Volume n° 1 - from PR01 to B15

Field Trip Guide Book - B03

32nd INTERNATIONAL GEOLOGICAL CONGRESS

SINKHOLE'S PHENOMENA IN LAZIO REGION: A LIVE POINT OF VIEW OVER CASE STUDIES

Leaders: F. Nolasco, A. Colombi

Florence - Italy
August 20-28, 2004

Pre-Congress **B03**

The scientific content of this guide is under the total responsibility of the Authors

Published by:
APAT – Italian Agency for the Environmental Protection and Technical Services - Via Vitaliano Brancati, 48 - 00144 Roma - Italy

APAT
Italian Agency for Environment Protection and Technical Services

Series Editors:
Luca Guerrieri, Irene Rischia and Leonello Serva (APAT, Roma)

English Desk-copy Editors:
Paul Mazza (Università di Firenze), Jessica Ann Thonn (Università di Firenze), Nathalie Marléne Adams (Università di Firenze), Miriam Friedman (Università di Firenze), Kate Eadie (Freelance indipendent professional)

Field Trip Committee:
Leonello Serva (APAT, Roma), Alessandro Michetti (Università dell'Insubria, Como), Giulio Pavia (Università di Torino), Raffaele Pignone (Servizio Geologico Regione Emilia-Romagna, Bologna) and Riccardo Polino (CNR, Torino)

Acknowledgments:
The 32nd IGC Organizing Committee is grateful to Roberto Pompili and Elisa Brustia (APAT, Roma) for their collaboration in editing.

Graphic project:
Full snc - Firenze

Layout and press:
Lito Terrazzi srl - Firenze

Volume n° 1 - from PR01 to B15

32nd INTERNATIONAL GEOLOGICAL CONGRESS

SINKHOLE'S PHENOMENA IN LAZIO REGION: A LIVE POINT OF VIEW OVER CASE STUDIES

AUTHORS:
F. Nolasco (Regione Lazio - Italy), A. Colombi (Regione Lazio - Italy)

Florence - Italy
August 20-28, 2004

Pre-Congress

B03

Front Cover:
1) Laghi del Vescovo (Pianura Pontina, Latina)
2) Doganella di Ninfa (Pianura Pontina, Latina)
3) Lago Paterno (Piana di S. Vittorino, Rieti)
4) Acque Albule (Tivoli, Roma)
5) Lago Leprignano (Capena, Roma)

Leaders: F. Nolasco, A. Colombi

Introduction

Since the Roman Period of Pliny the Younger and Vitruvius, the phenomenon of sinkholes has been registered in Central Italy, but their scientific interest and importance as a warning of safety problems have increased in the last century. This is the result of the development of infrastructures and industrial areas and the continuous necessity for residential buildings.

better understand the reasons for these occurrences. The field–trip will cover some of the most important geological landscape of Central Italy.

Scientists from the USA, Mexico, China and some European countries have been studying the sinkhole problem very intensively for many years, while in Italy this research has been undertaken just a few years ago.

