Geomorphologic survey and hydrological measures of a karst spring by means of cave diving techniques (Amaseno, Italy)

Giorgio Caramanna
Hydraulics, Transports and Roads, Faculty of Engineering, "Sapienza" University of Rome, V. Eudossiana 18, 00184 Rome, Italy
Present address: Centre for Innovation in Carbon Capture and Storage (CICCS), Fuels & Power Technology Research Division, Faculty of Engineering, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

Marco Giordani
[www.t-cube.eu]

Abstract

Scientific cave diving techniques were employed to explore and study the cave ''Capo d'Acqua d'Amaseno'', which is located in the southern Latium Region (Central Italy) about 80km southeast of Rome. The cave is fed by a karst system and its dimensions permit exploration through use of diving. Inside the cave a small underground lake was discovered and its level was monitored by deploying a water-level data-logger and comparing it with the rainfall measured in the area. First results highlight the fast response of the lake level to the rainfall; this is in agreement with the characteristics of a system fed by large karst conduits.

Keywords: SCUBA, cave diving, karst spring, hydrology, geomorphology, survey

1. Introduction

Scientific diving may be used in a wide range of environments to collect data for specific research. Karst springs, when their dimensions and environmental conditions permit the presence of divers, may be explored and studied by means of cave diving techniques. The direct presence of researchers within the cave system allows tasks to be performed such as survey, collection of samples and the deployment of monitoring instruments. All of these tasks could not be performed in any other way because of the restricted environment that forbids the practical use of remote systems such as ROVs. However, cave diving is a very demanding activity and it is essential to follow the international standards for safety rules strictly, using well-trained divers with equipment that is designed specifically for cave diving. Failing to follow any of the procedures may very likely result in serious injury or fatality.

In Italy there is a widespread presence of limestone outcrops with development of karst features such as sinkholes and caves. Many of these structures host huge amounts of groundwater that feeds several springs of large magnitude whose dimensions permit diving. In this paper we present the first results of the exploration and study of the ''Capo d'Acqua d'Amaseno'' karst spring. Direct explorations were conducted in order to map the cave and to survey its main geological and morphological features. Some water samples were also collected to measure the main physical–chemical parameters (pH, T, Eh, bicarbonate, electric conductivity, main ions concentration). Inside the cave a small underground lake was discovered and its level was monitored by a specially deployed data-logger. The data acquired were compared with the rainfall in the area.

2. Methodology and safety procedures

The first operation performed inside the cave was the deployment of a safe-line to be used both as a guide for the divers and as a reference from which to map the structure. The line was moored along the walls of the cave mainly by artificial fixings that were plugged inside the limestone using a special manual drill that was possible to operate underwater. At increments of 10m, arrows indicated the distance from the entrance and the direction of exit.

All of the dives were performed strictly following the cave diving safety rules with these minimum requirements:

- Two independent air sources were necessary, represented by two tanks of adequate volume (from 10 to 18 litres), each one connected to

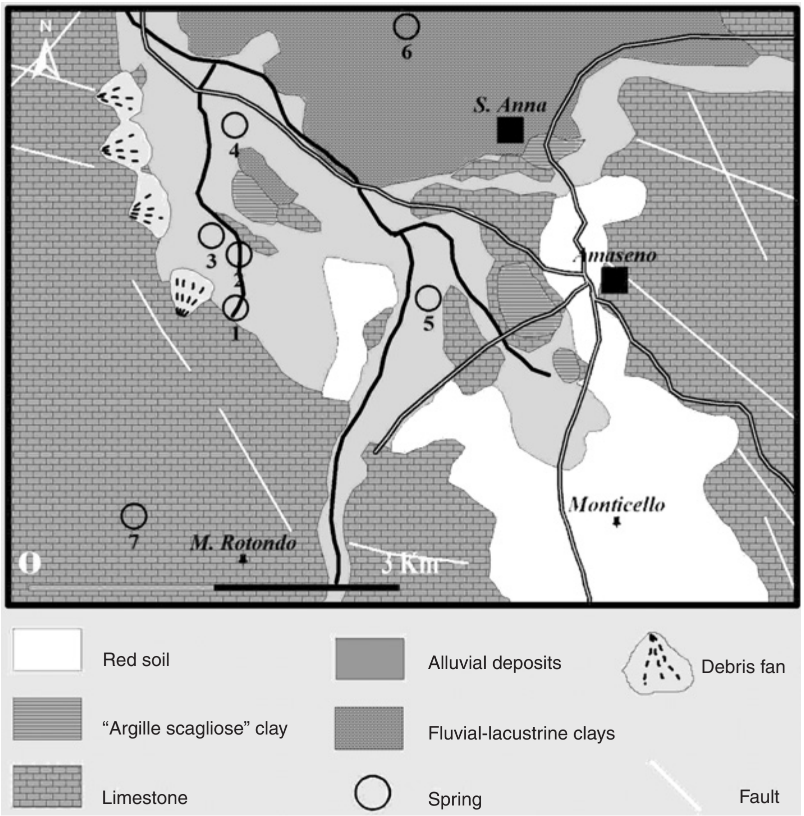

Fig 1: Schematic geological map of the studied area; the Capo d'Acqua d'Amaseno spring is number 1

a first and second stage regulator with pressure gauge.

