from the protohistoric frequentation, to the lapis specularis quarries, to the modern studies and explorations of the speleological groups.

(Piero Lucci)

A view of the Information center on karst rooms (photo P. Lucci).

The “Re Tiberio”(King Tiberius) karst system is composed of the hydrological connection between a series of caves and is the second largest cave system in the region (the first being Acquafredda-Spipola cave system near Bologna).

The highest lying cave connected to the karst system is the “Abisso Mezzano” (which entrance is located at 340 m asl. As most caves in this area of the Vena del Gesso, Mezzano has been intercepted by the nearby Monte Tondo Quarry, disrupting the original underground drainage, which is now diverted towards the mine tunnels. A secondary underground river in this cave has been dye traced and allowed confirming it to be part of the Re Tiberio cave system.

The “Abisso cinquanta” opens on one of the cultivation steps of the gypsum quarry, and since its discovery in 1996 its entrance passage has retreated by at least 10 metres due to the expanding quarry. This cave is connected to Re Tiberio cave by explorable branches, that were filled with sediments but were physically excavated by cavers.

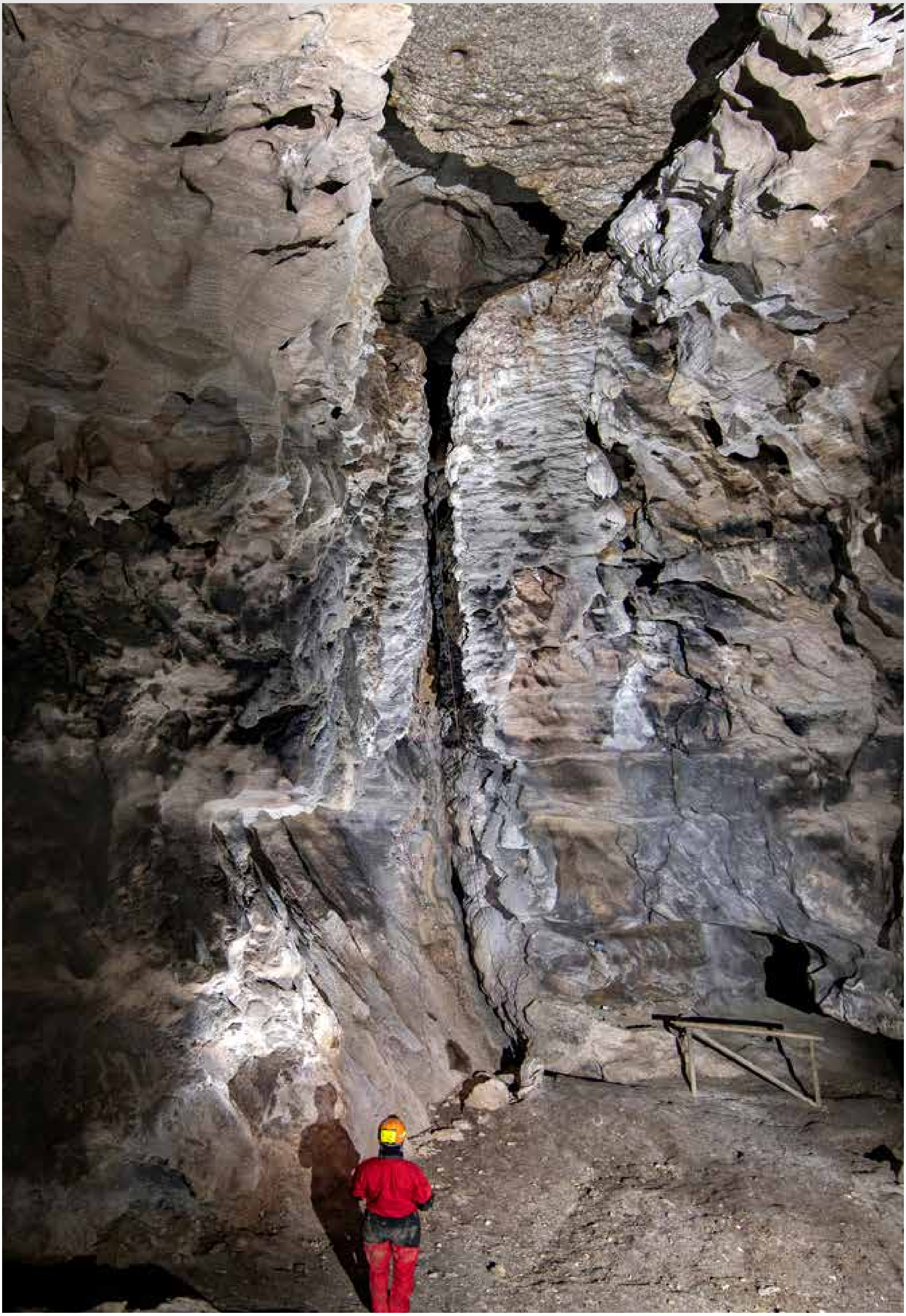
The main entrance level of Re Tiberio cave, which opens at 173 m asl (around 80 meters above the present level of Senio River) was known since prehistoric times, and only the first 330 meters were explored and documented until approximately 20 years ago. Explorations and digging campaigns have allowed to expand its known development and connect it to Cinquanta Abyss, making the explorable cave system over 4.4 km long. Dye tracing has shown that also the “Tre Anelli” cave is hydrologically connected to the system, but an explorable connection has not been made yet (excavations being needed). Also several branches of the cave, which were all part of a unique cave system that is now divided in multiple fragments, have been intercepted by the underground gypsum quarry. Summing up all the cave fragments making part of the original karst system an overall length of about 6,300 m can be calculated, developing over an altitudinal difference of over 220 m.

From a geological and geomorphological point of view the complexity of the Re Tiberio cave system has made it a reference site for the speleogenetic and landscape evolution of the entire Vena del Gesso area. The network of passages and shafts crosses at least four evaporitic cycles (from IV to VII), allowing to investigate the evaporitic cycles directly (the quarry cuts down through cycle III), and to recognize the main structural elements guiding speleogenesis.

A detailed analysis of the cave levels, coupled with the survey of the terraces of Senio River, and U/Th dating of calcite speleothems in various parts of the cave system, have allowed to construct a climate-driven speleogenetic model, in which cave storeys are carved during colder periods, and speleothems are deposited during warmer ones. The combination of sediments, antigravitative erosion morphologies, speleothem deposition, and vadose entrenchment phases make the Re Tiberio Cave system a unique study site to unravel the complex speleogenetic history, and the related evolution of the landscape.
(Jo De Waele)

A delicate, rather uncommon, gypsum stalactite (photo C. Pollini).