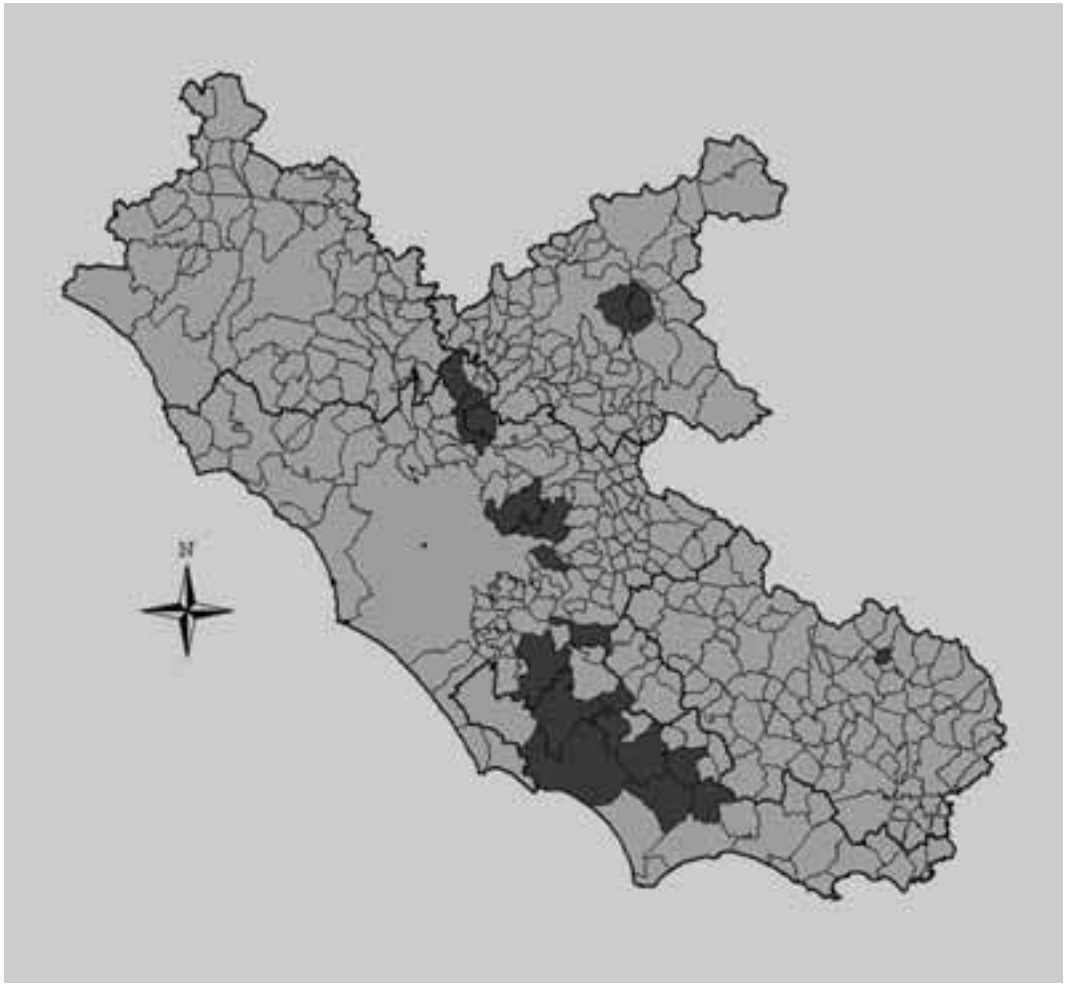


Figure 1 - Sinkhole in the Latium region

Italian sinkholes present many differences from other sinkholes throughout the world depending on their particular genesis, evolution and geological features (Colombi et al., 2001). During this field-trip observation of their geological framework will help us to

The increase in this phenomenon has stimulated the necessity for new and more specialized knowledge and has determined a new commitment by local authorities to manage the territory appropriately (Kemmerly, 1993).

Volume n° 1 - from PRO1 to B15

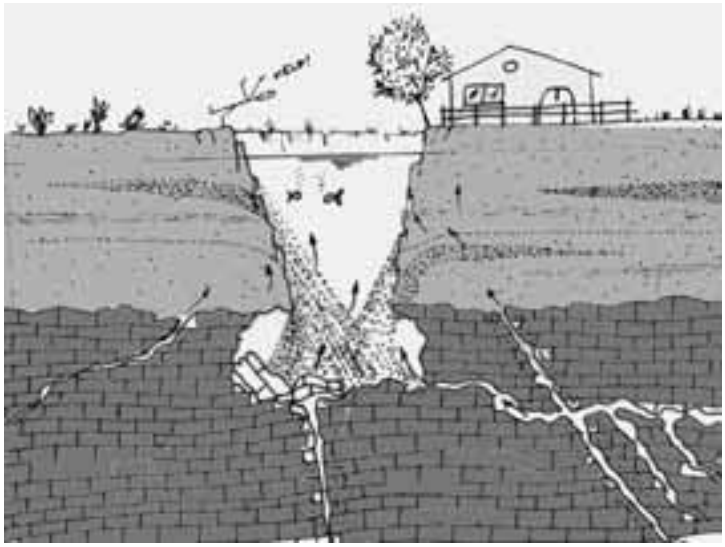


Figure 2 - Sinkhole Hazard

For any field references we recommend the "Guide Geologiche Regionali. Lazio" issued by BE-MA, the geological Map of Italy (1:100000) Sheet n 144 Rieti, 145 Avezzano and 158 Latina.

Regional geologic setting

The scientific importance of sinkholes has been determined by the complexity and multidisciplinary rules involved during their formation and evolution (*Faccenna, 1993*).

In Italy many sinkholes have occurred very close to urban areas, creating a geological hazard due to the high vulnerability of man-made structures.
The most important sinkholes (fig. 1) in the Latium region (S*an Vittorino plain, Pontina valley, Roman countryside and Marcellina*) demonstrate the high risk for the population and how far off our knowledge of the genesis and dynamics of these phenomena still is.

But how do sinkholes happen? This problem is not easy to define because although there are different respectable scientific theories; at the moment no one is absolutely certain which is the right one.
There is the classic theory of the *Cave collapse sinkhole,* where the sinking occurs from the cave in of the karstic carbonatic roof and the consequent collapse of the upper structure. Other scientists think that sinkholes occur in alluvial terrain from the strong transport of fine material due to a sudden change in hydraulic flow with the consequent collapse of the pertinent upper sediments, such as travertine and cemented sands (*Cover collapse sinkhole*).
The game is open but our real aim is to understand which theory will better justify the genesis, shape and evolution of sinkhole events.
Let us now examine a short history of the sinkholes occurring in the Latium region. Not going too far back in time, we will start with the sinkholes occurring in the XIX century. In October 1856, close to Leprignano lake or Puzzo lake, about 35 km north of Rome, a big sinkhole opened suddenly after the ground had sunk by several centimetres during the previous days. This sinkhole was announced *"…by loud noises and shaking*".
About 44 years later the sinkhole no longer existed, , filled in by lacustrine and marshy deposits; but in the same place in 1928 a new sinkhole occurred, 100 meters wide and 30 meters deep (*Segre, 1948*).
In 1935 about 3km to the north of Puzzo lake, a new sinkhole called Nuovo lake opened, accompanied by H_2S emissions; this event was also connected with *"…three strong detonations*". Today this sinkhole, 260 meters wide and 20 meters deep, no longer exists because of intensive agricultural activity (*Segre, 1948*).
Many other sinkholes occurred at the beginning of the XX century in different areas near Rome, close to Guidonia, Artena, Corcolle, Gallicano, Percile, and so on in the Pontina valley and in the Rieti area.