- The rule of thirds was enforced (1/3 used to go inside the cave, 1/3 to come out, and 1/3 as reserve).
- At least three independent lights were carried; these were usually mounted on a helmet allowing hands-free diving during the sampling and survey operations.
- Each diver was equipped with a primary and a secondary reel to be used as permanent link to the main-line during the operations performed away from the line and for emergency procedures in case of lost contact with the main-line.

The cave survey was conducted both via direct measurement and by video and photographic transects. The pictures were of help during the graphic elaboration of the map. The water-level of the inner lake was measured by a data-logger (STS: Sensor Technik Sirnach AG) moored along the wall of the cave by means of a housing fixed by a chemical concrete (*Subcoat S*). The data were downloaded every few months by retrieval of the logger from the cave.

Water samples were collected by divers by means of sampling bottles (3 samples for each location) that were purged using the air from the regulator and then filled with the water to be analysed. The analysis of the main ions concentration was conducted by liquid chromatography techniques. The temperature of the samples was recorded during the sampling procedure using a standard lab glass thermometer. Field pH and Redox meters were used to measure the parameters soon after the collection of the sample. The bicarbonate concentration was measured by titration immediately after the collection of the sample.

3. Results

3.1. Geomorphological and hydrogeological outlines of the area

Figure 1 shows a simplified geological map of the area. The area is characterised by the presence of the limestone outcrops of Lepini Mounts, Ausoni Mounts and Aurunci Mounts. These ridges are aligned NW–SE with a typical anti-Apennine trend. The ''Capo d'Acqua d'Amaseno'' spring is located at the foothill of the Ausoni Mounts; between this ridge and the Lepini Mounts lays the ''Amaseno Plain''; several small rivers and springs feed the main course of the Amaseno River that flows into the Tyrrhenian Sea on the western shore of Latium. This plain is a link between the main coastal Pontina Plain on the west and the Latina Valley on the east.

The carbonatic lythologies belong to the ''Successione Laziale–Abruzzese'' sequence that is typical

Table 1: Main hydrogeology parameters of the studied area (Boni et al., 1986, mod)

Total springs in the area	22
Surface (km^2)	908
Limestone (km^2)	901
Dolomite (km^2)	7
Annual rainfall (mm)	1276
Average measured total flow (m^3/sec)	16.8
Average estimated total flow (m^3/sec)	8,0
Total flow (m^3/sec)	24.8
Measured infiltration (mm/year)	583
Estimated infiltration (mm/year)	277
Total infiltration (mm/year)	860

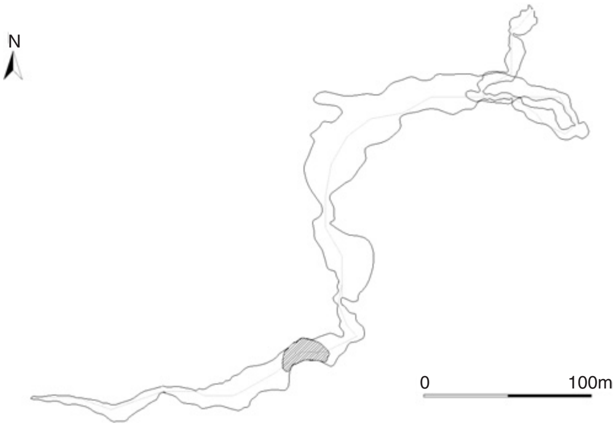

Fig 2: Map of the cave (Survey carried out by Giordani and Malatesta in 2003)

of a subsiding carbonatic platform. In this area, clay deposits (Miocene) and Red soils (Quaternary) are also present (Accordi, 1964; Chiocchini and Mancinelli, 1977; Accordi et al., 1988). The cave is inside limestone grainstones and packstones sediments with benthic foraminifera, green algae and rudistae shells. Mudstones and wackstones with small gasteropoda are also found in some spots. The age of the deposits is Late Cretaceous–Paleocene (Accordi et al., 1988).