.


The gotica room in the Re Tiberio cave (photo P. Lucci).

Day 6

Evaporiti di San Leo (CS6)- Gessi di Onferno (CS7)

The Rio Strazzano cave and the white gypsum alabaster

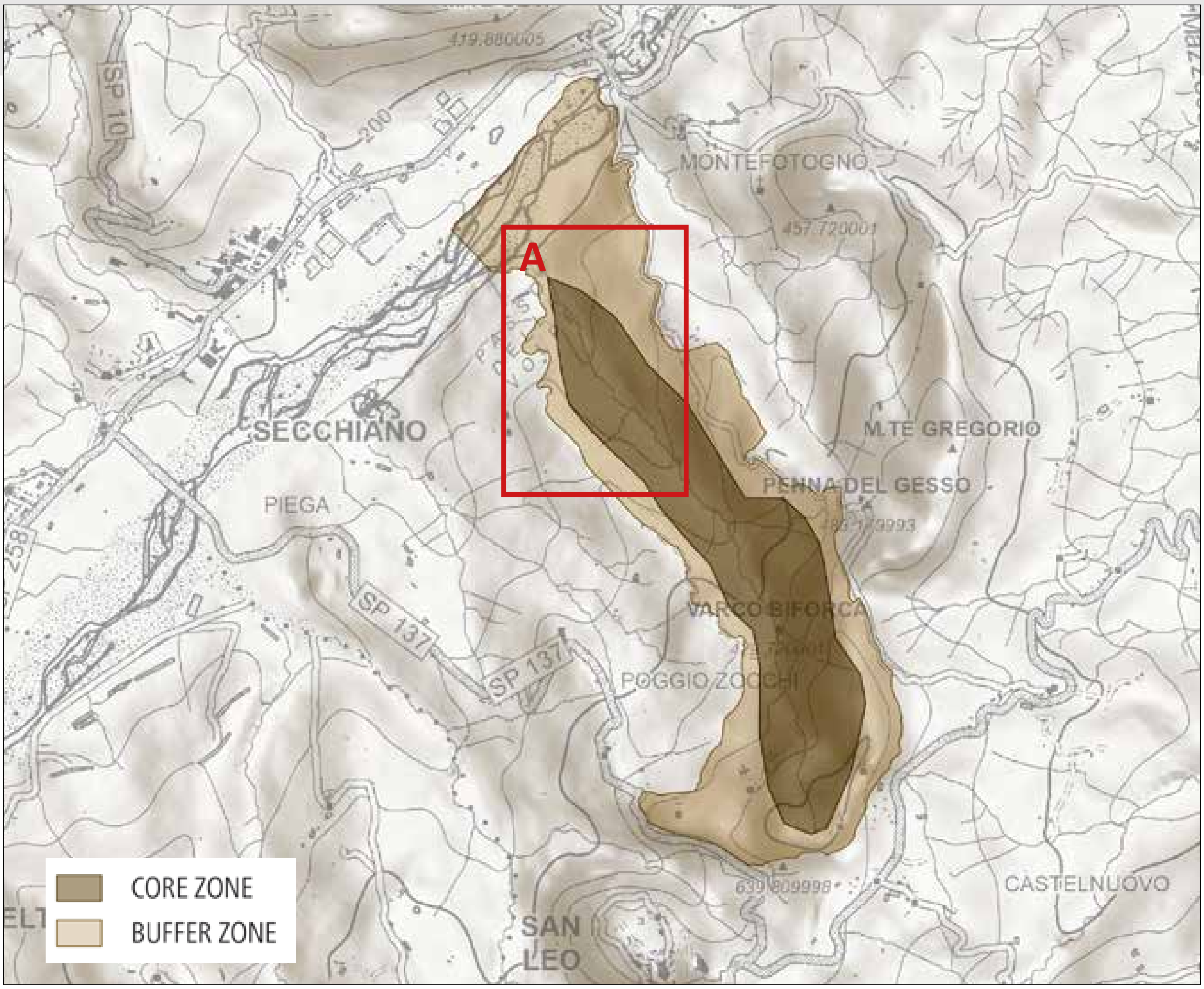
The Messinian gypsum of eastern Romagna has unique characteristics, not found in other parts of the Region. Here the karst rock consists of microcrystalline gypsum (alabaster) in alternating layers of white and black colour instead of the macrocrystalline (selenite) gypsum of the Vena del Gesso. The pure microcrystalline gypsum has a typical white colour, while the layers of dark grey gypsum owe their colour to the clay and organic matter content. Their origin is linked to huge submarine landslides that affected the selenite deposits in the Messinian, around 5.6 million years ago. The gypsum deposited in shallow waters slid down to the seabed and fragmented to form a sandy gypsum detritus that spilled out at depth (clastic gypsum). The gypsum rock was then buried below younger sediments below 500 m depth and gypsum was turned into anhydrite. Anhydrite, in turn, was hydrated back to gypsum at outcrop exposure, forming the gypsum alabaster.

The white microcrystalline gypsum of the Strazzano stream, a small tributary of the Marecchia River located north of San Leo, is cut by a peculiar karst system. Parallel to its external course, which partly takes place in ravine environments, the stream has generated karst conduits that today constitute the normal flow path. The external valley is suspended at about 1.5 m above the conduit and is normally dry unless the underground system is completely flooded.

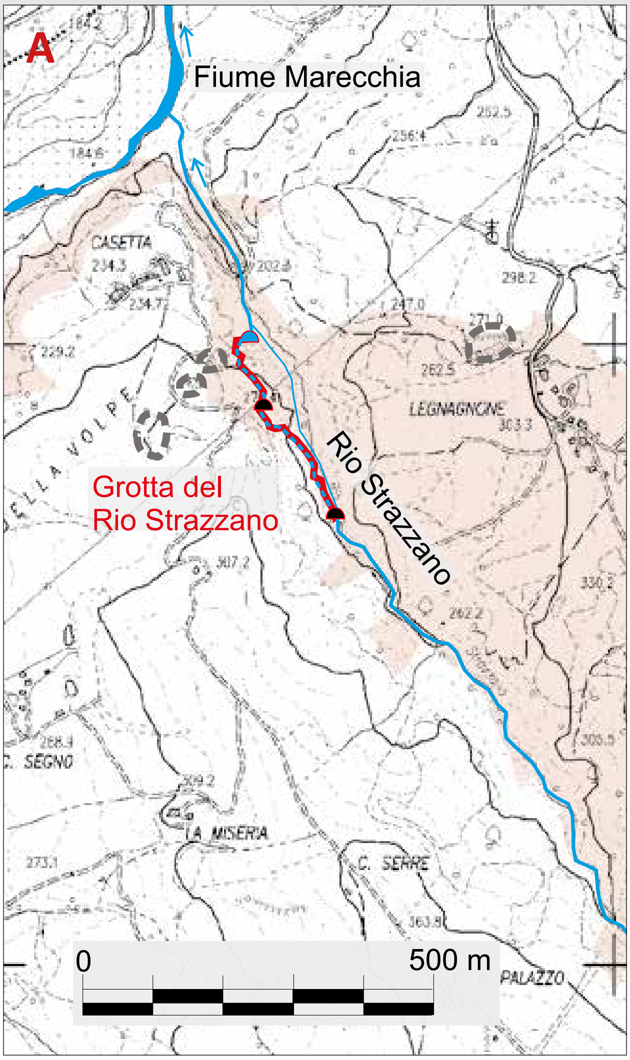
As far as we know the cave represent the only example in the world where karstic conduits cut alabastrine gypsum formed at the expenses of the selenite still visible as ghosts of the original crystals. The shape of the crystals (pseudomorphs), which are up to 30 cm across, are beautifully exposed in the walls of the cave. The protected environment of the cave and the karst dissolution produced a unique exposure to observe the crystals in great details, which cannot be appreciated at surface outcrops.

(Stefano Lugli)

The white alabastrine gypsum in the Rio Strazzano gorge.

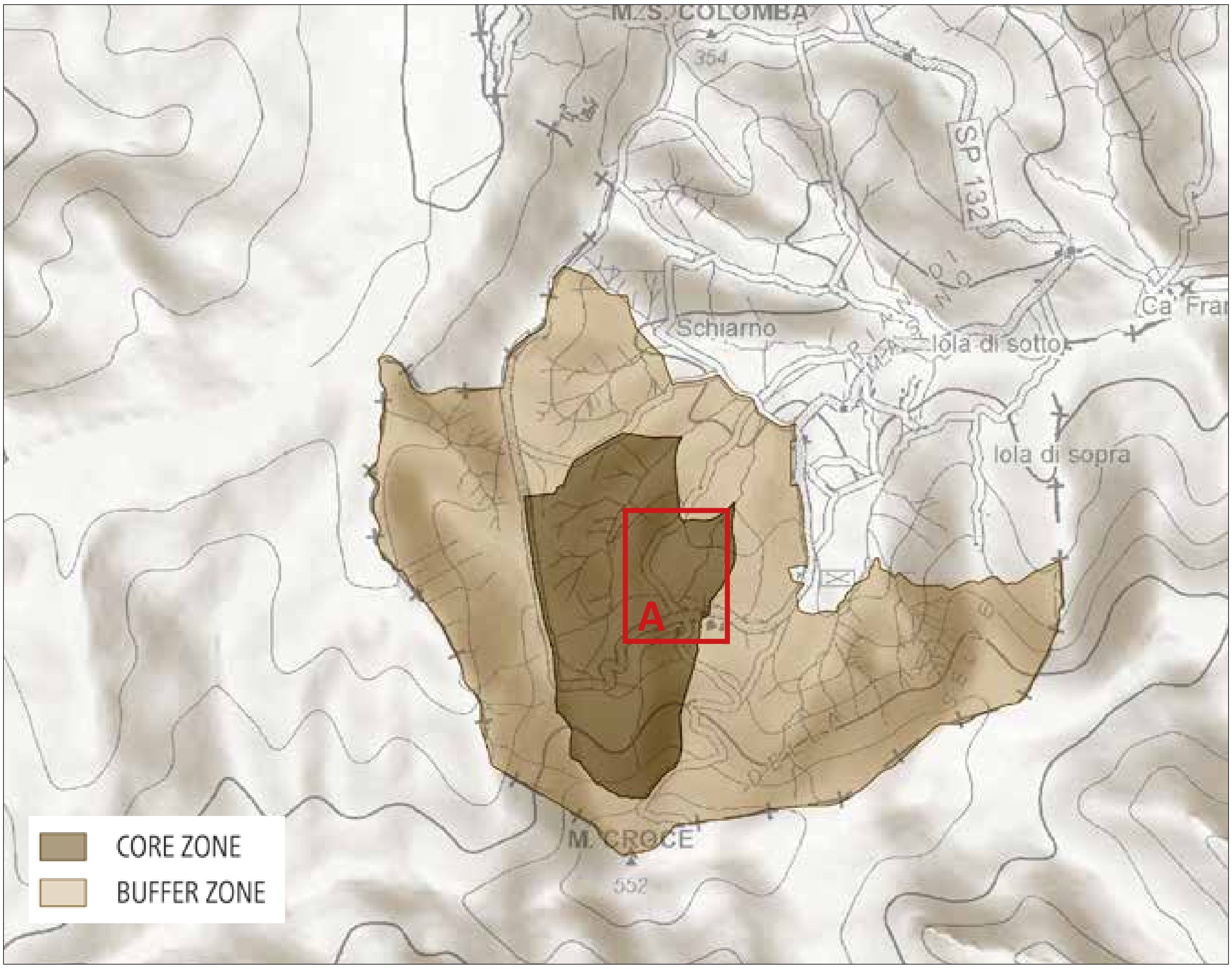


Views of the Rio Strazzano cave cut into the alabastrine gypsum Photo F. Grazioli).


A
Fiume Marecchia
CASETTA
LEGNAGNONE
Grotta del
Rio Strazzano
Rio Strazzano
C. SEGNO
LA MISERIA
C. SERRE
PALAZZO
0
500 m

The karst system crosses one mountain-size gypsum block

The Onferno Cave, described since the 18th century, is by far the best-known cave in eastern Romagna. It is a hydrogeological tunnel cutting through an allochthonous block of selenite gypsum.
This represent one of the best examples of karst developed in a relatively small evaporite outcrop. The streams flow for long stretches outside on non-karstifiable sediments. As soon as the stream reaches the gypsum block, the water enters the vertical gypsum wall in depth forming a blind valley. The cave consists of a high meander crossed by a stream with outstanding erosive morphologies and extensive, thick deposits of gravel, sand and fine-grained sediments.
Here there is the largest mammelloni structure ever described in the world up to now for a natural cave. The structure is more than 2 m in diameter and protrudes from the ceiling for more than 2 m. The mammelloni structures formed by sinking in the underlaying mud of the very first selenite crystals formed at the beginning of every climatic cycle that formed the 16 strata of the Vena del Gesso.
At Onferno we can see also enormous blocks of selenitic gypsum not completely disintegrated by ancient underwater landslides. Only in eastern Romagna and Sicily the interaction between gypsum and natural oil has allowed the formation of large accumulations of native sulfur. Remarkable is the presence of numerous sulfurous springs, which are quite rare in other gypsum caves in the region.
(Stefano Lugli)



(photo P. Lucci)

Views of the Onferno cave, with the ceiling dotted by large gypsum mamelons (photo F. Grazioli).

Day 7

Gessi bolognesi (CS4)

Acquafredda karst system

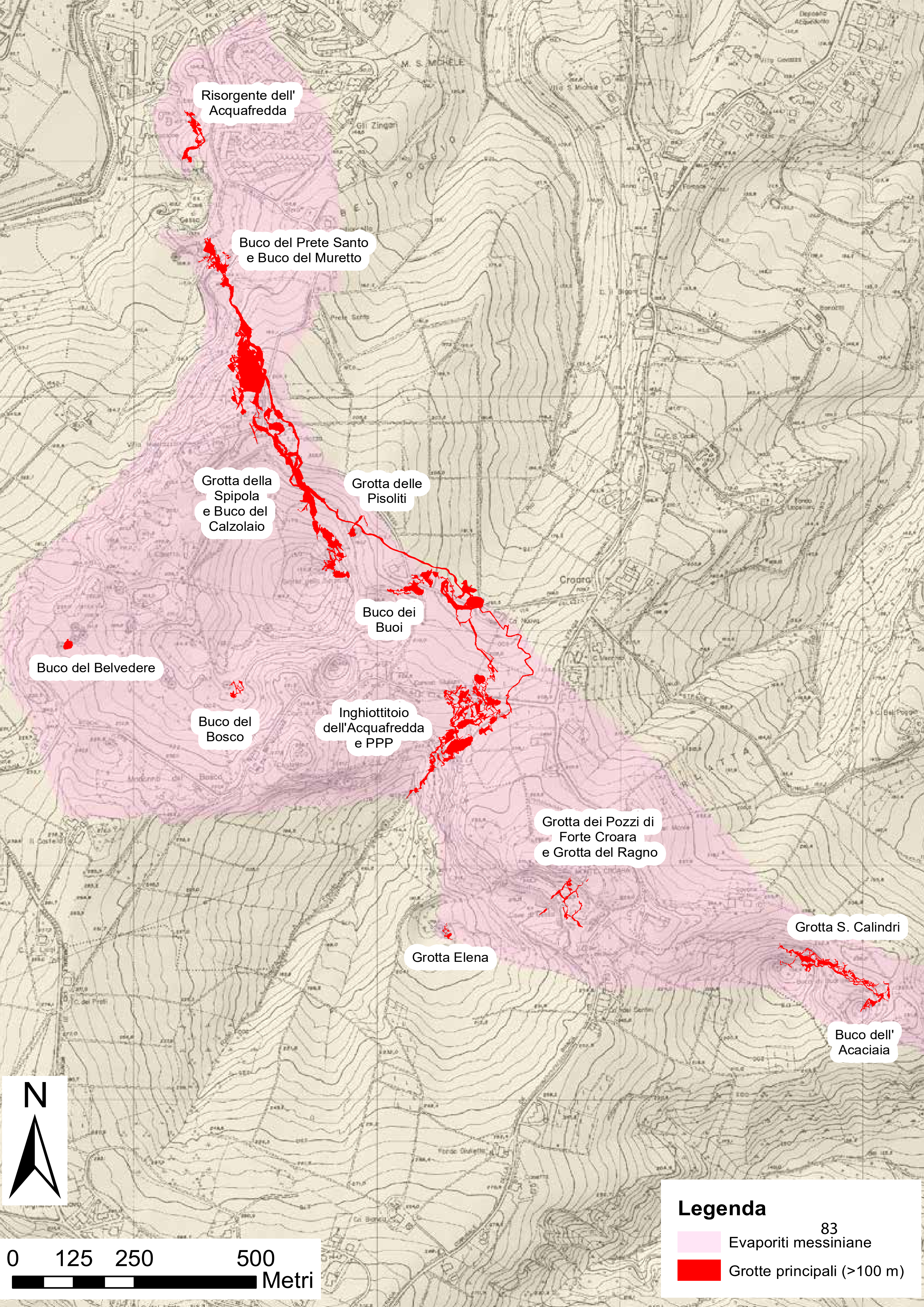
Acquafredda is the name given to the most important blind valley in the gypsum area of Bologna, now carving the clays and marls of the Termina Formation (pre-evaporitic Late Tortonian-Early Messinian in age) in a straight SSW-NNE direction. This rather short - 1.5 km - valley is what remains of a larger drainage system, and entirely disappears underground forming the Acquafredda-Spipola Cave System. Before this underground capture occurred, the paleo-Acquafredda river was one of those “simple” fluvial incisions that ran from SSW to NNE on the less permeable and insoluble clays and marls that covered the gypsum formations until roughly 400 thousand years ago. The slow Apennine uplift caused both the erosion of the cover, progressively exposing the Messinian gypsum beds, and the entrenchment of the main rivers in the area (Savena and Zena). During this evolution, the surface water was gradually captured forming an underground drainage which mostly followed the structural grain of the evaporite succession (i.e. prevalently NW-SE striking bedding planes and high-angle faults and joints, and secondarily SSW-NNE striking antiapennine directions related to the bed dipping azimuth and subvertical joints and faults). These captures left hanging valleys on the downstream direction, whereas the headward retreat of the tributaries of Savena and Zena slowly reduced the extension of the upstream recharge areas of these originally SSW-NNE incisions, beheading most of the lateral underground drainage systems and ultimately only leaving the central one (Acquafredda).

The Acquafredda cave system starts where the surface water touches the exposed gypsum (162 m asl), at the foot of a 40-meter-high steep slope. The underground stream firstly flows to the NE, following a main high-angle fault and associated joints and splay joints, having a very labyrinthine character. Acquafredda stream then turns to the NNW flowing mainly along a bedding plane discontinuity. The stream receives two main underground tributaries from the East (coming from the Buco dei Ragni and from Grotta Elena blind valley and cave) before becoming a low crawling passage, connecting to the Spipola Cave. This subterranean river then flows along the lower levels of Spipola cave, crosses the Buco del Prete Santo, and then flows out into the Savena River along an artificial tunnel related to the underground gypsum quarry, that was active until 1977. This capture isolated the natural Acquafredda spring, which is now completely dry. The Acquafredda-Spipola Cave system, counting all its lateral branches, is 11.5 km long and almost 120 meters deep, representing the longest epigenic gypsum cave system in Europe. The underground river is over 2 km long, and curiously is longer than its external portion (the Acquafredda blind valley)!

Acquafredda-Spipola cave system has four main speleogenetic levels, related to the progressive rising of the Apennine chain and related entrenchment of the main rivers carving the area, lowering the local base level of the caves. The highest of these levels are over 200 thousand years old, based on old dated flowstone levels.

(David Bianco, Jo De Waele)

Next page: maps and caves of the Acquafredda system area.


Risorgente dell' Acquafredda
Buco del Prete Santo e Buco del Muretto
Grotta della Spipola e Buco del Calzolaio
Grotta delle Pisoliti
Buco dei Buoi
Buco del Belvedere
Buco del Bosco
Inghiottitoio dell'Acquafredda e PPP
Grotta dei Pozzi di Forte Croara e Grotta del Ragno
Grotta Elena
Grotta S. Calindri
Buco dell' Acaciaia
N
0 125 250 500
Metri
Legenda
Evaporiti messiniane
Grotte principali (>100 m)

Spipola cave

Most of the Messinian gypsum outcrops between the Savena and Zena streams is drained by a single, large cave system, called "Acquafredda-Spipola", which includes seven major connected caves and many other minor caves, which hydrological connections has been ascertained. Spipola Cave is the median part of the Acquafredda-Spipola cave system and is accessed from the bottom of the Spipola Doline. This the largest karst depression in the area, 500 m wide and 90 m deep. It is crowned by a series of satellite sinkholes, the most important of which are the "Buca dei Buoi" (a collapse doline giving access to a cave) and the "Buca dei Quercioli" (a solution doline).

Acquafredda-Spipola karst system is the largest gypsum karst system of the region and in western Europe, which existence was hypothesized already in 1781 by Serafino Calindri. The first real explorations started only in 1903 by Giorgio Trebbi, and were later fostered by Luigi Fantini and his "Gruppo Speleologico Bolognese" (GSB) caving club, reaching in 1932 three kilometres in explored passages. To date, the system has a development of 11.5 km and an overall depth of 118 m. It includes a large number of hydrologically connected caves, such as Grotta Elena and Grotta del Ragno, upstream and respectively South and East of the Acquafredda sinking stream, the P.P.P. of Sant'Antonio Cave, the "Buco dei Buoi", the "Buco del Bosco", the "Buco dei Quercioli", the Spipola Cave itself, the "Grotta delle Pisoliti", the "Buco del Belvedere", the "Buco del Muretto", the "Buco del Prete Santo" and the Acquafredda Resurgence, most of which with gated and with regulated access.

Ceiling channels in the Spipola cave testifying the antigravitative dissolution by the stream when the cave was partially filled by sediments (photo G. Agolini).

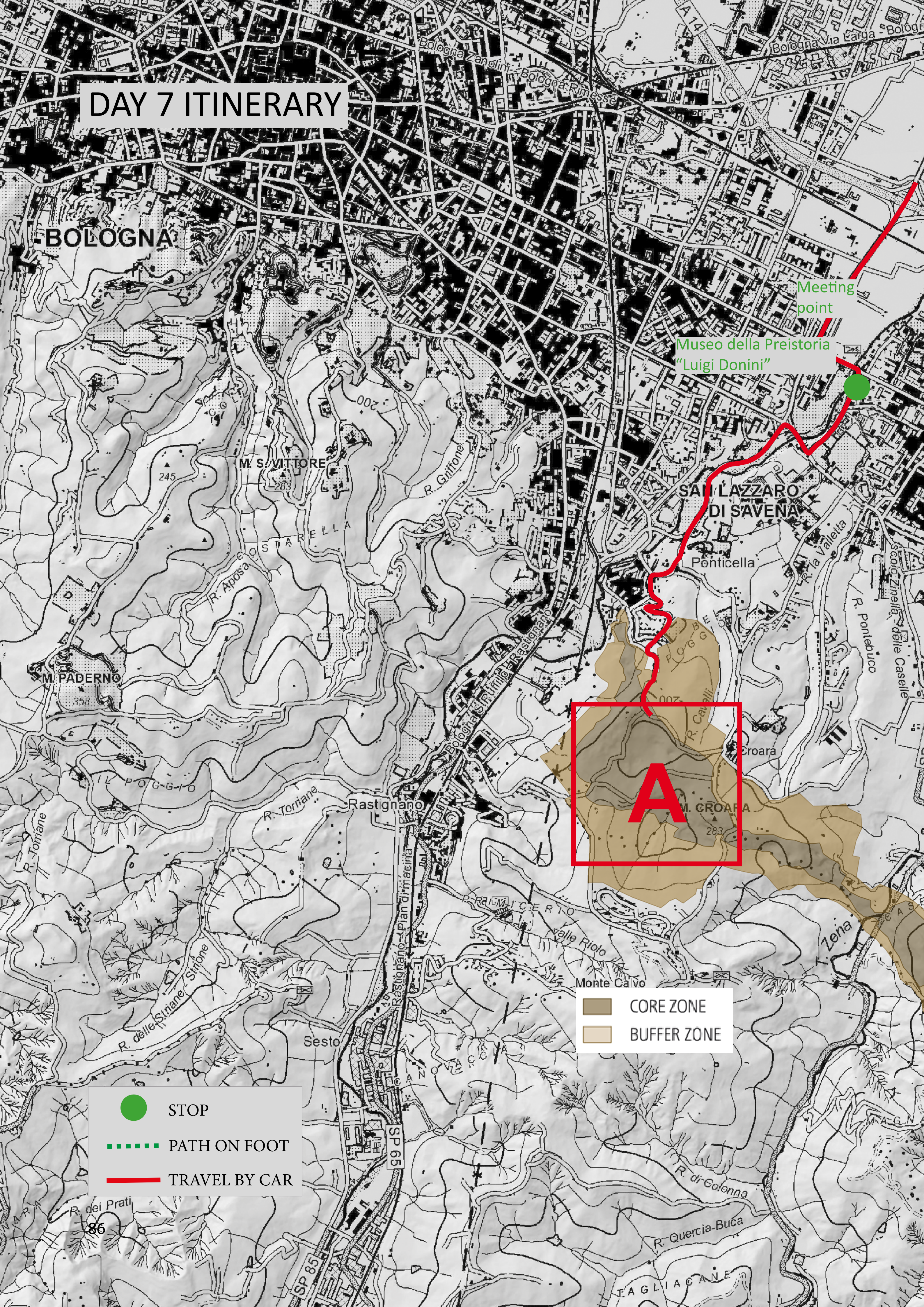
Within the Spipola Cave, alongside an exceptional variety of conical sedimentary features known as "mammeloni", exposed in correspondence of the clayey interbeds, there are many solutional morphologies of major importance, such as the antigravitative ceiling channels, and the great collapse halls (the Giorgio Trebbi and the Giulio Giordani Halls), among the greatest natural underground rooms known in epigenic gypsum caves. Numerous fossils of Messinian plants have been discovered in the marly interbeds of Spipola Cave very recently (2009).

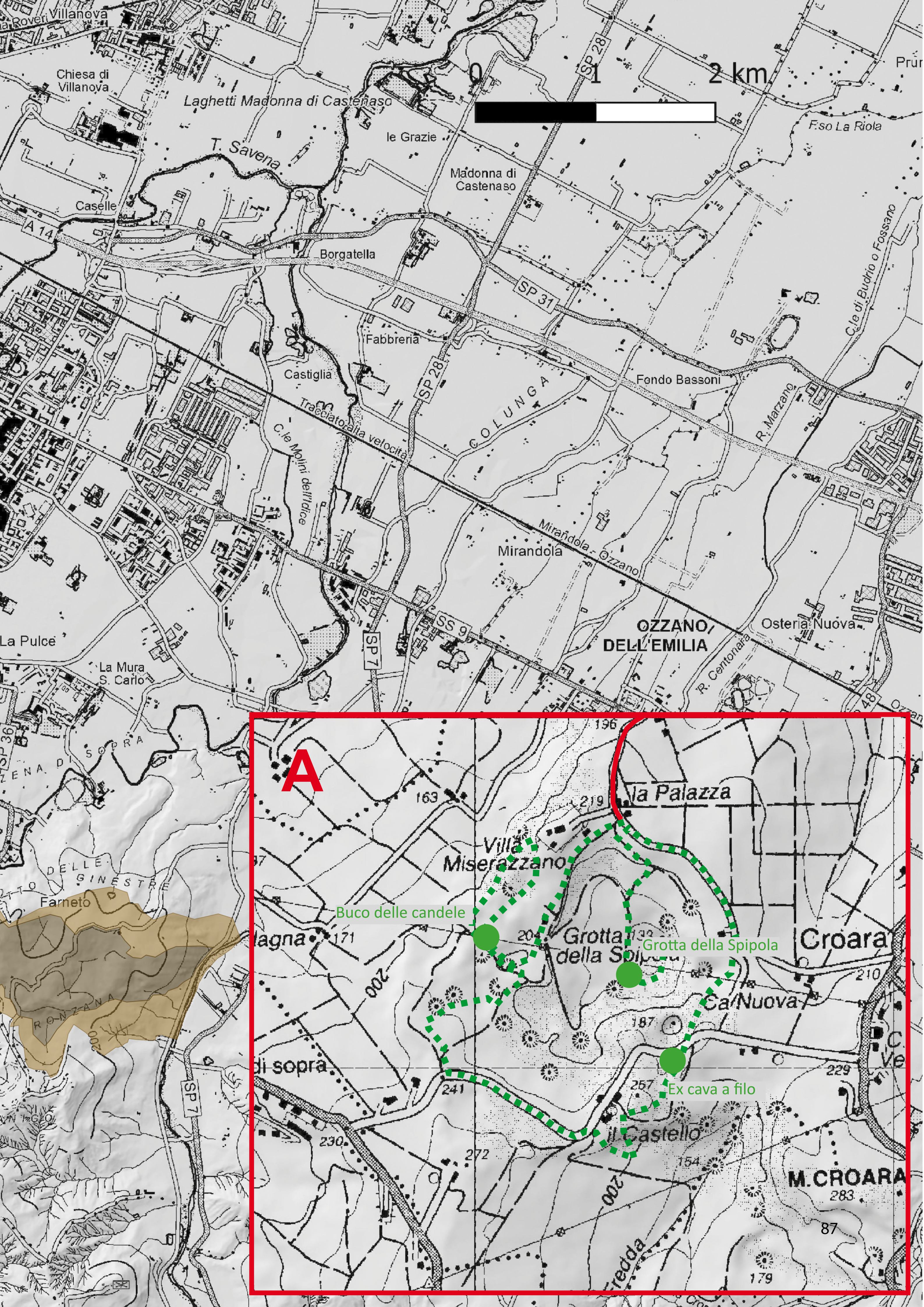
The main axis of the system is set along two faults, which intersect at the P.P.P cave. A flooded tunnel, 955 m long and interrupted by some collapse areas, connects the Acquafredda to Spipola Cave. This underground river, Rio Acquafredda, is the main collector of the System, and has variable flow rates between 0.5 and 800 L s^{-1}.

Thanks to the modernization of preliminary works carried out between 1935 and 1936 by the GSB, since 1994 it is possible to visit the cave under the supervision of trained cave guides, managed by the Regional Park of the "Gessi Bolognesi e Calanchi dell'Abbadessa". The access to the cave takes place through an artificial entrance, opened in 1935 on the bottom of the Spipola doline, equipped with a gate that ensures the transit of bats and other micro-mammals. The tourist route (700 m long) winds along the main and dry cave level and reaches the large Giulio Giordani Hall.

(David Bianco, Jo De Waele)

Partial view of the large Giordani room in the Spipola cave. The room evolves by rockfall of gypsum layers from the ceiling (photo F. Grazioli).


DAY 7 ITINERARY
BOLOGNA
Meeting point
Museo della Preistoria "Luigi Donini"
SAN LAZZARO DI SAVENA
Ponticella
M. S. VITTORE
M. PADERNO
Rastignano
Croara
M. CROARA
A
Monte Calvo
Sesto
SP 65
CORE ZONE
BUFFER ZONE
STOP
PATH ON FOOT
TRAVEL BY CAR



0
1
2 km
Villanova
Chiesa di Villanova
Laghetti Madonna di Castenaso
le Grazie
Madonna di Castenaso
T. Savena
Caselle
A 14
Borgatella
SP 31
SP 28
Fabbreria
Castiglia
Tracciato alta velocità
C.le Molini dell'Idice
COLUNGA
Fondo Bassoni
R. Marzano
C.le di Budrio o Fossano
F.so La Riola
Mirandola
Mirandola - Ozzano
OZZANO DELL'EMILIA
Osteria Nuova
R. Centonara
SS 9
SP 7
La Pulce
La Mura S. Carlo
SP 36
Farneto
A
la Palazza
Villa Miserazzano
Buco delle candele
Grotta della Spipola
Grotta della Spipola
Croara
Ca Nuova
Ex cava a filo
il Castello
M.CROARA
di sopra
163
219
196
171
204
187
257
241
230
272
154
210
229
283
87
179
200

“Buco delle Candele” (Hole of Candles)

The “Buco delle Candele” is probably one of the main scenic hotspots of the “Gessi Bolognesi” Natural Park. In reality, this geosite needs to be seen in combination with the nearby “Buco del Belvedere” swallow hole, since these two landforms are closely and genetically related, the first being an older (and abandoned) version of the latter.

The “Buco delle Candele” has been discussed scientifically by Giovanni Capellini in 1876, together with some nice drawings, and as such is one of the earliest karst geosites described in the area of Bologna. It looks like an amphitheater, formed by high pinnacles of Messinian gypsum, which are the result of the combined action of corrosion caused by rainwater, and erosion by the concentrated runoff on the bare gypsum rocks. Whereas the “Buco delle Candele” is completely clogged by sediments, the “Buco del Belvedere” is still activated during heavy rainstorms, representing a still active swallow hole. This cave has a vertical access in between the vertical gypsum pinnacles, dropping into a vast subterranean room, the vault of which is characterised by a macro-crystalline gypsum layer displaying large conical forms of over a metre in diameter. These are the casts of the gypsum crystal aggregates that grew onto the marly substrate of the shallow sea, their weight causing them to “sink” into the muddy layer forming these conical structures, which are now visible due to the removal of the underlying marls. Both caves are part of the Acquafredda-Spipola Cave system, and the water flowing into them eventually reaches the Spipola cave and the Acquafredda Spring.

(David Bianco, Jo De Waele)

The Buco delle candele (Hole of candles) with its remarkable karst features represents one of the most celebrated spot in the Gessi bolognesi.

Cava filo

The paleontological deposit is located on the western front of Monte Castello (Croara - 256 m a.s.l.). The most recent investigations, still in progress, indicate that abundant faunal remains of large and small mammals (*Bison priscus, Megaceros giganteus, Capreolus capreolus, Marmota marmota, Meles meles meles timidus*), birds, pollen and a small number of lithic finds were sedimented within a system of sub-horizontal karst conduits, by water flowing northward during a cold climatic phase of the last glacial expansion.

The deposit cover a time span between 25,000 and 17500 cal BP. The oldest phase (25005-23842 cal BP) corresponds to a cold peak of the Last Glacial Maximum. The pollen content indicate widespread cold and arid grasslands dominated by a steppe bison megafauna and by specialized ecomorphic predators, such as wolf (*Canis lupus*).

The deposit proved to be of the utmost importance not only for the very high number of remains of Bison priscus, which make it one of the most important deposits at national level, but also because studies on ancient DNA have shown that some wolf finds, dating back to about 2500 years ago, indicates a genetic continuum with domestic dogs, backdating the origin of this animal and the beginning of domestication in Europe.

The anthropogenic materials consist of a series of small lithic splinters and bones with traces of animal flaying by groups of hunters from the upper Paleolithic.

(Gabriele Nenzioni)

The paleosinkhole at Cava a filo around 1962 (photo L. Fantini).

Bison priscus *remains (photo F. Grazioli).*

Cava a Filo excavations in 2007 (photo M. Marchesini).

Named in memory of the speleologist Luigi Donini, who was awarded a gold medal for civil valor, the museum is inspired by the themes of the origin of Man and the Quaternary paleoecology. It focuses on the evidence of human material culture connected to the environment in the territorial system, the heart of which is the Regional Park of Gessi Bolognesi and Calanchi dell'Abbadessa.

The Room of the Environment reconstructs a rare paleoenvironmental sequence, largely from the prehistoric deposits discovered in the gypsum karst. Characterized by sudden and extreme climatic variations, it is distributed between 44000-43000 (Monte Croara -IECME quarry) and 24500-17500 years ago (Cava Fiorini and Cava a Filo quarries). The faunal component - museographically enhanced by the alternation of original bone finds, skeletal reconstructions of the main macro faunas and life-size three-dimensional scenographic apparatus - includes fossil remains of *Bison priscus, Megaloceros giganteus, Bos primigenius, Capreolus capreolus, Marmota marmota, Lepus timidus, Canis lupus*.

Some fossil are unique in the regional panorama such as the bones of the cave hyena (*Crocuta crocuta spelaea*), of Ghiottone (*Gulo gulo*) - a large mustelid today present only in some Holarctic areas - the rare remains of Megacero, a large steppe grassland cervid extinct in the final stages of the Last Glacial, and the exceptional concentration, unique in Europe, of steppe bison present in the Cava Filo deposit.

Display dedicated to the fossil fauna from the Cava a filo quarry (photo F. Grazioli).

The Hall of Evolution is developed by addressing the complex theme of the first human communities. Thousands of stone chips are evidence of the presence of Paleolithic hunter-gatherer communities, starting 800,000 years ago. Spectacular three-dimensional reconstructions illustrate the first hominids (australopithecines) and of *Homo abilis, Homo heidelbergensis, Homo neanderthalensis, Homo sapiens*.

Among the numerous contexts on display, the funerary materials of the Sottoroccia del Farneto - the collective burial ground of the late Neolithic-early Copper Age discovered by Luigi Fantini - are of particular relevance, arrowheads, polished tools, stone ornaments and bone from the coeval settlement of Monte Castello and the showcase dedicated to the Grotta del Farneto cave.

(Gabriele Nenzioni)

Room of the environment: diorama con models of Bison priscus *and* Megaloceros giganteus *(photo F. Grazioli).*

The beginning of cave science: history of research in the Gessi Bolognesi

The Gessi Bolognesi area is most studied internationally and discoveries that took place here are considered milestones in the development of hydrogeology, mineralogy and speleology in evaporitic karst systems since 16th century.

The first scientific note concerning a stalactite found in a natural cave in the Gessi Bolognesi is due to Ulisse Aldrovandi (1527-1605), whereas Tommaso Laghi (1709-1764) gives an account of the discovery of the cave mineral hepsomite from the Risorgente dell'Acquafredda. Serafino Calindri (1733-1811) visits and describes some caves. Tommaso Santagata (1774-1858) described for the first time the fibrous variety of gypsum (satin-spar) from the Grotta Gortani and his son Domenico (1811-1901) the gypsum crystals formed within clay deposits. Giovanni Capellini (1833-1922) describes for the first time the famous candle-like dissolution features, giving a first scientific explanation for their formation.

Recognized as "pioneer of speleology in gypsum" is however Francesco Orsoni (1849-1906), author in 1781 of the discovery of the Grotta dell'Osteriola, in Farneto, where he conducted a long series of excavations in one of the most important stations for the Bronze Age. The news was disclosed to the Academy of Sciences by Giovanni Capellini (1833-1922), Director of the Institute of Geology in Bologna. He himself published in 1876 the first morphological and genetic annotations on the development of local kars.

A new season of speleological research opened in 1903 with the foundation in Bologna of the Italian Society of Speleology by three young students of Capellini: G. Trebbi, M. Gortani, C. Alzona and C. Barbieri. The Society, published the Italian Speleology Magazine, a periodical in which - between 1903 and 1904 - fundamental contributions by Trebbi and Alzona appear, referring respectively to the deep karst phenomenon and to the cave-dwelling fauna in the Gessi Bolognesi. The geographer Olinto Marinelli (1874-1926) provided a detailed overview of the surface karst phenomenology in 1917 using the writings of G. Trebbi (1880-1960), who in 1926 completed the first and most exhaustive study on a the gypsum cave.

The Italian Speleological Society had a short life, but resurrected in 1950, as the Italian Speleological Society, while the Italian Institute of Speleology, founded in 1929 in Postumia by Michele Gortani (1883-1966), remained active in Bologna. With the establishment of the Bolognese Speleological Group by Luigi Fantini (1895-1978), a new season of systematic exploration began and over 60 caves were discovered in the span of five years. After the Second world war the speleologists conducted - from 1960 to 1988 - an effective struggle to close the gypsum quarries and for the establishment of the Gessi Bolognesi Regional Park. In 1979, the Bolognese Speleological Group and the Bolognese Speleological Union united in the Regional Federation and initiated an intense collaboration with the Universities of Bologna and Modena, which further amplified the vast wealth of knowledge acquired on the superficial and deep karst of the territory.

There are 265 caves in the Gessi Bolognesi listed in the National Cadastre including some of large lenght, such as the Spipola-Acquafredda complex, mapped for more than 10 km, the Partigiano-Modenesi complex, more than 4 km and four others that branch off for 1-2 km.

(Paolo Grimandi)

References

Balestrieri M.L., Pandeli E., Bigazzi G., Carosi R., Montomoli C., 2011, Age and temperature constraints on metamorphism and exhumation of the syn-orogenic metamorphic complexes of Northern Apennines, Italy, Tectonophysics, 509, 254-271.

Benton M.J. 2016, The Triassic, Current Biology 26, R1205–R1225.

Bernardi M. 2018. "Dinosaur diversification linked with the Carnian Pluvial Episode". Nature Communications 9: 1–10.

De Graciansky P.C., Roberts D. G., 2011, On the Origin of the Alps: The Vanished Oceans, Developments in Earth Surface Processes, 14, 55-75.

Delmonte C., De Waele J., Fornaciari E., Pasini G.,Vaiani S., Correale C., Fabbri F. 2013, Mine Caves/ Grotte di Miniera, Memorie Istituto Italiano di Speleologia, 28, 177-189.

Faccenna, C., Becker, T. W., Auer, L., Billi, A., Boschi, L., Brun, J. P., Capitanio F.A., Funiciello F. Horvàth F., Jolivet L., Piromallo C., Royden L., Rossetti F., & Serpelloni, E. (2014). Mantle dynamics in the Mediterranean. Reviews of Geophysics, 52(3), 283-332.

Forti P. & Francavilla F. (1990) - Gli acquiferi carsici dell'Emilia-Romagna: conoscenze attuali e problemi di salvaguardia. Ateneo Parmense, Acta Naturalia, 26 (1-2), pp. 69-80.

Lugli S. 1993, - Considerazioni geologiche sulla genesi delle cavità ad "ansa ipogea" nelle evaporiti triassiche dell'alta val di Secchia. Le Grotte D'Italia - Atti XVI Congresso Nazionale di Speleologia (4) XVI, 1992-1993, p. 257-266.

Lugli S., Morteani G and Blamart D., 2002 - Petrographic, REE, fluid inclusion and stable isotope study of the magnesite from the Upper Triassic Burano Evaporites (Secchia Valley, northern Apennines): contributions from sedimentary, hydrothermal and metasomatic sources. Mineralium Deposita, 37: 480-494.

Lugli S., Manzi V., Roveri M. & Schreiber B.C., 2010. The Primary Lower Gypsum in the Mediterranean: A new facies interpretation for the first stage of the Messinian salinity crisis. Palaeogeography, Palaeoclimatology, Palaeoecology, 297, 83-99.

Lugli S., 2019, Il gesso in natura e nell'arte. GeoArcheoGypsum2019, Geologia e archeologia del gesso: dal *lapis specularis* alla scagliola, (a cura di) D. Gulli S. Lugli, R. Ruggieri, R. Ferlisi. Palermo, Regione siciliana, 17-31.

Lugli S., 2019, I grandi cristalli di gesso di Monte Mauro, quasi un primato mondiale. In: I gessi di Monte Mauro, studio multidisciplinare di un'area carsica nella Vena del Gesso romagnola, Costa M., Lucci P. e Piastra S. (a cura di). Memorie dell'Istituto Italiano di Speleologia, s. II, v. 34, 45-48.

Scotese C.R. 2001, Atlas of Earth History, PALEOMAP Project, Arlington, Texas, 52 pp.

Notes

EKCNA

Regione Emilia-Romagna

MINISTERO DELLA
TRANSIZIONE ECOLOGICA