Figure 3 - Marcellina sinkhole (A. Colombi)

From the research carried out by the Latium Regional Administration with the collaboration of the University of Rome Three (*Capelli et al., 2001; Colombi et al. 200; Regione Lazio, 2002*), it has been possible to compare recent topography with earlier topography existing before the land reclamation operated during the Fascist period. It has been discovered that the Pontina valley has always been affected by sinkholes, and at the moment many of them have been erased by the reclaimed land or by urban activity (*Colombi, 2001; Salvati et al. 2001*). Sinkholes called "*gli Sprofondi (the Collapses)*" and "*Laghi del Vescovo (Bishop lakes)*" are old sinkholes occurring in the XIX century. The former are twin sinkholes with vertical cliffs and a diameter greater than 50 meters, hidden by a little wood.

The "*Laghi del Vescovo*", are three little lakes with low cliffs and different colours of water (*light blue, emerald green and blue*) because of different concentrations of gas in each one.

During August of 1989 a new sinkhole opened in Sermoneta County, between the village of Doganella di Ninfa and the Natural Oasis of Ninfa. Luckily this sinkhole only involved an agricultural area and a rural road. Presently, its progress has ceased, but in the first five years the diameter quickly grew until reaching about sixty meters and a depth of 35 meters (*Bono, 1995*).

In October 1993, again in the Pontina valley, close to the village of Foro Boario, during water drilling an induced sinkhole occurred at the edge of the Appian Way; the drill machine was completely sucked in and has never been found. At present the area is a big cemented parking lot for nearby industries.

The San Vittorino plain, the first area visited during the field-trip, is the area in Latium with the most sinkholes and also with heavily concentrated human activity.. In this area there is a busy road (*SS4 Salaria*), a railway (*Terni-Aquila*), a hanging riverbed (*Velino river*), the most important European springs (*Peschiera springs*), villages, small industries and a gas pipeline, so that many specialised studies are still being carried out (*Nolasco, 1995*).

Since 1995 the Latium regional administration with the collaboration of the University La Sapienza of Rome has been monitoring the area through multiparameter drilling, microgravity prospecting, tomography and topographic surveys, hydrogeological and geochemical studies. In 1997 the Latium Region issued the first resolution with the aim of containing the sinkhole risk areas and the related protection rules.

The last sinkhole occurring in the Latium Region was near the village of Marcellina (photo 1), in February 2001; the sinkhole occupied an agricultural area 70 meters in diameter and 20 meters deep; the sinkhole struck a high voltage power line and a gas pipeline (*Argentieri et al. 2001*).

Field itinerary

DAY 1

The field-trip starts in Florence, reaching the village of Greccio about midday, after visiting the Marmore falls. Going along the Rieti–Terni road towards Rieti we turn right at the village of Limiti of Greccio, climbing until the village of Greccio where we will stop for lunch at "*Nido del Corvo*" restaurant.

From the Greccio viewpoint we can observe (**Stop 1.1**) the Rieti intermontane basin, where the Velino River flows to Marmore falls. In front of us the western front of the Terminillo chain can be seen.

This Mesozoic carbonatic chain is a limestone and dolomite sequence in slope-ramp facies, with the presence of many tectonic discontinuities that have determined six tectonic units, each one separated by thrust surfaces. In the lower part of the western side of the Terminillo chain Plio-Pleistocene fluvial and fluvial-glacial deposits outcrop.

The Rieti intermontane basin is a tectonic basin filled by alluvial deposits. The present-day fluvial pattern of the basin is the product of a series of land reclamations and artificial hydraulic changes operated in the past centuries.

The basin presents many old and recent neotectonic signs, such as a NW-SE strike slip fault system involving the Pleistocene lacustrine deposits with some westward down lift. Another neotectonic sign is the presence of a cataclasis zone at the edge of the lower part of the western side of the Terminillo chain and, moreover, in the same area, the presence of alluvial cones located at different topographic levels, often disrupted.

After lunch we move from Greccio to Rieti along the SP Ternana. Along the road we will border the southwestern edge of the Rieti basin with some isolated hills of Cenozoic deposits, located in the middle of the basin. The hills and mountains on the right of the road are the Meso-Cenozoic outcroppings of the northern margin of the Sabini Unit, represented by the siliceous-clastic and carbonatic deposits of the Umbro-Sabina sequence.

Figure 4 - Paterno lake and San Vittorino Plain (A. Colombi)

Once we have reached Rieti the field-trip leaders will introduce the program for the next two days.
Free night in Rieti.

DAY 2

This second day starts off in the town of Rieti and going along the Salaria road towards Aquila we will reach the San Vittorino plain, the site of our next stops. The heavy human activity doesn't allow for important geological outcroppings during the first kilometres. After the Cittaducale junction road we enter the San Vittorino plain, bordering its northern margin; we move for several kilometres over the contact between the continental deposits on the right, and the Scarp sequence of the Terminillo chain, on the left.
At the bottom of the Terminillo carbonatic deposits many springs are visible directly from the vehicle. Some of these are sulphurous springs (*Terme di Cotilia)* while others have no gas concentration (*San Vittorino)*.
Passing the Cotilia junction road we arrive at the village of Vasche, where we turn left to climb up along an unpaved path, until arriving at an observation point (**Stop 2.1**) near two old dolines, now quite hidden by vegetation. From this point it is possible to have a general view of the San Vittorino plain (Figure 4), with the carbonatic shelf sequence on the left of the Mount Nuria Unit, sinking along the old tectonic Olevano-Antrodoco discontinuity, where the carbonatic scarp sequence of the Terminillo Unit, where we are, overlaps the Mount Nuria Unit. This thrust is hidden by the alluvial deposits filling the plain and are more than 100 meters thick (*AA.VV., 1993; Bigi et al. 2000; Capelli et al. 2001*).
The Peschiera spring, visible at the southern margin of the plain behind the ACEA building, supplies Rome with more than 10m^{3}sec of water. Peschiera springs are the final point of a very extended regional aquifer that goes from the Velino chain, in the Abruzzi region, to the Nuria mountains.
This stop is a magnific viewpoint for verifying the real fragility of the San Vittorino plain with its geological hazards (*active seismicity, presence of sinkholes, Peschiera springs, landslides, hanging riverbed)* and the extremely developed human context (*villages, railway, main road, industries, power supply, gas pipeline*); all these things make this area a high geological risk zone.
From the observation point we go down to the village of Vasche (**Stop 2.2**) where near the Church it is possible to see, the monitoring system (*a multiparameter continuos drill*) ordered by the Regional Administration to evaluate all warning parameters for the occurrence of possible sinkholes. On foot we arrive at Paterno lake, an old sinkhole with the village built around it.

We again take the SS4 "Salaria" towards Rieti and after a few hundred meters turn left onto a secondary road to the San Vittorino plain until reaching Peschi-

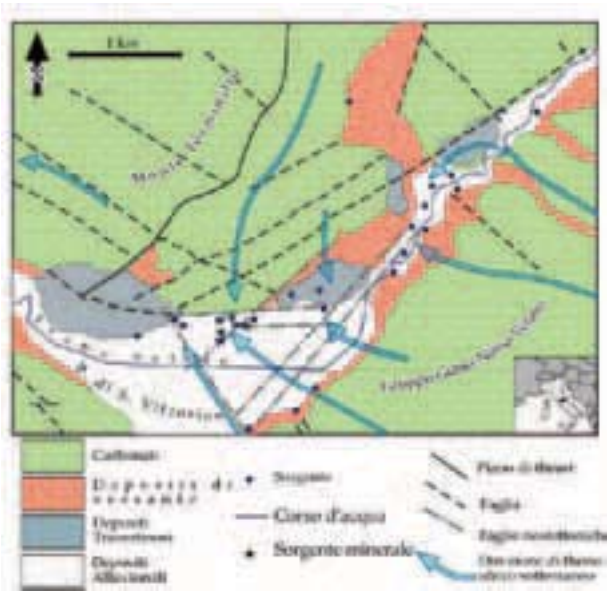


Figure 5 - Schematic geological setting of San Vittorino plain (from Boni et al. modified 1995)

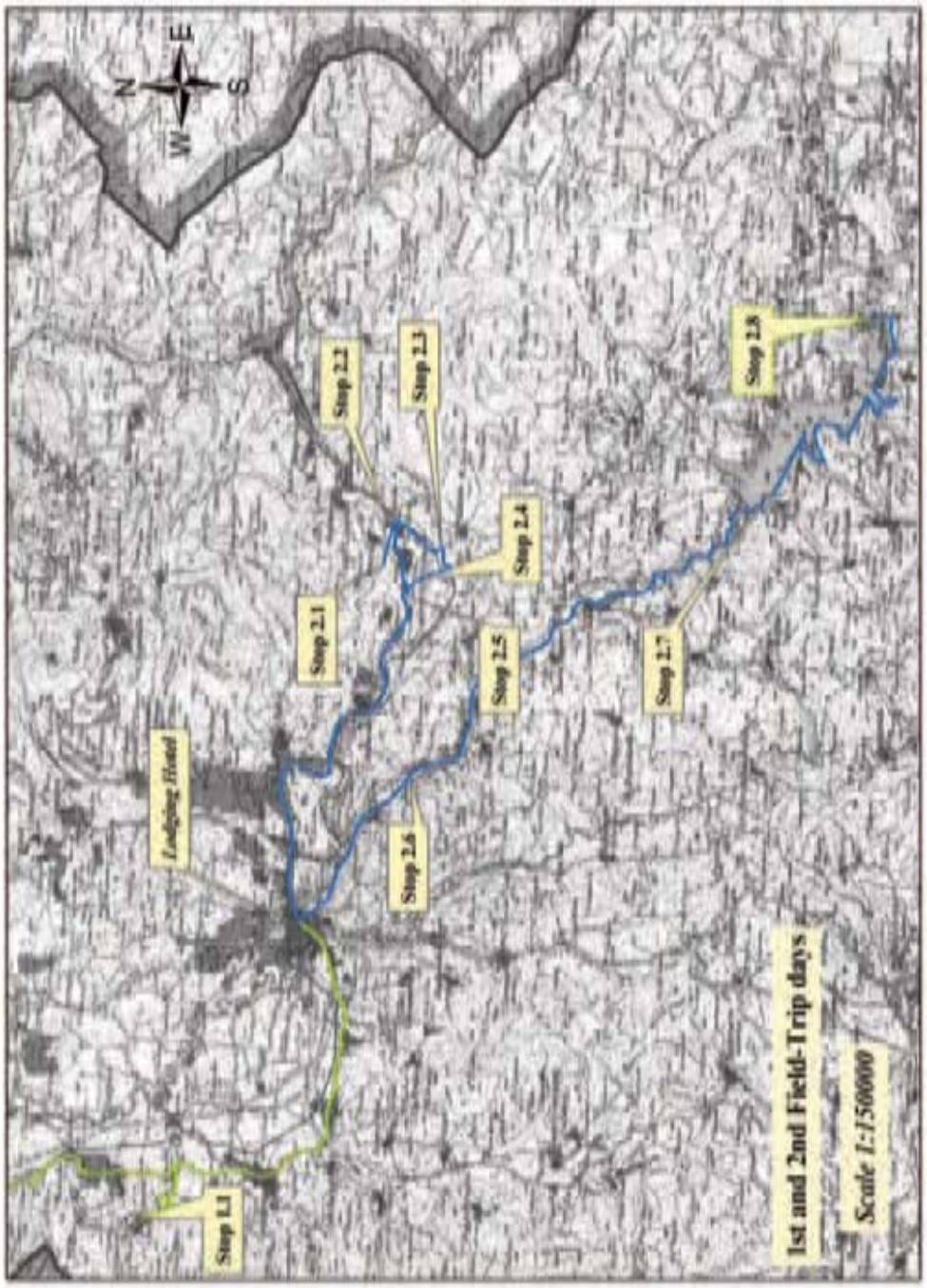

N
E
S
W
Stop 1.1
Stop 2.1
Stop 2.2
Stop 2.3
Stop 2.4
Stop 2.5
Stop 2.6
Stop 2.7
Stop 2.8
Lodging Hotel
1st and 2nd Field-Trip days
Scale 1:150000

Figure 6 - San Vittorino sinkhole (R. Salvati)

era Springs (**Stop 2.3**).
The springs are located at the southwestern margin of the San Vittorino Plain and the spring extends for more than a kilometer, where the carbonatic sediments of the Monte Nuria Unit are in contact with the recent fluvial-lacustrine deposits, composed of sands, clays and sandy-clay with some travertinous layers.
After visiting Peschiera springs with the kind collaboration and organization of the ACEA technicians, we continue the field-trip along a secondary road to look at the hanging riverbed of Velino and sinkholes occurring on the plain (Figure 5), some of which are recent events (1986-92). Some sinkholes have involved the hanging riverbed (**Stop 2.4**).
Coming back to the SS4 Salaria, after the village of Terme of Cotilia, with its small sulphur-colored lakes, we arrive at km 100+700, near the church of San Vittorino (**Stop 2.5**). This deconsecrated church of the 1700s has slowly sunk more than 2 meters below the original surface beacuse of a sinkhole. Inside the church there is a spring and the waters go out through the church portal.
After lunch we follow the Salaria road until the junction with SP 578 Salto-Cicolana, arriving in the Salto Valley. Between the villages of Casette and Grotti the next stop (**Stop 2.6**) shows a beautiful geological landscape, where an impressive outcrop of Lower Villafranchian gravel in an alluvial fan environment unconformably superrimpose the carbonatic bed-rock (Maiolica). Above the gravel Upper Villafranchian fluvial-lacustrine deposits outcrop (*AA.VV., 1993*).
Continuing along the SP 578 we reach the Salto Dam, and crossing it we arrive at the next stop (**Stop 2.7**); The dam, which forms Salto Lake, is on the left and its strucuture inside the mountains where the Sabine Unit, in anticlinal form, consisting of Bryozoan and Lithothamnia limestone and Guadagnolo Marls, thrusts eastwards towards the Orbulinae Marls and Messinian clayey-arenaceous Flysch, along a sector of the Olevano-Antrodoco discontinuity (*AA.VV., 1993*).
Following SP 578, with the beautiful view of Salto Lake on the left, we reach the Fiumata Bridge where we will make our the last stop on this first day of our field-trip **(Stop 2.8)**; in front of us in the mountains it is possible to see the Fiamignano Fault, a discontinuity of several kilometers puts the Cretaceous Carbonatic structures of "Monte tra le Serre" in contact with the plio-pleistocene lacustrine and palustrine deposits, where it is possible to observe beautiful neotectonic examples in the Poggio Poponesco breccia formation. The fault-line is clearly visible from the entire Salto valley.
Presently, there is discussion about the activity of this fault and some authors indicate that this long discontinuity could be a deep gravitational plain reactivated by seismic events.
From the village of Fiumata we arrive at the Salto-Cicolana motorway and continue until the A24 Highway. Right near the "Valle del Salto" tollhouse we can see the impressive Velino Group flank that may represent an old flat thrust-ramp for the tectonic units during the Apennine orogenesis.
We take the highway and arrive in Rome at approxi-

Figure 7 - The Cathedral of Campo Soriano (R. Maurizi)

Figure 8 - "Laghi del Vescovo" sinkholes (A. Colombi)

mately 8 p.m.
Lodging in Hotel and a free night to visit Rome.

DAY 3

Departure at 8.30 a.m. by van from Rome to Campo Soriano, in the South of Latium. From Rome we take the SS158 Pontina until the town of Terracina and along the way we can see on the left the Colli Albani volcanic structure and then the Lepini carbonate chain. After Latina, the fence of the Circeo National Park is visible with its dense forest.
From Terracina the road starts climbing up to the mountains until the ancient Roma temple of Jupiter Anxur, built over the carbonatic shelf sequence composed of limestone and dolomite with Late Cretaceous Rudista (*AA.VV., 1993*).
The winding road continues climbing, crossing "red earth" bed terraces and the view of the Tyrrenian sea is absolutely superb.
After about 10km we arrive at the fossil polje of Campo Soriano (**Stop 3.1**), a 300m wide and 3km long valley established by two main branches, the first in the direction of the Apennine and the second with a N-S direction. The Campo Soriano area was proclaimed a Natural Monument in 1985. This karstic depression is one of the most beautiful and fascinating examples of karst landscape in Italy, with dolinas, sinkholes, "lumen", fields with tracks, representing a unique scientific geological landscape in central Italy.
The typical aspects of Campo Soriano are represented by the particular structure and lithological nature of the rocks, the peculiar modelling of the ground, the strong morphological aspect of the surface and the deep, evident dryness along with the absence of active drainage and the localized underground water circulation.
At the same time, Campo Soriano is the most important area for water infiltration connected to several springs at the contact point between the Ausoni chain and the Pontina valley.
The shape of the area is a closed valley, surrounded by hills and mountains. The valley is covered with a "red earth" bed, residual part of the chemical dissolution of limestone, taking place during the long karstic process. The "red earth" formation is used as farmland, in particular for vineyards.
The most important morphological elements are represented by the karren, hum, towers, high pinnacles, and by several others typical karst formations and shapes.
The most famous of them is "the Cathedral or Sonnino's Artichoke" (photo 4), a 15-meter tall peak, the symbol of the Natural Monument.
We leave Campo Soriano and after the village of Sonnino we go down until the south eastern edge of the Pontina Valley. The first stop in this sector is close to the Priverno red dune quarries (**Stop 3.2**), where siliceous sands with quartz, feldspar and iron mineral are well exposed. On the slopes of the quarries it is possible to see the lithological contact between the sands and the carbonatic rocks. The "red earth" paleosol bed inserted between the sands and carbonate rocks indicates the continental environment of deposition of these dunes. The social-economic importance of these sands is quite high.

After visiting the quarries we take the SS156 Monti Lepini towards Latina, with a short stop at Fossanova Abbey (**Stop 3.3**), a magnificent example of a XII century Cistercian abbey, settled inside the quiet and beautiful old village.
After lunch at the village of Fossanova, we again take the SS156 Monti Lepini, until the Pontina Plain sinkholes. These sinkholes occurred in a large area filled by alluvial deposits (*sand, gravel, clay and travertine*) and where sampling indicates carbonatic karstic bedrock more than 100 hundred meters below the surface (*Regione Lazio, 2002).*
Going along the piedmont road the first sinkholes we will find are called the "Laghi del Vescovo" (**Stop 3.4**). The "*Laghi del Vescovo*" (photo 5) are three little lakes with low cliffs and different coloured water (*light blue, emerald green and blue*) because of different gas concentrations in each one.
Continuing along the piedmont road, a few hundred meters after the Monticchio quarry, where the ruins of an ancient castle stand alone on top of the calcareous pinnacle, we arrive at "gli Sprofondi" (**Stop 3.5**). These are two round sinkholes with vertical cliffs and

Figure 9 - Doganella di Ninfa sinkhole (A. Colombi)

a diameter greater than 50 meters, hidden by a little wood.

A few hundred meters from "gli Sprofondi", the Natural Oasis of Ninfa is located in a spectacular environmental context. This stop ((**Stop 3.6**) will allow us to briefly visit this beautiful and incomparable natural garden. Unfortunately this stop has not been confirmed at the moment, because of the owner's rules on the number of visitors. So this stop is unconfirmed as of now.

After the entrance to the Ninfa Oasis, on the same road, just to the left of a bend to the right, there is a path. After a few meters on foot we can see the Doganella di Ninfa Sinkhole (**Stop 3.7**). This is the last sinkhole occurring in the Pontina valley. In fact in August 1989 a sinkhole opened (photo 6). Fortunately, the sinkhole involved only an agricultural area and a rural road. At present its development has stopped, but in the first five years the diameter quickly increased, reaching about sixty meters with a depth of 35 meters (*Bono, 1995*).

We take now the road towards Cisterna of Latina and after the "Acque Medie" artificial channel, we turn to the right onto a secondary road until the locality of Casa Affondata (*Sunken House*) where we will make the last stop of this field-trip (**Stop 3.8**).

This sinkhole (photo 7) is a lens 30 meters wide and about 20 meters deep; the geology of this area presents a stratigraphic succession of travertines, on the top, and then layers of fine sands and clays with lens of tuff and calcareous sands.

This sinkhole was discovered by scientist a few years ago, but the area is known for a strange and fantastic legend, in which the evil owner of an ancient inn killed and ate the pilgrims stopping to sleep there. Fate decided to punish the entire family by making the house sink and killing the owner and his daughters.

Departure for Rome (*arrival at about 20.30 p.m*) and lodging in Hotel.

Accompanying Persons Programme: This field trip has been planned alternating specialist stops with other sightseeing stops, so as to accomodate any people accompanying the group of geologists.

Acknowledgments

We kindly thank the Latium Regional Administration, the ACEA for the visit to Peschiera springs and the Caetani Foundation for the entrance to the Ninfa Natural Oasis garden.

References cited

Argentieri A., Capelli G., Loretelli S., Salvati R., Vecchia P. (2001) – La pericolosità da sinkhole nel territorio della provincia di Roma: il caso di Marcellina. *2° Incontro di Studi sul Carsismo nell'area Mediterranea. Lecce 14-16 settembre 2001*

AA.VV. (1993) – Guide Geologiche Regionali. Lazio, a cura della Società Geologica Italiana - *BE-MA Editrice, Roma.*

Bigi G., Capelli G., Mazza R., Parotto M., Petitta M. & Salvati R. (1999) - Strutture di collasso nella piana di S.Vittorino (fiume Velino, Lazio): interazione tra circolazione idrica sotterranea e tettonica attiva. *Convegno "Conoscenza e Salvaguardia delle aree di pianura. 11 contributo delle Scienze della Terra ". Ferrara 8-11 novembre 1999.*

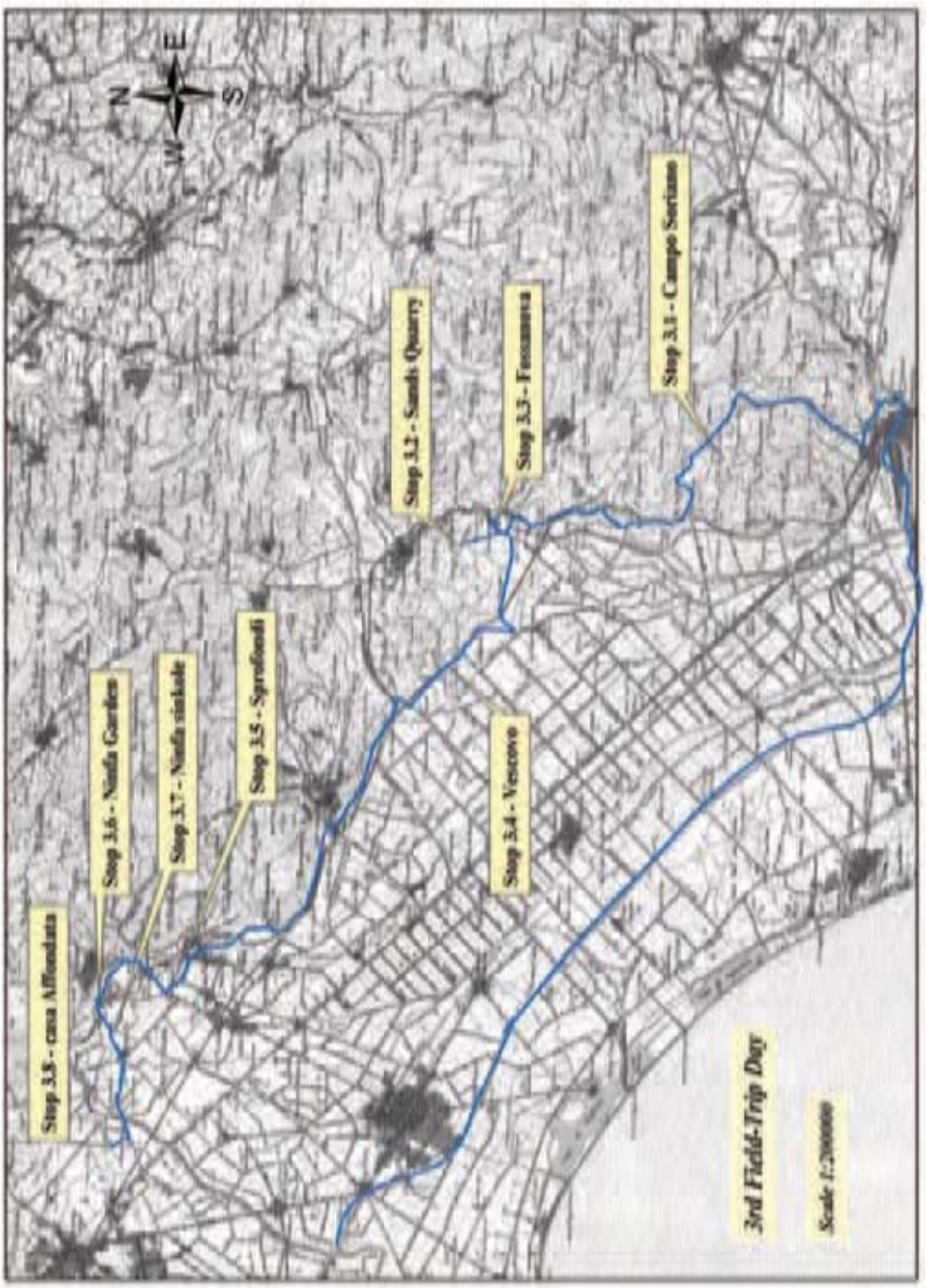
Bono P. (1995) – The sinkhole of Doganella (Pontina Plain, central Italy) – *Environmental Geology 26: 48-52*

Capelli, G., Petitta M. & Salvati, R. (2000) - Relationships between catastrophic subsidence hazards and groundwater in the Velino Valley (Central Italy). *SISOLS 2000, Ravenna-Italy, Sept. 2000*

Capelli, G., Salvati, R. & Colombi A (2001) - Catastrophic subsidence risk assessment. A conceptual matrix for sinkhole genesis. 8th Conference of Sinkhole and Karst…", *Louisville-USA, Apr. 2001*

Colombi A, Nolasco F., Capelli G. & Salvati, R. (2001) – Sinkhole in Latium Region: Purpose of main project. *8th Conference of Sinkhole and Karst…", Louisville-USA, Apr. 2001*

Colombi A., Salvati R. & Capelli G. (2001) - Groundwater overexploitation. Triggering issue in catastrophic subsidence genesis and occurrence (Pontina Plain, Central Italy). *Conference on Future Groundwater Resources at Risk, June 25th-27th 2001 Lisbon, Portugal.*



Volume n° 1 - from PR01 to B15

Faccenna C., Florindo F., Funiciello R. & Lombardi S. (1993) - Tectonic setting and sinkhole features: case histories from Western Central Italy. *Quaternary Proceedings 3*

Kemmerly P.R. (1993) - Sinkhole hazards and risk assessment in a Planning Context. *Journal of American Planning Association 59/2*

Nolasco F. (1995) - La Piana di S. Vittorino: contributo allo studio dei processi evolutivi. *Vol. issued by Regione Lazio.*

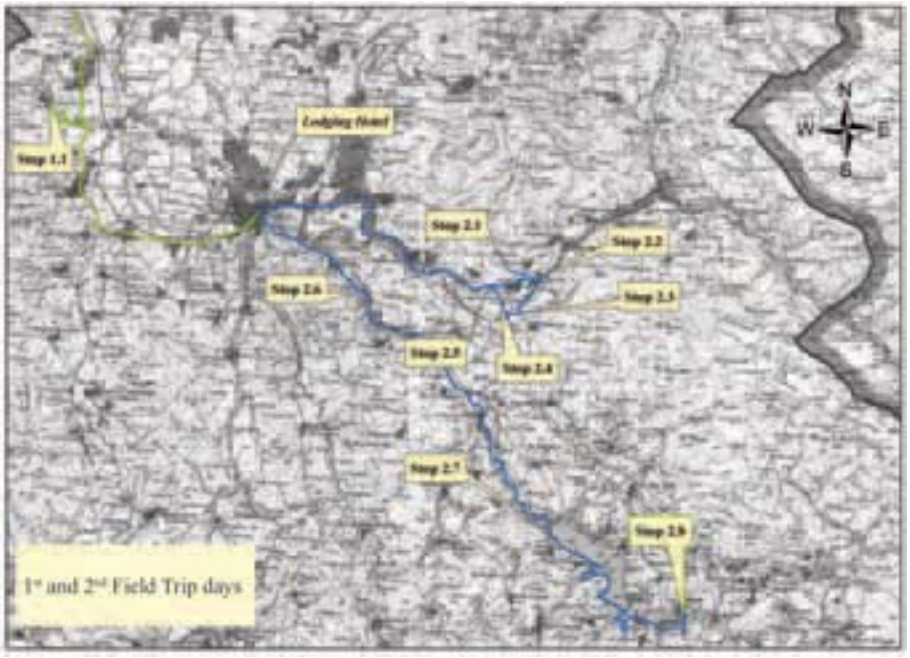
Regione Lazio & Università di Roma Tre (2002) – Progetto Sinkhole del Lazio. *Vol. Unpublished by Regione Lazio.*

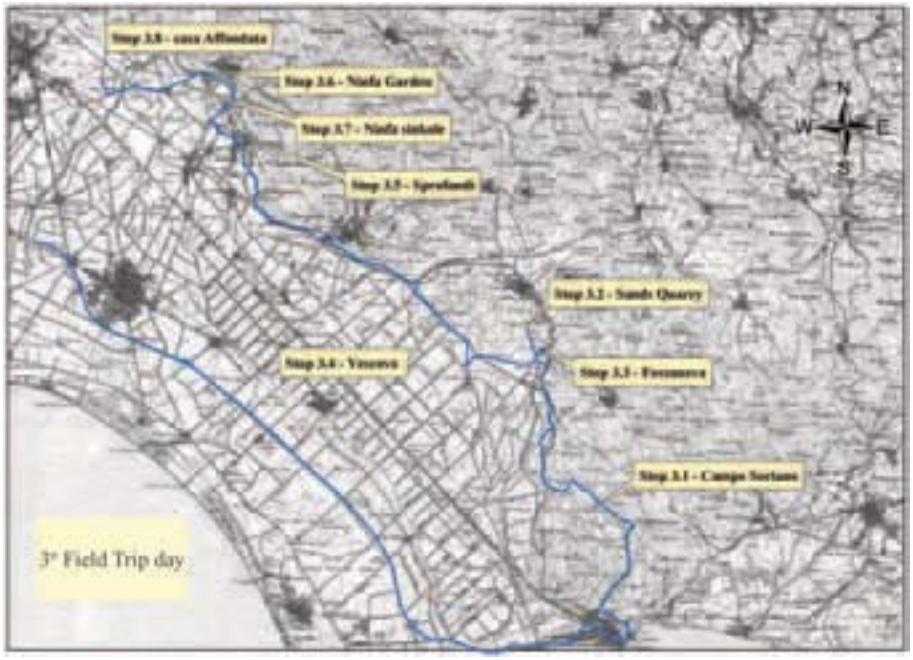
Salvati R., Tharp T. & Capelli G. (2001) - Conceptual Model for Evaluating Sinkhole Risk in the Pontina Plain (Latium, central Italy*). 8th Multidisciplinary Conference on Sinkholes & the Engineering & the Environmental Impacts of Karst. April 1st-4th Louisville, Kentucky.*

Segre A.G. (1948) – I fenomeni carsici e la speleologia del Lazio. *Pubblicazioni dell'Istituto di Geografia dell'Università di Roma. Serie A num. 7*

Back Cover:
field trip itinerary

FIELD TRIP MAP





32nd INTERNATIONAL GEOLOGICAL CONGRESS

Edited by APAT