The sedimentary cover of the Amaseno plain is made up of alluvial deposits (Pleistocene–Holocene) and some pyroclastic deposits on the most northern sector (Accordi et al., 1988). The structural setting of the Lepini Mounts, north of the Amaseno Plain, is characterised by the presence of bends and trusts with a NE trend in the northern part and by direct faults in the southern. The Ausoni Mounts are intersected by a network of direct faults that lower the structure so that the outcrop is made by almost cretaceous terrains only (Naso et al., 1993).

From available bore-hole data the carbonatic bedrock is more that 160m thick and the outcrops have no or very limited sedimentary cover. The lithology is made up of a sequence of compact and fractured limestone with local evidence of karst dissolution as highlighted by the presence of cavities and red soils. The limestone hosts a confined aquifer with piezometric level laying a few metres below the terrain level (ISPRA, 2004).

The Ausoni and Aurunci ridges are considered to be the recharging area of the ''Capo d'Acqua d'Amaseno'' spring (Boni et al., 1986). The carbonatic structure is widely fractured with high secondary permeability. The annual average infiltration is from 750 to 1000mm, allowing the existence of a large regional aquifer that feeds many first magnitude springs with an average flow of $20m^3s^{-1}$ (Table 1).

3.2. Geomorphology of the cave

The entrance of the cave was about two metres below the surface level of a small artificial pond created by a concrete dam in front of the spring. The system is permanently flooded and, therefore, without any stalactites or stalagmites. It was composed of a main conduit and several small secondary caverns (Figure 2); the conduit, 50m beyond the entrance, twists and creates four consecutive wells that led to a sub-horizontal tight passage at 27m depth, the deepest point of the cave. After this passage, at about 120m from the entrance, the cave enlarged and ended at about 170m in a laminar passage. After this a rising slope led to the inner lake (260m from the entrance). This is the only area where it was possible to surface. The cavity hosting the lake had a free ceiling of about 6m, depending on the lake surface level, and a diameter of a few metres. After the lake, the cave is permanently flooded and was developed into larger rooms. At about 320m from the entrance on the right wall (going inside the cave) a smaller sub-elliptical tunnel opened into the limestone; a steady water flow exited from this breach. The dimensions of the opening (about 1.5m main axis and less than 0.5m secondary axis) did not permit any further exploration by divers. This conduit probably represented the outlet of a part of the karst system that was large enough to allow the accumulation of fine sediments. This hypothesis was supported by the presence of silt, that remained in the water flow from the sub elliptical tunnel for several days after high flow phases. The cave ended in a fracture that progressively narrowed. The total length of the whole system was estimated to be about 360m.

A direct fault (direction 270°, dip 10°–15°) was clearly visible intersecting the main conduit and a large bed of fossils (Rudists) was present along almost the whole cave length, both on the ceiling and on the floor. The floor of the cave, mainly in the larger rooms, was covered by a thick deposit of clay and silt; vegetal chunks were found inside

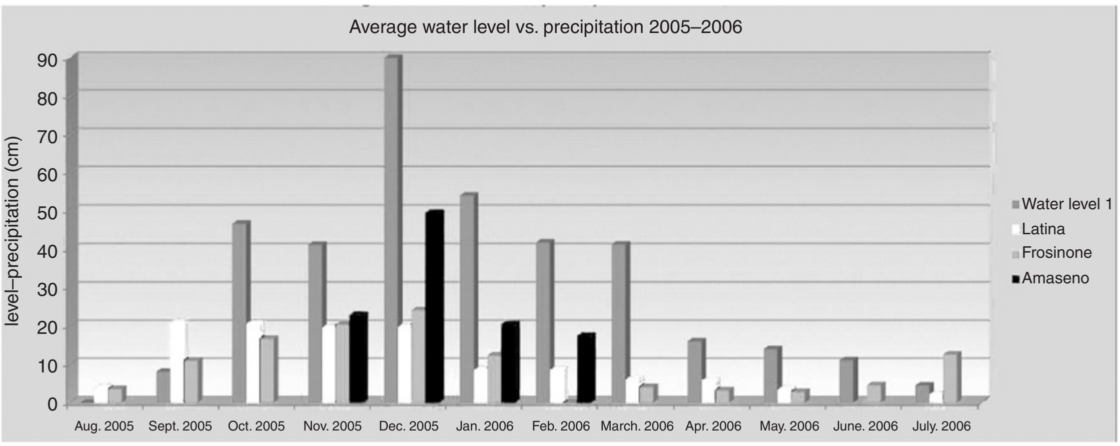

Fig 3: Precipitation and lake water level oscillation in the studied period

Table 2: Dimensional classes (cm) of the measured scallops and their proportion of all measured scallops expressed as a percentage

Class	Number of scallops	%
4	3	6
6	7	15
8	13	27
10	10	21
12	9	19
14	6	13

the sediment. This was considered a clue of the presence of some kind of large connection with the surface that allowed these materials to enter the system.

Several ''scallops'' were measured along the main conduit. These karst features can be used as indicators for the direction and the speed of the water inside a cave system with smaller scallops being associated with faster flows (White, 1988). The observed scallops were clustered into size classes depending on their dimension (Table 2). The smaller ones were often included inside the bigger highlighting a possible temporal evolution of the water velocity with faster flows following slower ones.

3.3. Water chemistry

The main physical and chemical parameters of water samples collected inside the cave at various distances from the entrance are shown in Tables 3 and 4. The water chemistry is bicarbonate-calcic with medium mineralisation; the values are typical of a karst reservoir.

3.4. Lake level measures

The level of the inner lake was measured from August 2005 to July 2006 and compared with the precipitation in the towns of Latina and Frosinone. From November 2005 to February 2006, data from a rain-gauge placed in the village of Amaseno were also available (Figure 3).

The lake level curve showed a pseudo-Gaussian trend with the maximum level in December 2005,

Table 3: Main physical and chemical parameters measured at locations (mean values; $n = 3$ in all cases) within the cave system

Sample date	Sample location (distance from cave entrance; m)	Water temperature (°C)	Water pH	Water conductivity (μs/cm)	Redox (mV)	Bi-carbonate (mg/l)	Total dissolved solids (mg/l)
09/01/2005	50	11	7.34	478	62	268	342
09/01/2005	0	13	7.34	485	110	293	347
05/02/2005	150	11	7.21	413	184	268	295
20/03/2005	0	15	7.25	440	151	262	315
20/03/2005	170	10	7.37	430	177	262	307

Table 4: Main ion concentrations analysed by liquid chromatography from samples taken at two locations within the cave (9-01-2005: mean values; $n = 3$ in all cases) system on the same date (9-01-2005)

Distance m	Na^+ mg/l	K^+ mg/l	Mg^{2+} mg/l	Ca^{2+} mg/l	HCO_3^- mg/l	SO_4^{2-} mg/l	NO_3^- mg/l	F^- mg/l	NH_4^+ mg/l	PO_4^{3-} mg/l
0	5.5	0.64	5.96	73.92	232.41	4.66	7.24	0.03	<0.1	<0.1
50	7.32	0.91	6.59	73.87	247.66	4.67	7.73	0.03	<0.1	<0.1

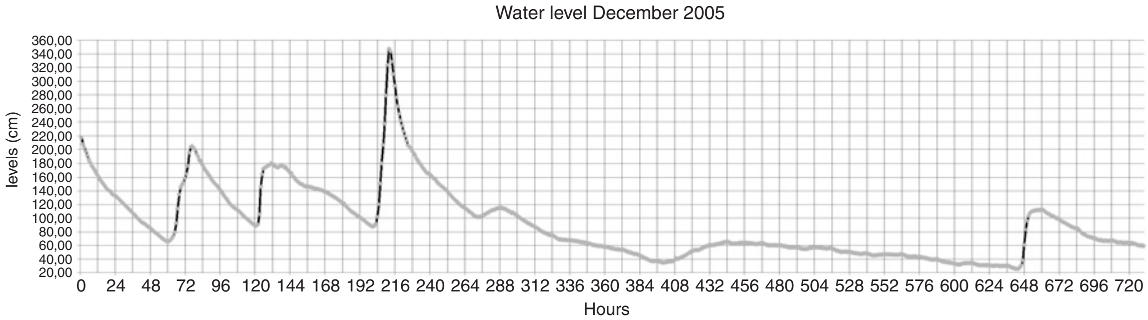

Fig 4: Lake water level oscillation highlighting steep rising followed by a slower discharge phase

the month of maximum rainfall. There was a clear positive relationship between the rainfall at the Amaseno pluviometric station and the level of the lake with a fast response. More detailed analysis of the lake water level showed sharp increases over a few hours, followed by a longer discharge phase (Figure 4).

4. Conclusions

The morphology of the cave was in good accordance with a model of a cave system developed along structural faults and strata joints. The absence of any speleothem is a proof of the permanent flooding of the structure. The water chemistry is typical of bicarbonate-calcic groundwater with medium total dissolved solids. The response of the level of the inner lake to the rainfall showed a very fast recharge followed by a slower discharge of the system which could be explained by the presence of a wider reservoir that, once triggered above a certain volume, feeds the spring with a large volume of water. