UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

DIPARTIMENTO DI SCIENZE DELLA TERRA E GEOAMBIENTALI

Using cave data for improving the reliability of karst groundwater flow models

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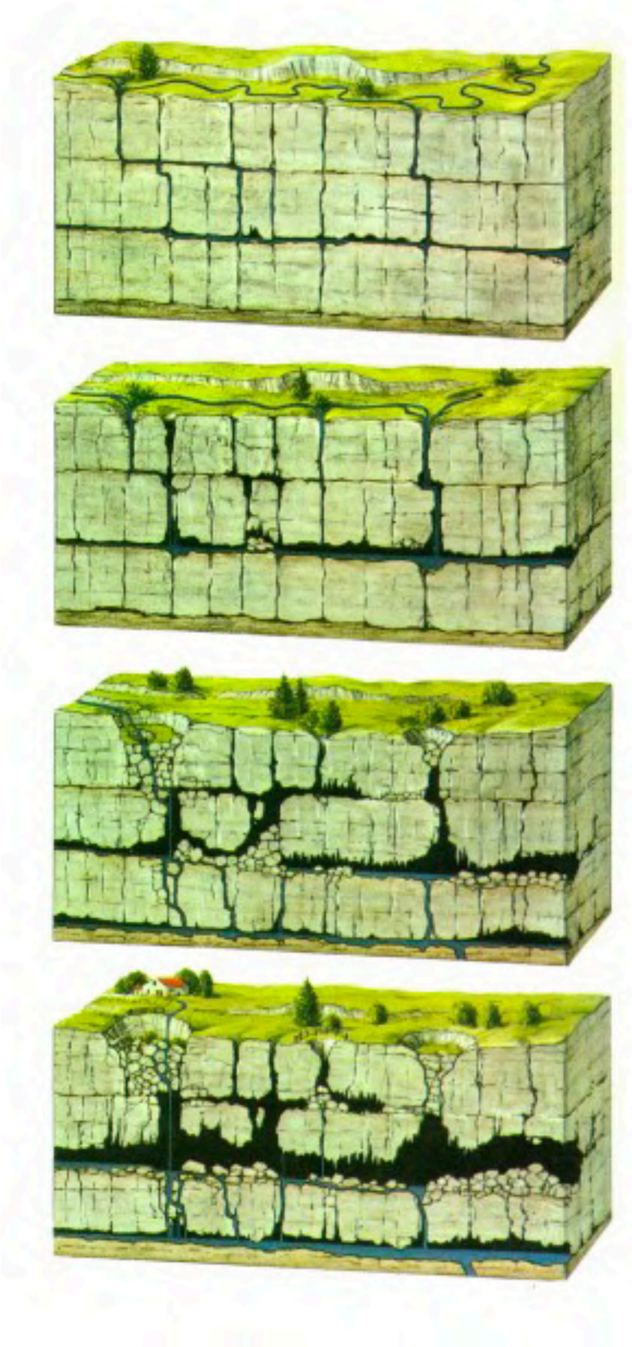
EVOLUTION OF KARST SYSTEM



Time

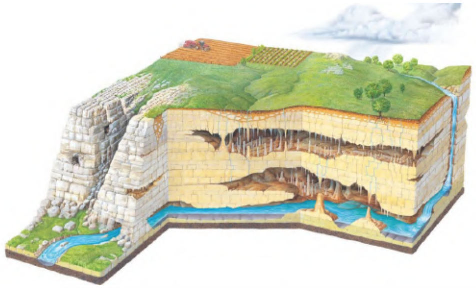
1. Initial discontinuities in limestone: bedding, joints, faults

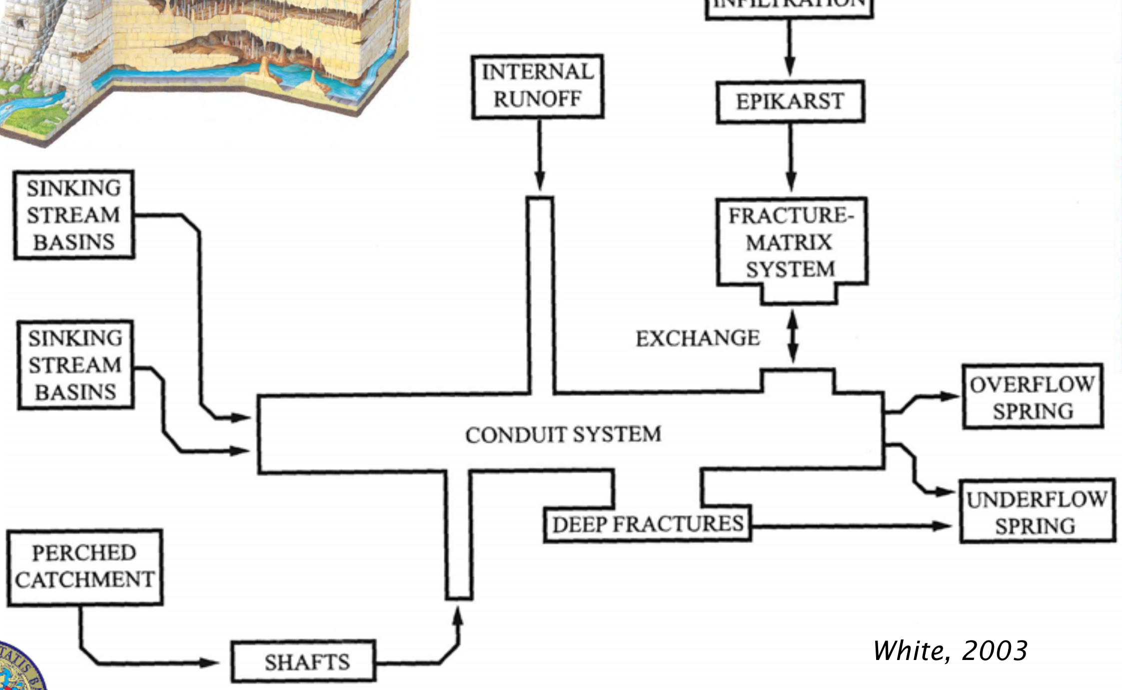
Karst processes:
water flow enlarges the initial discontinuities
+
fluctuation of karst base level

2. Complex network of channels, conduits and fractures, variable in space and time

KARST GROUNDWATER FLOW MODEL

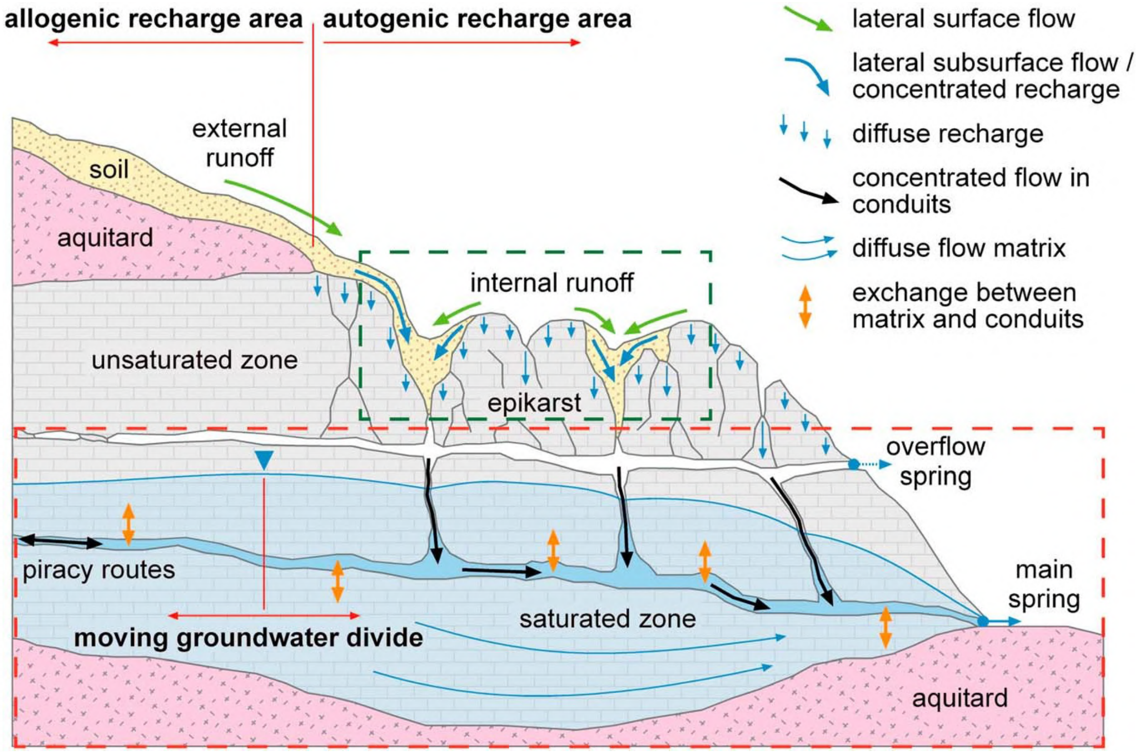
*The conceptual model is usually physical, an interconnected sequence of recharge areas, permeability distributions, and geologic substrates that collectively provide a visualization of **the way in which water is added to the system, stored in the system, transmitted through the system, and discharged from the system** (White, 2003).*





White, 2003

Computational modeling of groundwater flow closer to natural environment



Hartmann et al., 2014

CLASSICAL GEOLOGICAL FIELD WORK (AT THE SURFACE)

+

DIRECT OBSERVATIONS AND MEASUREMENTS IN CAVES (UNDERGROUND)

METHODS

Table 11.1. Summary of methods available for hydrogeological investigations in karst areas.

Method or group of methods	Data obtained/advantages	Disadvantages/limitations
Geological methods	Aquifer framework and geometry information Karstifiability of the rock Orientation, location, type and frequency of potential flow paths Theoretical hydraulic conductivity and porosity	Data not necessarily directly related to groundwater Often not a predictable and unambiguous relation between lithology and hydrogeology
Geomorphological methods	Degree of karstification Types of recharge Historical hydrogeomorphology	Data mainly from the surface (indirect) Static framework rather than hydrodynamics Limited data from covered karsts
Speleological methods	Locating and mapping conduits in 3D Monitoring water quality and quantity within the aquifer Determining the temporal evolution of conduit systems	Access to cave systems may be limited or non-existent Specialist speleological skills required Only a small and perhaps unrepresentative part of the aquifer is likely to be accessible
Hydrological methods	Water budget compilation Characterisation of flow systems by spring hydrograph analysis	Water budget often incomplete, as catchment boundaries are not always clear, and not all inputs and outputs can be monitored Hydrograph alone gives limited information of the origin of the water (needs to be combined with chemograph)
Hydraulic methods	Determination of transmission and storage characteristics Determination of piezometric level Determination of groundwater velocity and flow direction	Many methods not wholly appropriate under non-Darcian conditions Estimates of flow directions and magnitudes may not be accurate Pumping tests may not give representative results
Hydrochemical methods	Hydrochemical characterisation of groundwater bodies Information on water quality and contamination problems May be used as natural tracers for the origin and movement of the water	Difficulties in developing an adequate sampling strategy (high temporal variability) In karst aquifers, microbial contamination is often of greater importance than chemical
Isotopic methods	May be used as natural tracers for the origin and movement of the water; this includes: Identifying sources of karst waters and mixing processes Determining residence time/age of karst waters	Input function not known precisely Ambiguities possible in interpreting data
Tracer methods	Determination of flow routes and velocities Determining contributing areas for springs Information on contaminant transport Usually very reliable, precise and unambiguous information	Difficulty in recognising "negative" tracings Usually only gives information for selected points and the hydrological conditions during the tracer test Limited applicability for very deep and large systems with very long transit times Visible colouring and toxicity concerns for some tracers
Geophysical methods	Determining geological structures and overburden thickness Locating conduits, fractures and other preferential flow paths Data can be obtained over wide areas Information on the structure and properties of the underground without drilling, i.e. at relatively low cost	Results may be difficult to interpret without ambiguity (non-uniqueness) Resolution vs. depth of investigation (i.e. the greater the depth, the lower the resolution) Some techniques require very precise location control (gravimetry), others have noise problems or require heavy or expensive equipment

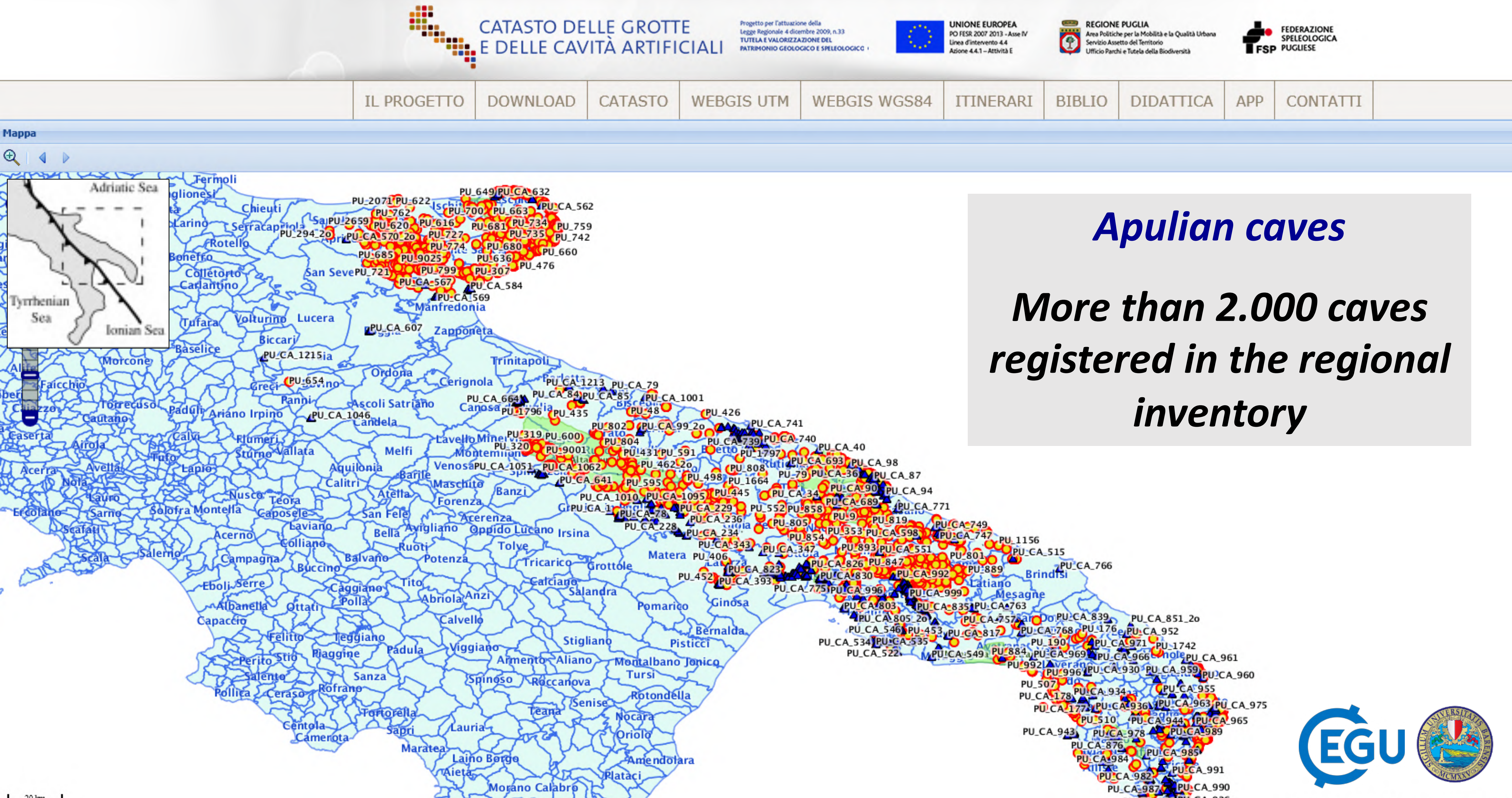
(Continued)

Goldscheider & Drew, 2007

DATA DERIVED FROM

GEOLOGICAL FIELDWORK
GEOMORPHOLOGICAL CHARACTERIZATION
SPELEOLOGICAL INVESTIGATION
GEOPHYSICAL SURVEY
HYDRAULIC TESTS
RAIN AND WELLS DATA COLLECTION
HYDROCHEMICAL ANALYSIS
ISOTOPIC ANALYSIS
TRACER TESTS
LASERSCANNER
ROCK AND WATER SAMPLING
PROBES INSTALLATION

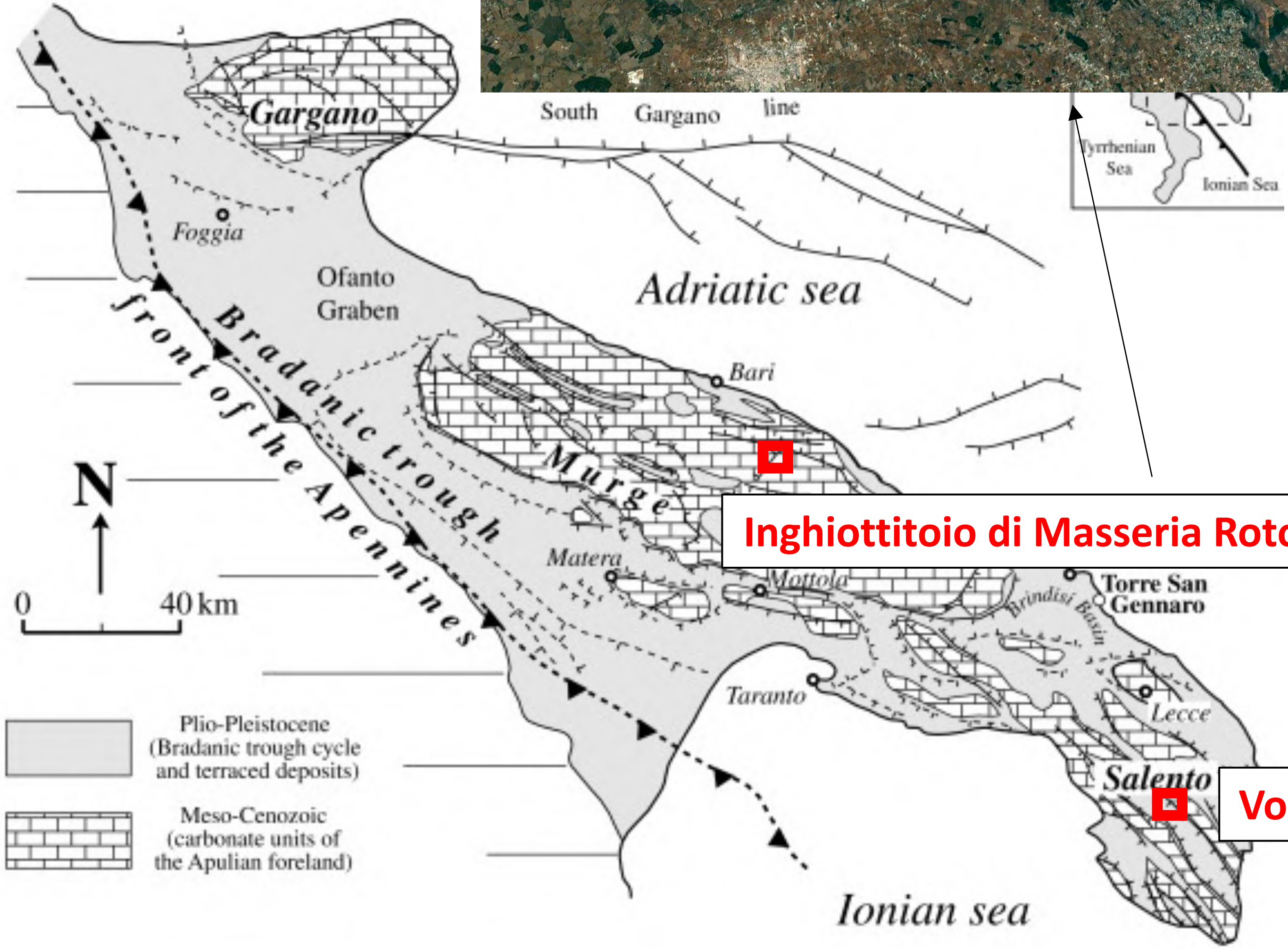
FIRST ATTEMPT TO APPLY GROUNDWATER FLOW MODEL TO APULIAN KARST



Apulian caves

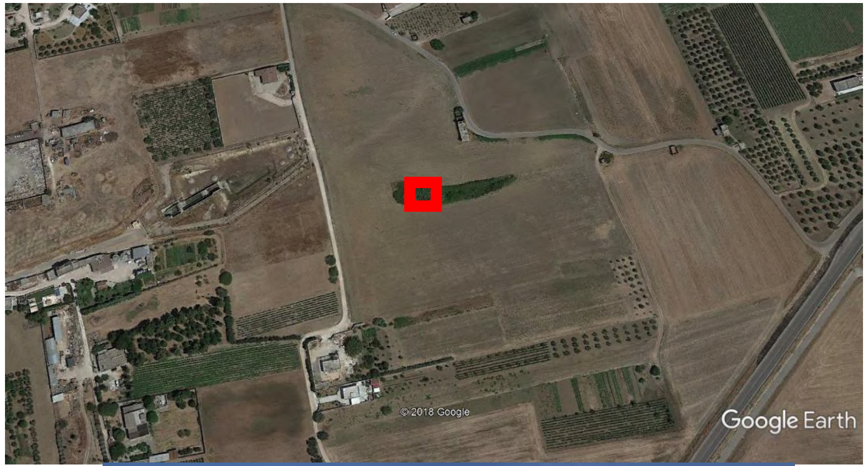
More than 2.000 caves registered in the regional inventory

STUDY AREAS



Inghiottitoio di Masseria Rotolo

Vora Bosco




FIELD ACTIVITIES

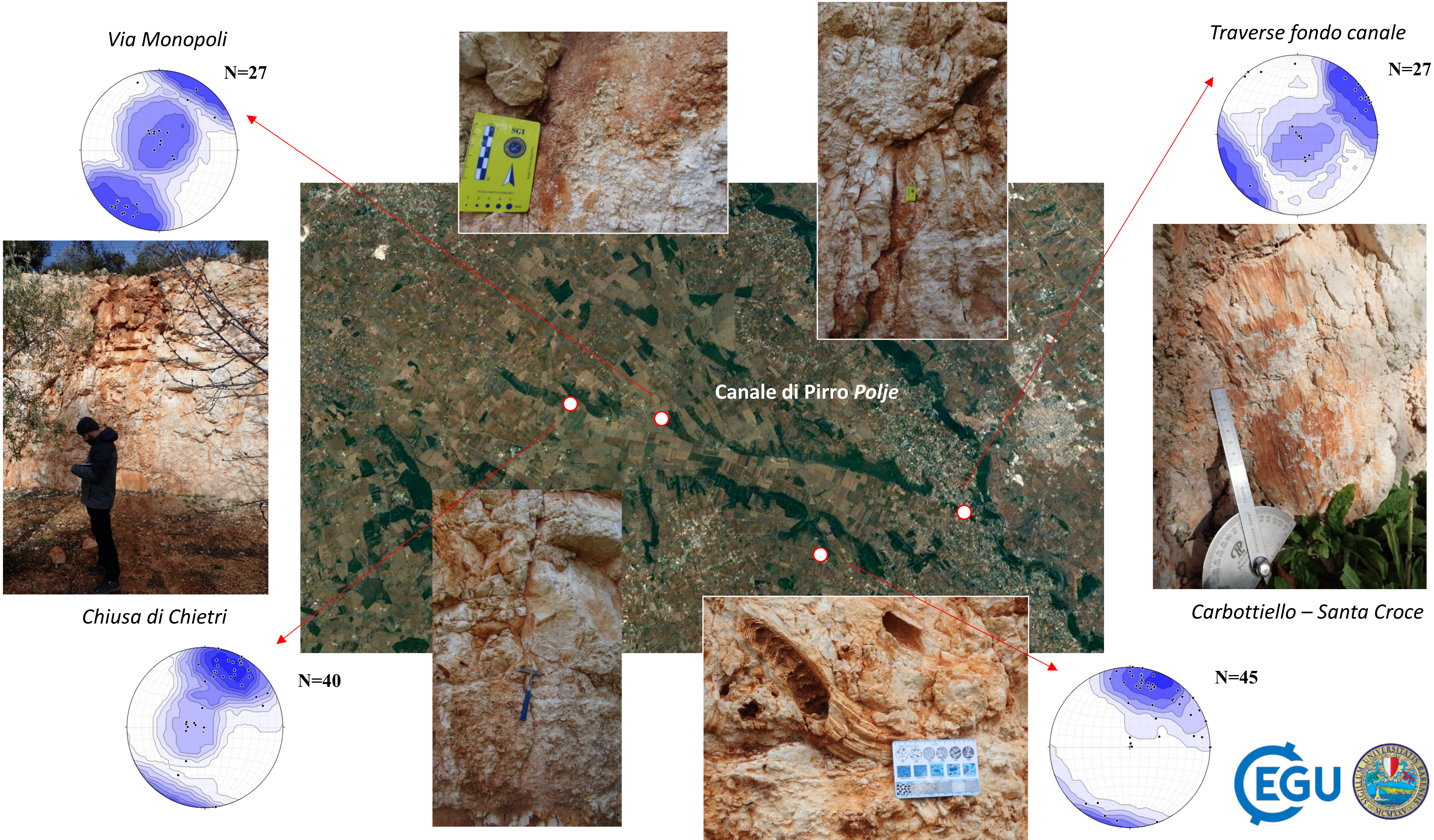
LIMESTONE OUTCROPS

BEDDING, STRUCTURAL AND KARST DISCONTINUITIES

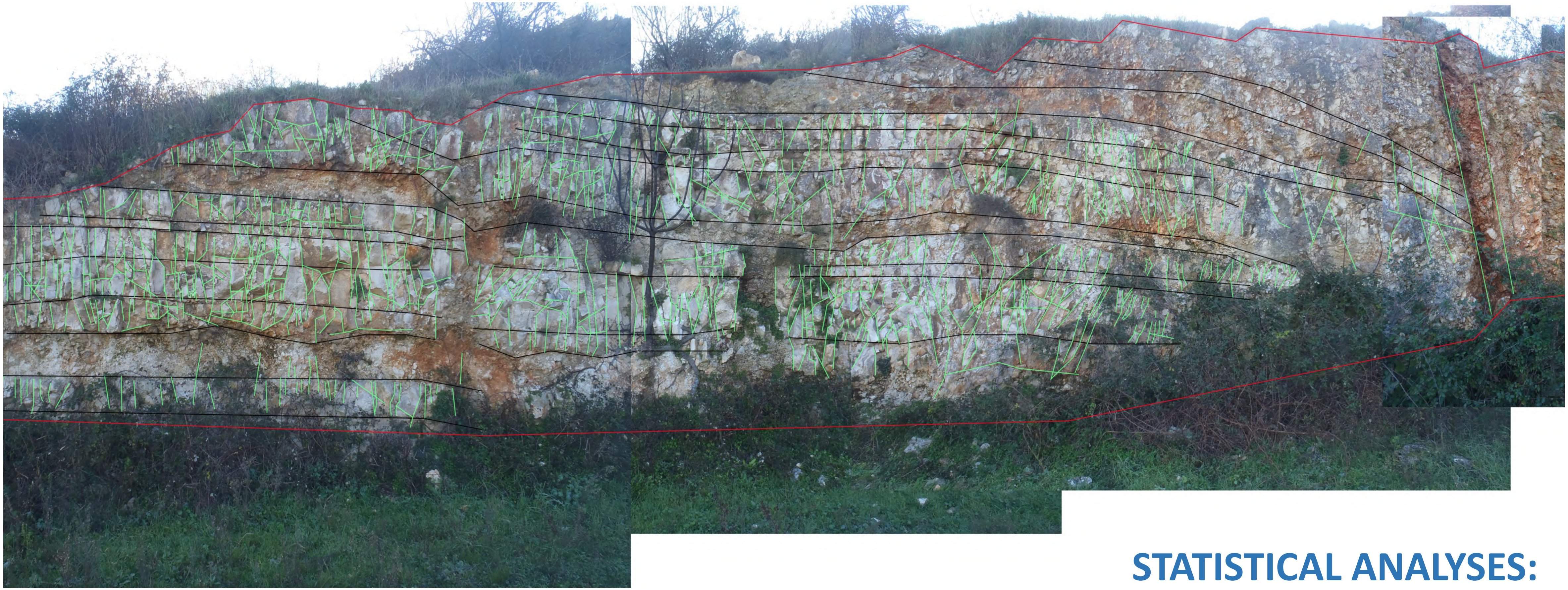
GEO-STRUCTURAL SURVEY

ROCK MASS DISCONTINUITIES CHARACTERIZATION

GEO-STRUCTURAL CHARACTERIZATION AT THE SURFACE



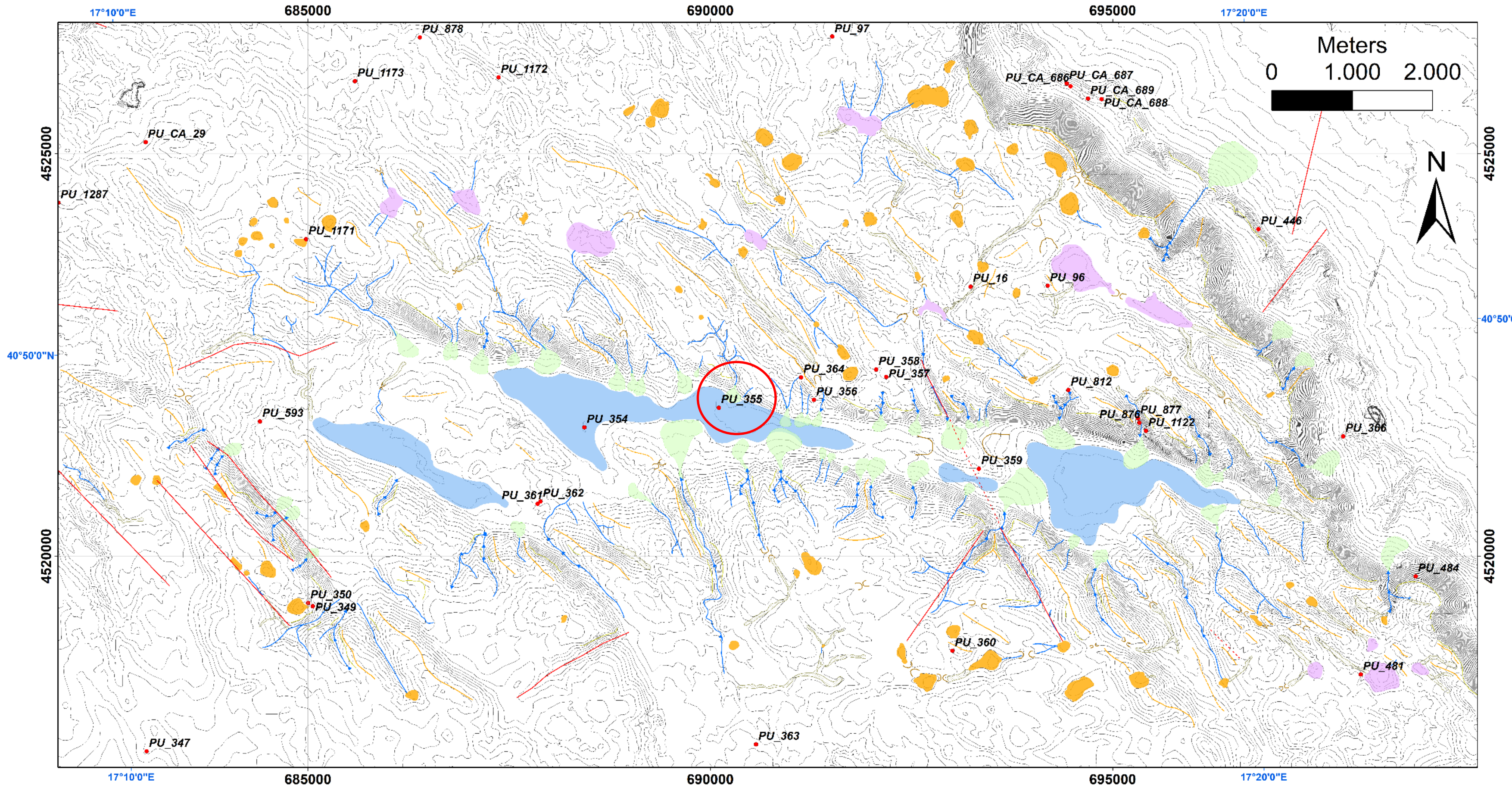
DISCONTINUITIES: IMAGE PROCESS SOFTWARE



STATISTICAL ANALYSES:

- orientation
- size
- frequency
- pervasiveness

KARST GEOMORPHOLOGICAL MAP

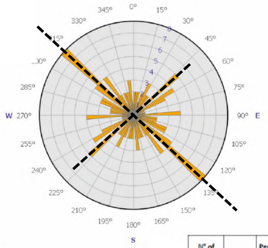


LEGEND

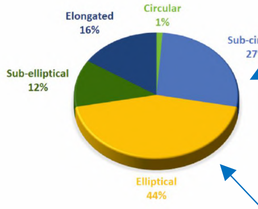
- Doline
- Recapito finale di bacino endoreico
- Conoide
- Polje
- Lama
- Sella morfologica
- Faglia
- Cresta
- Corso d'acqua
- Corso d'acqua in incisione
- Orlo di scarpata
- Ingressi grotte

Rotolo Cave

MORPHOMETRIC PARAMETER:
Orientation of main axis



MORPHOMETRIC PARAMETER:
shape

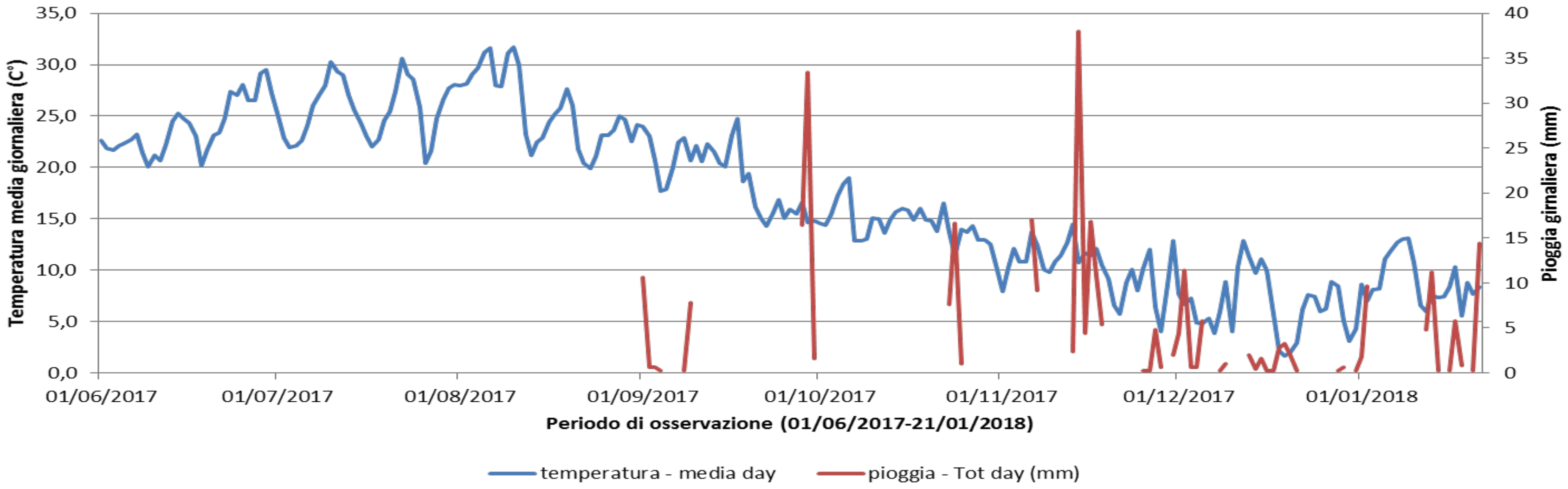


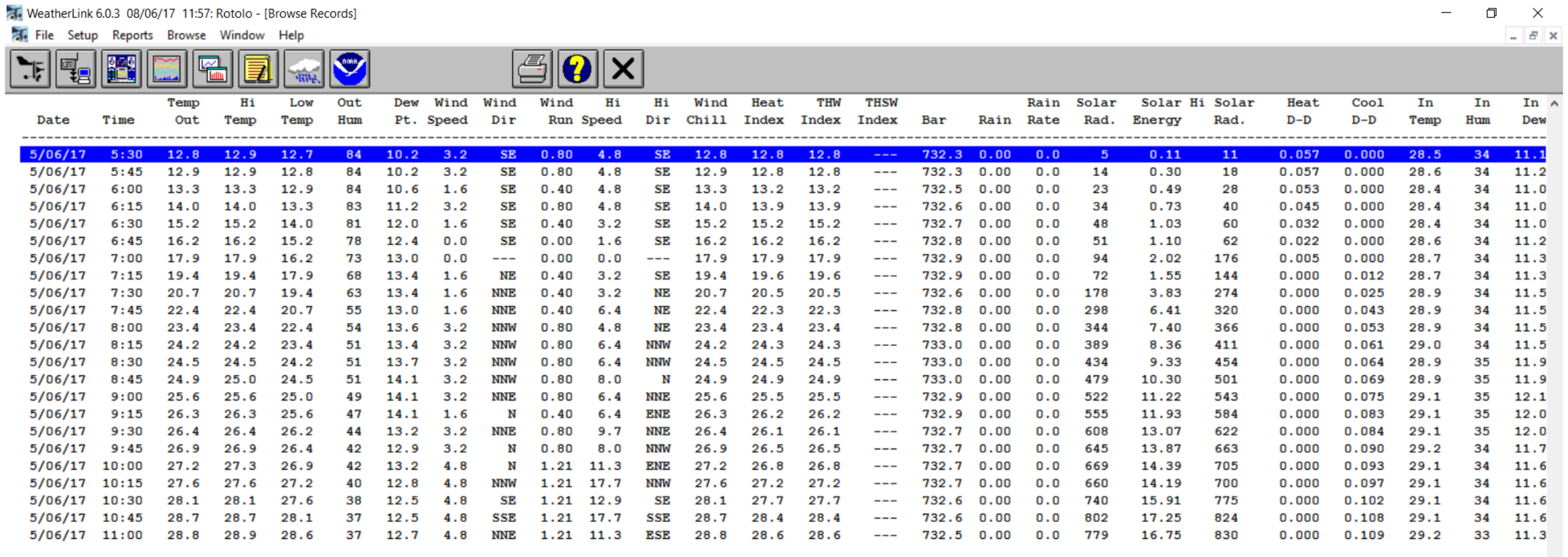
SINKHOLES

ENDORHEIC BASINS

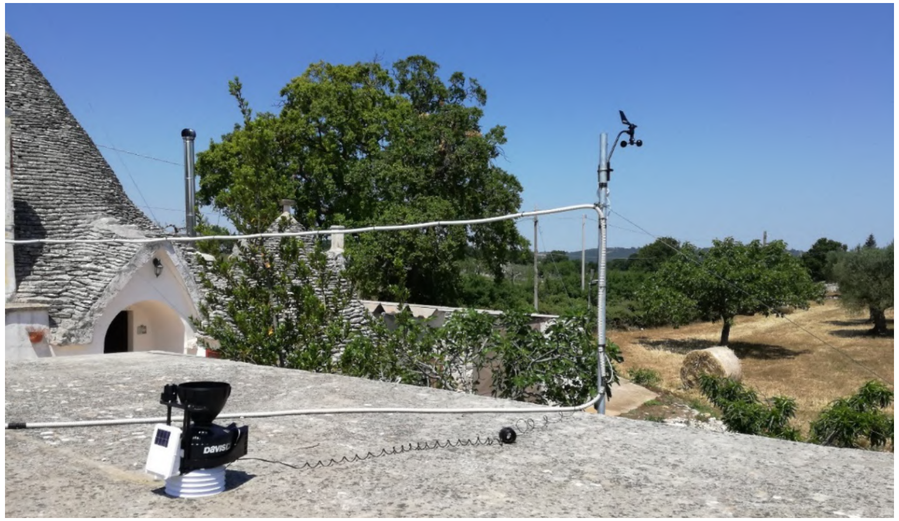
	N° of Elements	Statistic	Perimeter (m)	Area (m²)	Width (m)	Length (m)	Depth (m)	CI	ER
Endorheic Basins	12	max	2337,36	240593,89	449,96	890,42	20,01	0,98	3,01
		min	497,64	16904,30	132,01	173,21	4,44	0,37	1,10
		mean	1227,79	90354,06	257,77	455,02	11,33	0,71	1,73
		median	1080,51	69393,76	251,37	388,22	11,01	0,78	1,68
Doline	49	max	1405,29	109919,90	280,92	516,74	20,58	0,99	2,76
		min	134,35	1250,63	32,94	49,23	0,60	0,53	1,01
		mean	493,78	19349,95	124,22	176,02	7,42	0,86	1,44
		median	435,55	12959,21	110,83	153,82	7,09	0,91	1,31

WEATHER DATA COLLECTION





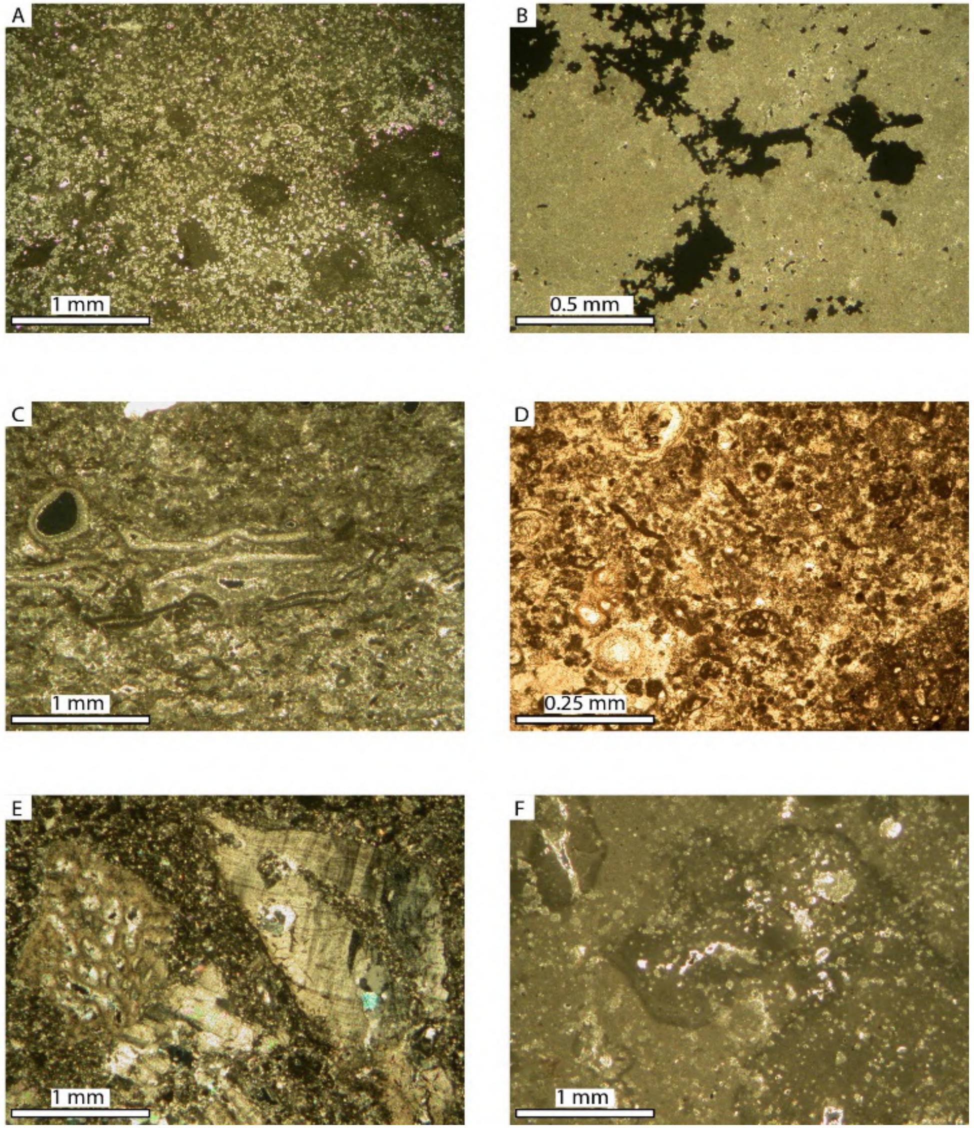
Date	Time	Temp Out	Hi Temp	Low Temp	Out Hum	Dew Pt.	Wind Speed	Wind Dir	Wind Run	Hi Speed	Hi Dir	Wind Chill	Heat Index	THW Index	THSW Index	Bar	Rain	Rain Rate	Solar Rad.	Solar Energy	Hi Solar Rad.	Heat D-D	Cool D-D	In Temp	In Hum	In Dew
5/06/17	5:30	12.8	12.9	12.7	84	10.2	3.2	SE	0.80	4.8	SE	12.8	12.8	12.8	---	732.3	0.00	0.0	5	0.11	11	0.057	0.000	28.5	34	11.1
5/06/17	5:45	12.9	12.9	12.8	84	10.2	3.2	SE	0.80	4.8	SE	12.9	12.8	12.8	---	732.3	0.00	0.0	14	0.30	18	0.057	0.000	28.6	34	11.2
5/06/17	6:00	13.3	13.3	12.9	84	10.6	1.6	SE	0.40	4.8	SE	13.3	13.2	13.2	---	732.5	0.00	0.0	23	0.49	28	0.053	0.000	28.4	34	11.0
5/06/17	6:15	14.0	14.0	13.3	83	11.2	3.2	SE	0.80	4.8	SE	14.0	13.9	13.9	---	732.6	0.00	0.0	34	0.73	40	0.045	0.000	28.4	34	11.0
5/06/17	6:30	15.2	15.2	14.0	81	12.0	1.6	SE	0.40	3.2	SE	15.2	15.2	15.2	---	732.7	0.00	0.0	48	1.03	60	0.032	0.000	28.4	34	11.0
5/06/17	6:45	16.2	16.2	15.2	78	12.4	0.0	SE	0.00	1.6	SE	16.2	16.2	16.2	---	732.8	0.00	0.0	51	1.10	62	0.022	0.000	28.6	34	11.2
5/06/17	7:00	17.9	17.9	16.2	73	13.0	0.0	---	0.00	0.0	---	17.9	17.9	17.9	---	732.9	0.00	0.0	94	2.02	176	0.005	0.000	28.7	34	11.3
5/06/17	7:15	19.4	19.4	17.9	68	13.4	1.6	NE	0.40	3.2	SE	19.4	19.6	19.6	---	732.9	0.00	0.0	72	1.55	144	0.000	0.012	28.7	34	11.3
5/06/17	7:30	20.7	20.7	19.4	63	13.4	1.6	NNE	0.40	3.2	NE	20.7	20.5	20.5	---	732.6	0.00	0.0	178	3.83	274	0.000	0.025	28.9	34	11.5
5/06/17	7:45	22.4	22.4	20.7	55	13.0	1.6	NNE	0.40	6.4	NE	22.4	22.3	22.3	---	732.8	0.00	0.0	298	6.41	320	0.000	0.043	28.9	34	11.5
5/06/17	8:00	23.4	23.4	22.4	54	13.6	3.2	NNW	0.80	4.8	NE	23.4	23.4	23.4	---	732.8	0.00	0.0	344	7.40	366	0.000	0.053	28.9	34	11.5
5/06/17	8:15	24.2	24.2	23.4	51	13.4	3.2	NNW	0.80	6.4	NNW	24.2	24.3	24.3	---	733.0	0.00	0.0	389	8.36	411	0.000	0.061	29.0	34	11.5
5/06/17	8:30	24.5	24.5	24.2	51	13.7	3.2	NNW	0.80	6.4	NNW	24.5	24.5	24.5	---	733.0	0.00	0.0	434	9.33	454	0.000	0.064	28.9	35	11.9
5/06/17	8:45	24.9	25.0	24.5	51	14.1	3.2	NNW	0.80	8.0	N	24.9	24.9	24.9	---	733.0	0.00	0.0	479	10.30	501	0.000	0.069	28.9	35	11.9
5/06/17	9:00	25.6	25.6	25.0	49	14.1	3.2	NNE	0.80	6.4	NNE	25.6	25.5	25.5	---	732.9	0.00	0.0	522	11.22	543	0.000	0.075	29.1	35	12.1
5/06/17	9:15	26.3	26.3	25.6	47	14.1	1.6	N	0.40	6.4	ENE	26.3	26.2	26.2	---	732.9	0.00	0.0	555	11.93	584	0.000	0.083	29.1	35	12.0
5/06/17	9:30	26.4	26.4	26.2	44	13.2	3.2	NNE	0.80	9.7	NNE	26.4	26.1	26.1	---	732.7	0.00	0.0	608	13.07	622	0.000	0.084	29.1	35	12.0
5/06/17	9:45	26.9	26.9	26.4	42	12.9	3.2	N	0.80	8.0	NNW	26.9	26.5	26.5	---	732.7	0.00	0.0	645	13.87	663	0.000	0.090	29.2	34	11.7
5/06/17	10:00	27.2	27.3	26.9	42	13.2	4.8	N	1.21	11.3	ENE	27.2	26.8	26.8	---	732.7	0.00	0.0	669	14.39	705	0.000	0.093	29.1	34	11.6
5/06/17	10:15	27.6	27.6	27.2	40	12.8	4.8	NNW	1.21	17.7	NNW	27.6	27.2	27.2	---	732.7	0.00	0.0	660	14.19	700	0.000	0.097	29.1	34	11.6
5/06/17	10:30	28.1	28.1	27.6	38	12.5	4.8	SE	1.21	12.9	SE	28.1	27.7	27.7	---	732.6	0.00	0.0	740	15.91	775	0.000	0.102	29.1	34	11.6
5/06/17	10:45	28.7	28.7	28.1	37	12.5	4.8	SSE	1.21	17.7	SSE	28.7	28.4	28.4	---	732.6	0.00	0.0	802	17.25	824	0.000	0.108	29.1	34	11.6
5/06/17	11:00	28.8	28.9	28.6	37	12.7	4.8	NNE	1.21	11.3	ESE	28.8	28.6	28.6	---	732.5	0.00	0.0	779	16.75	830	0.000	0.109	29.2	33	11.3




CAVE ACTIVITIES

Rock sampling

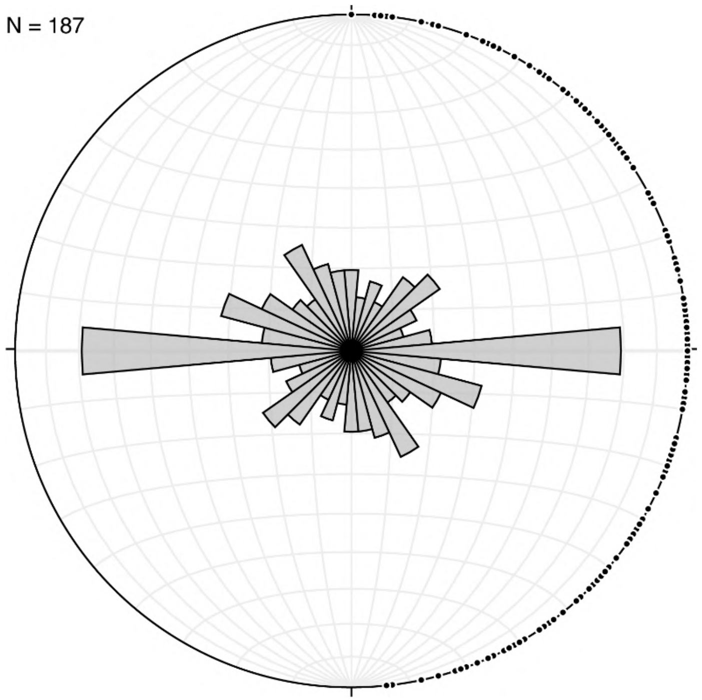
STRATIGRAPHY



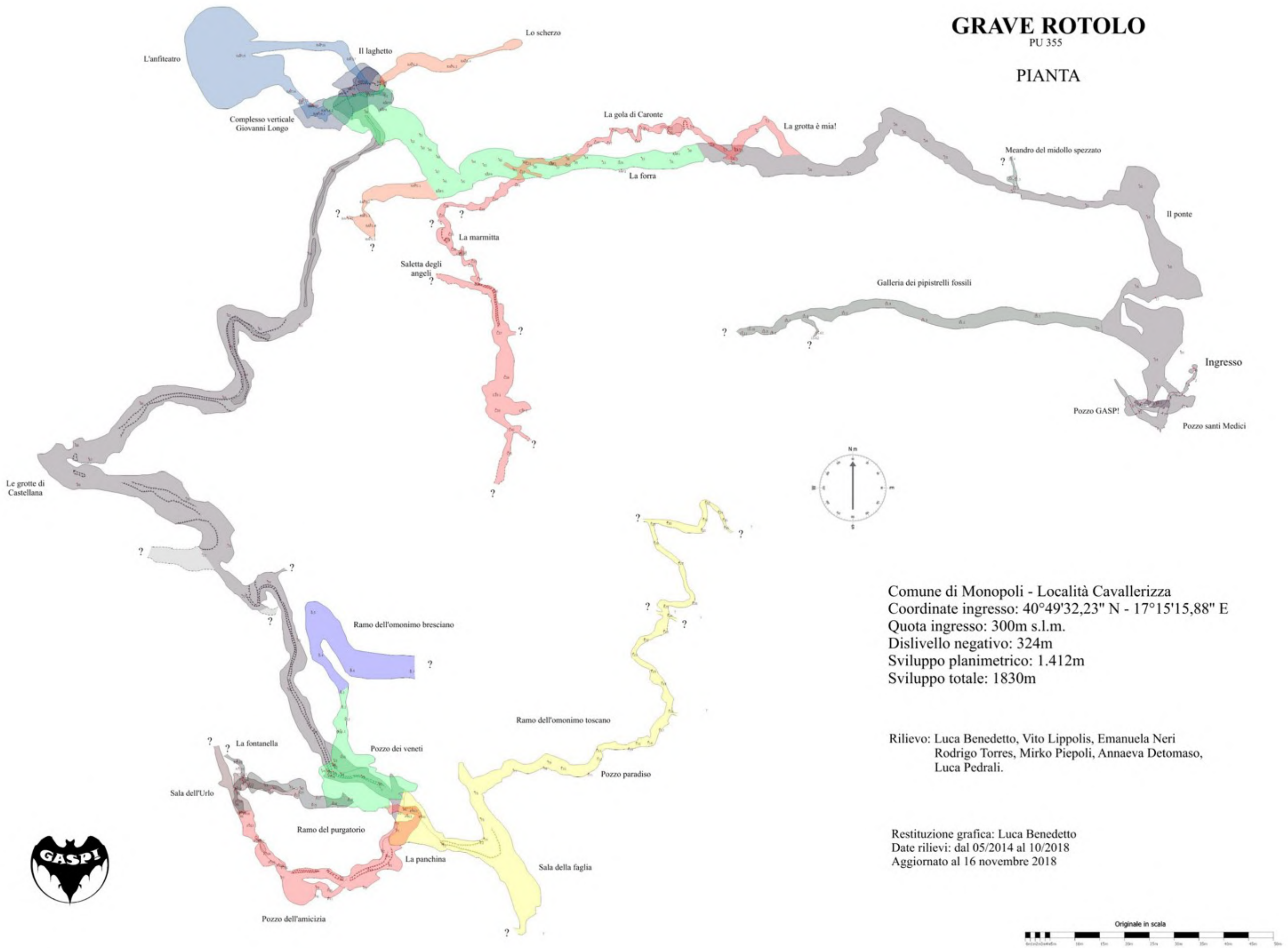
A) Mudstone *B)* Limestone
C) Wackestone/packstone *D)* Packstone
E) Floatstone *F)* Mudstone

GEOREFERENCED CAVE MAP AND SECTION

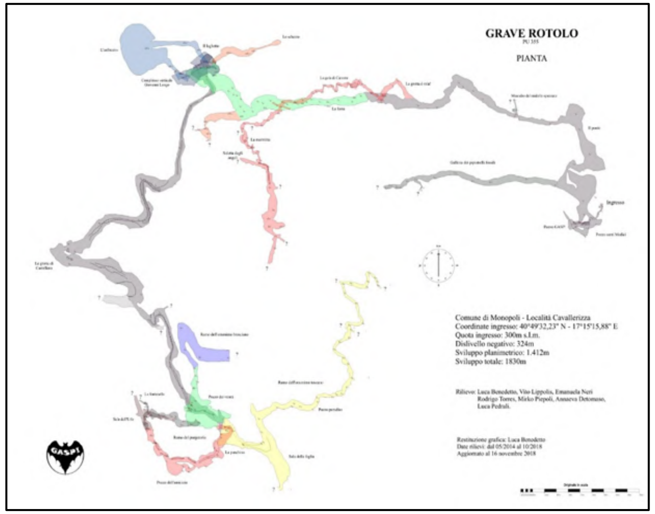
CAVE PASSAGE SPATIAL ORIENTATION



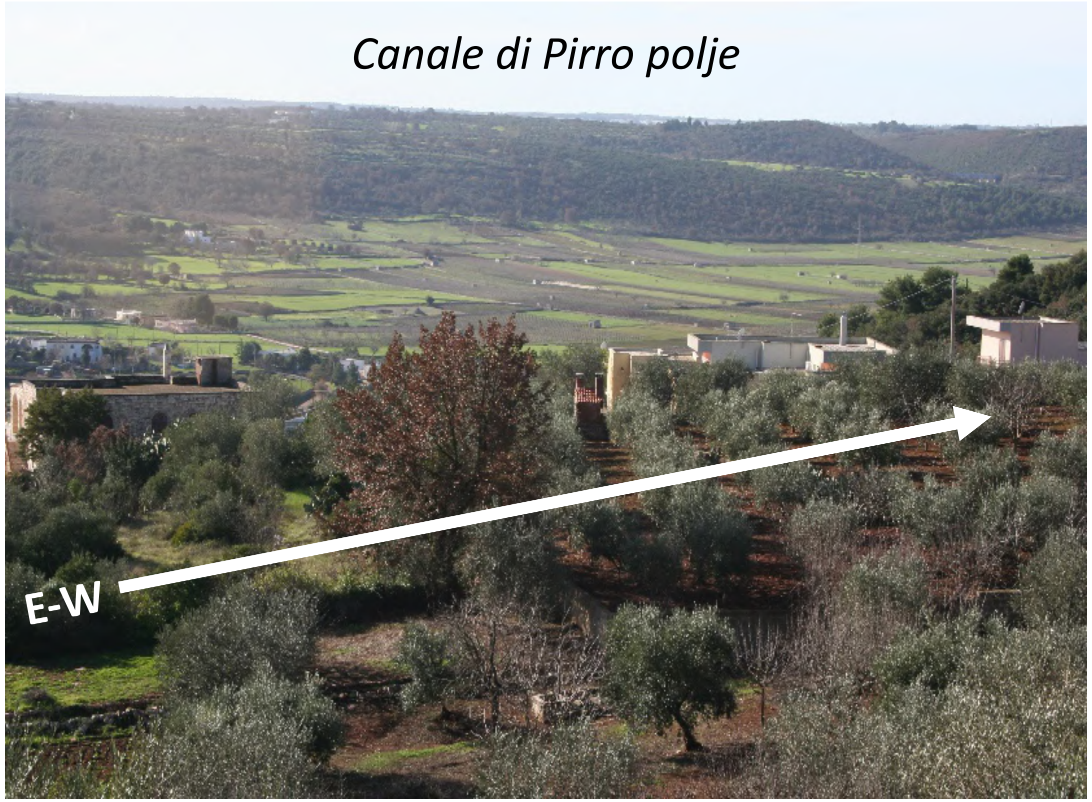
The ROSE DIAGRAM shows the preferential CONDUITS development direction of the Rotolo Cave, that is in E-W direction.

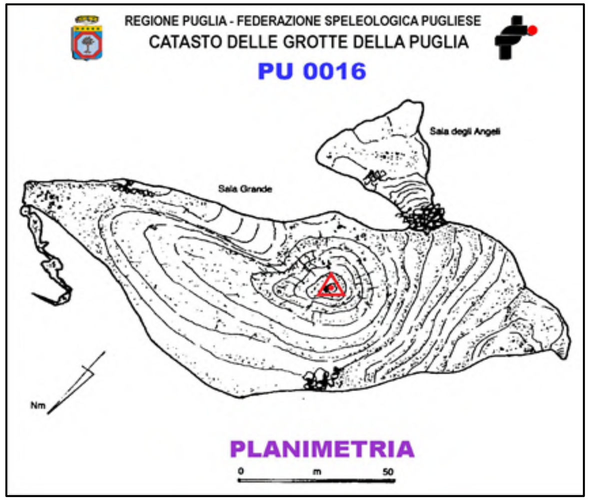


CAVE SPATIAL ORIENTATION

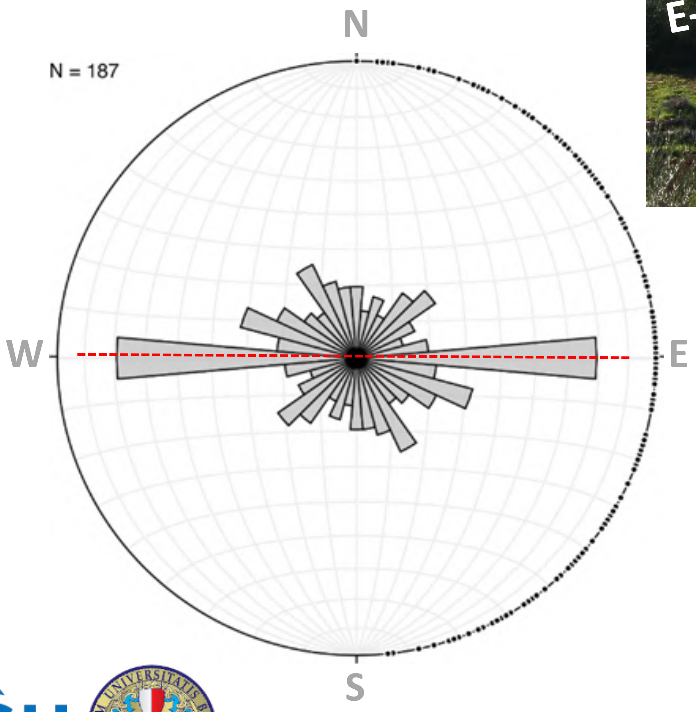


ROTOLO CAVE



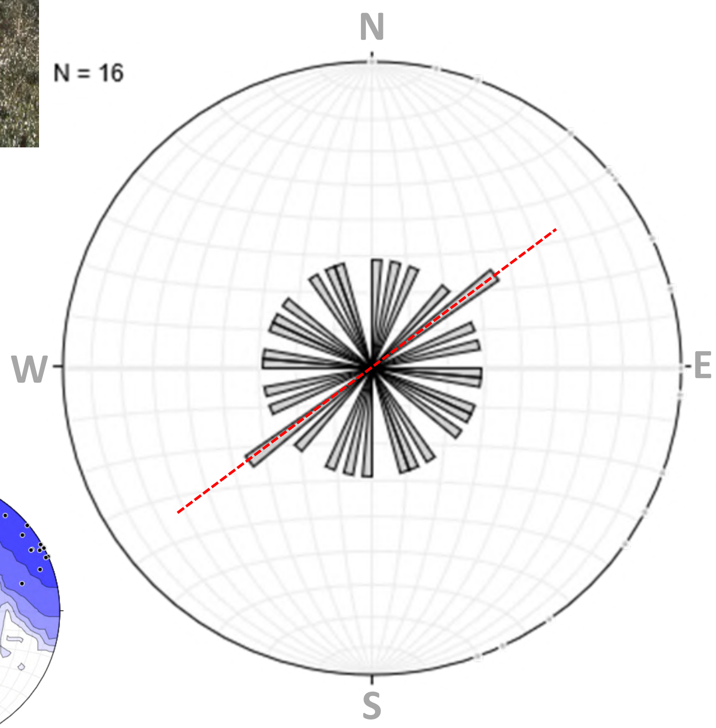


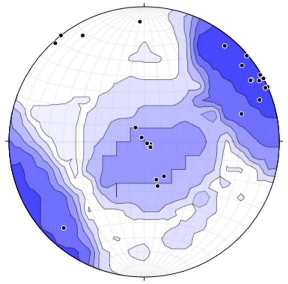
SANTA LUCIA CAVE



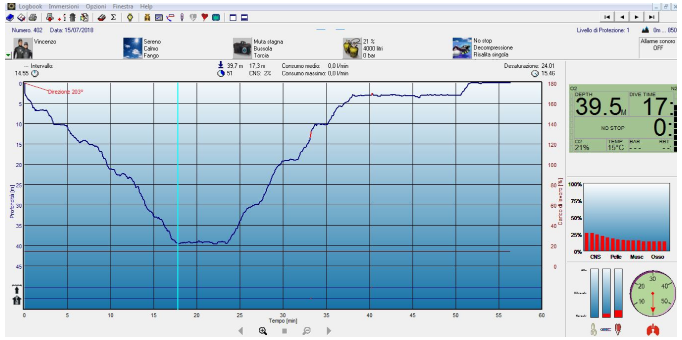
W-E
Polje orientation

SW-NE
Regional tectonic trend
(Anti-Apenninic trend)

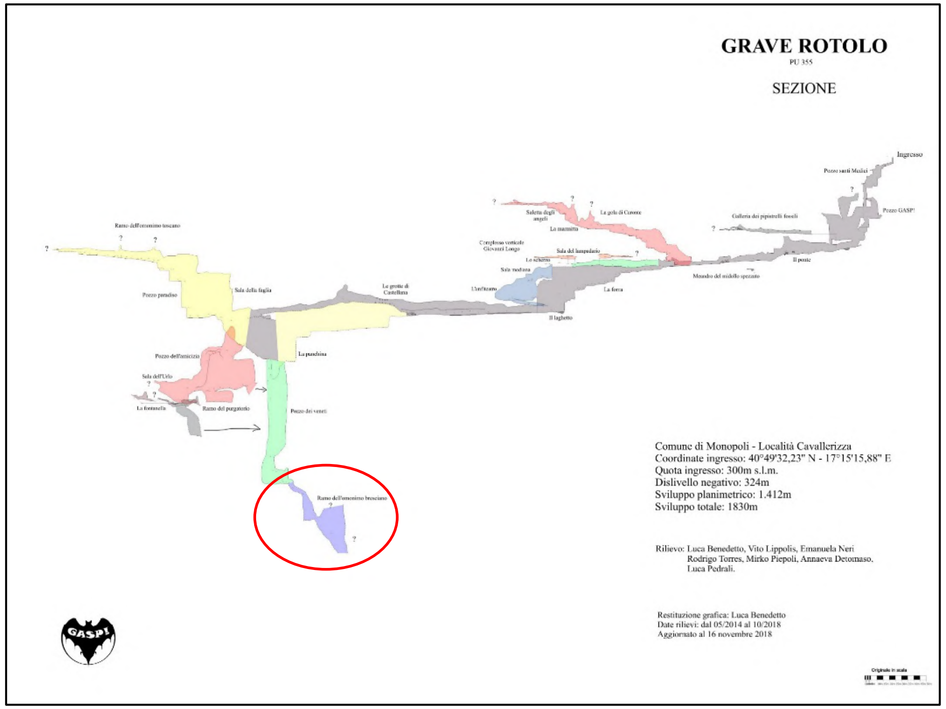


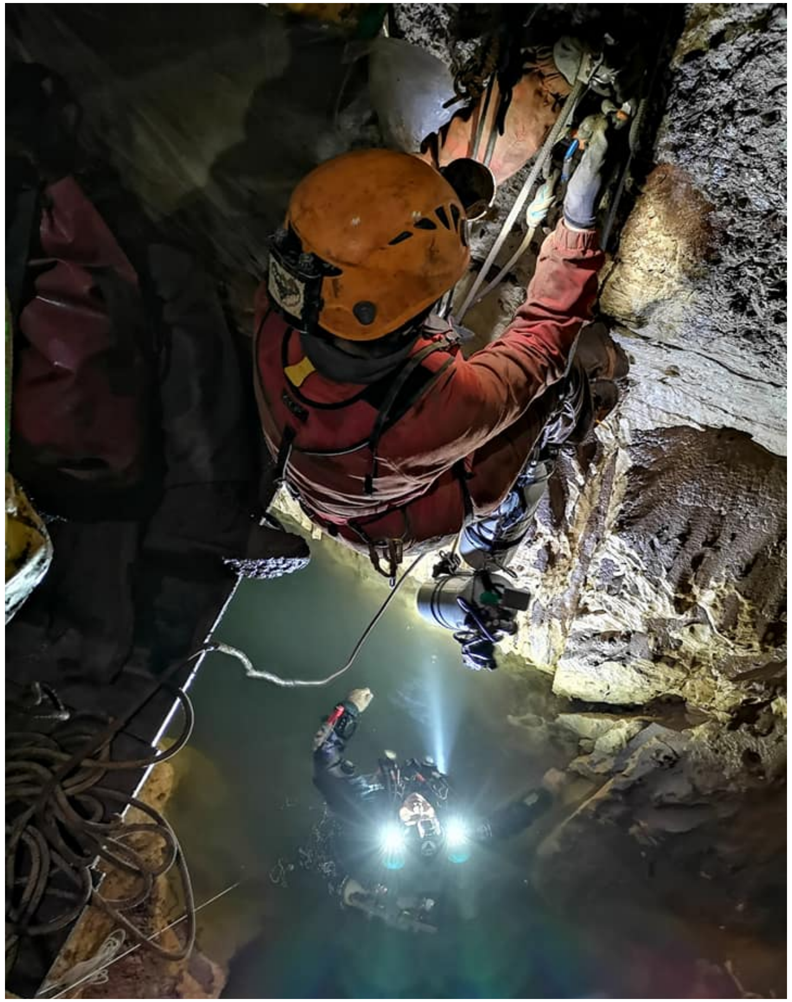


EXPLORATION OF FLOODED CHANNELS



ROTOLO CAVE





Max depth:

***-60 m** below water table*

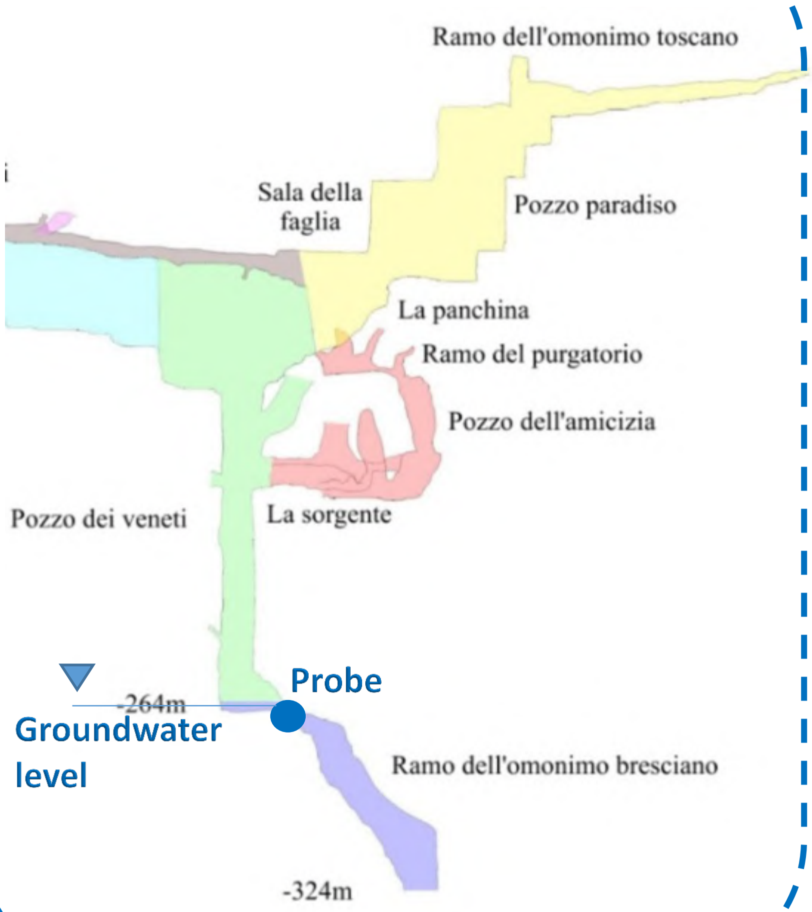
MULTIPARAMETER PROBE IN CAVE

Multi-parameters probe (water) OTT

T, level, EC

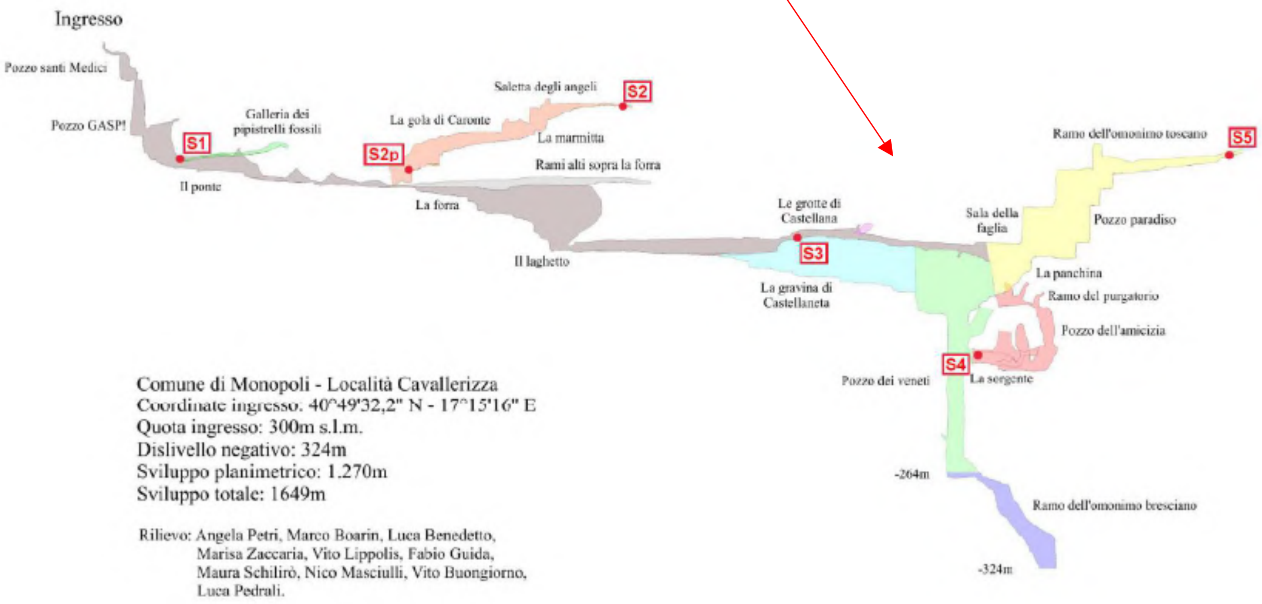
Orpheus mini (Vora Bosco)

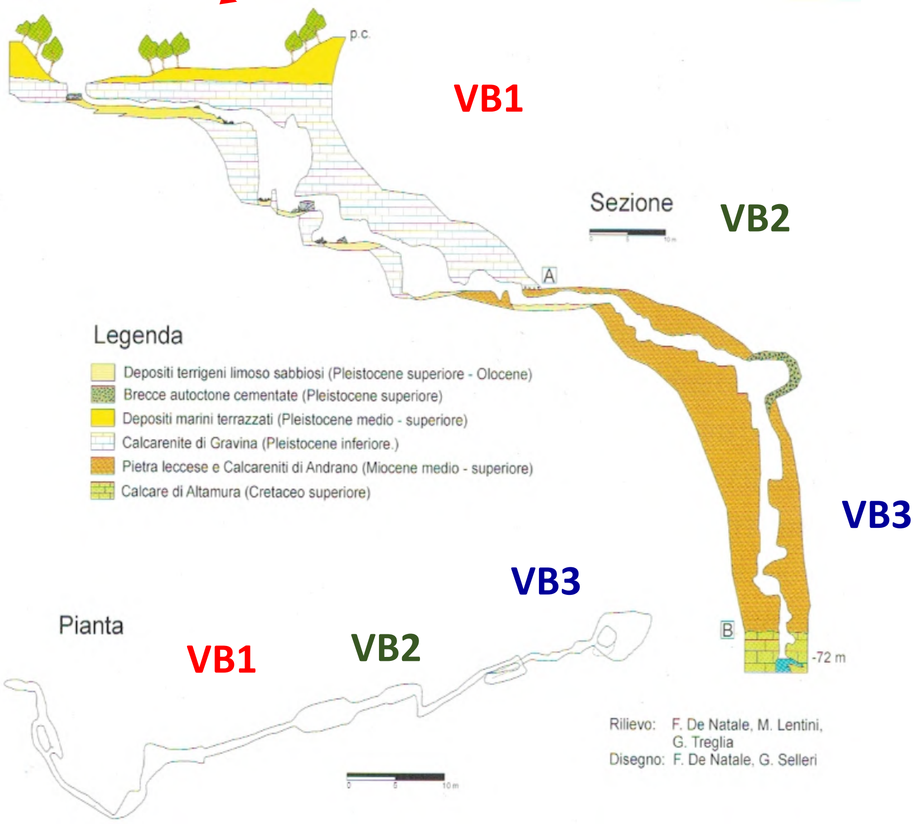
EcoLog800 (Grotta Rotolo)



DATA COLLECTION

Cave climate (air)
T, RH
HOBO Pro v2 - onset





Karst aquifer characterization for modeling

<u>NEDEED INFORMATIONS</u>

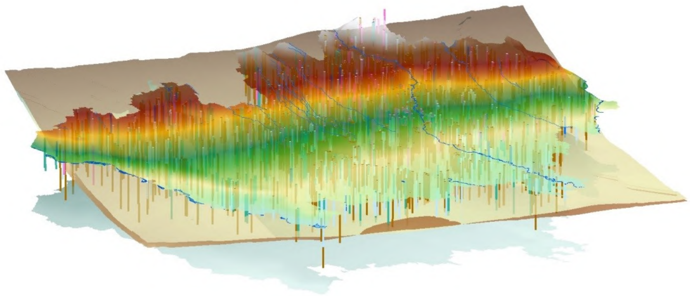
Area of the groundwater catchment;
Inflow:

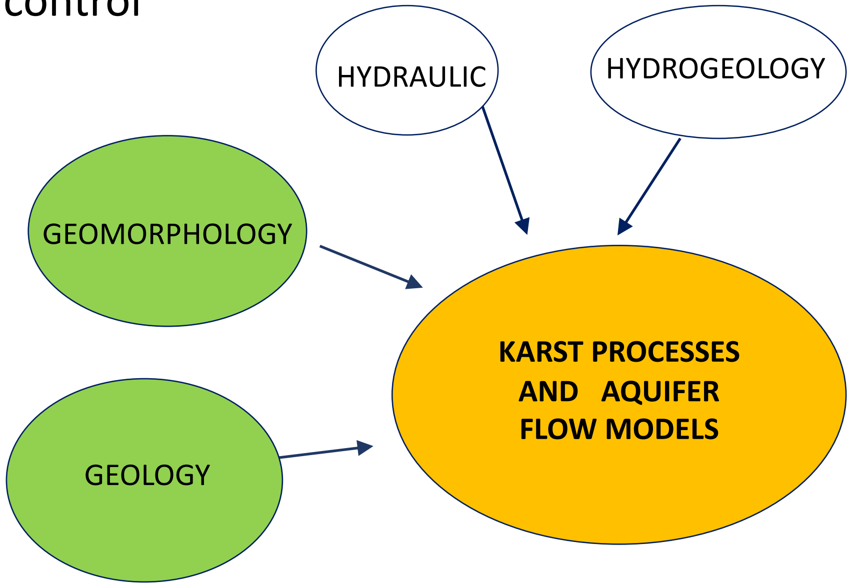
- ALLOGENIC
- INTERNAL RUNOFF
- DIFFUSE INFILTRATION
- FROM PERCHED CATCHMENTS

Conduits geometry
Matrix hydraulic conductivity
Fracture system hydraulic behaviour
Conduit-system response time
Conduit-fracture coupling effect

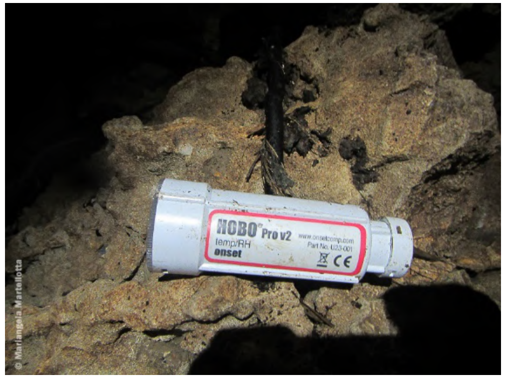
<u>GEOLOGIC BOUNDARY CONDITIONS</u>

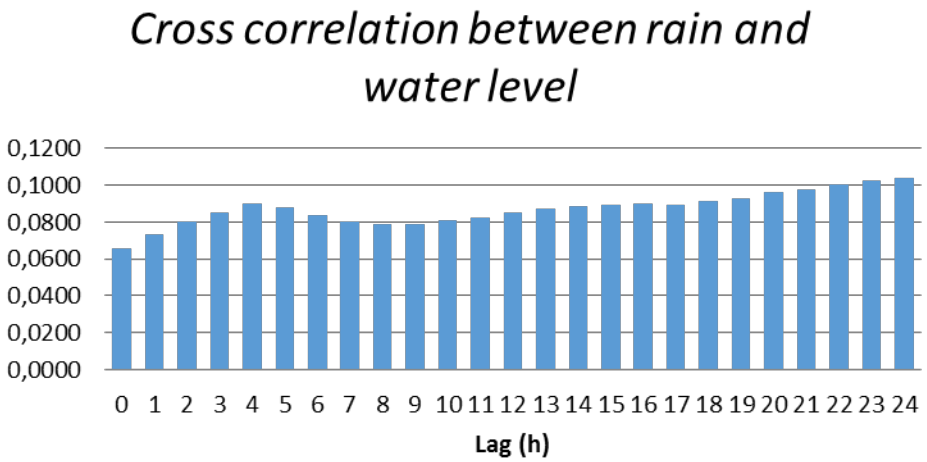
Karst aquifer architecture
Surface catchment architecture
Catchment relief
Lithologic factors
Stratigraphic factors
Structural influence and fluxes control





Ongoing activity





- Hobo sensors data collection
  - temperature and humidity of cave air
- Statistical study of system delay
  - Rain VS water level
- Groundwater samplings
  - chemical and microbiological analysis
- Biospeleological samplings
  - Checking for environmental markers

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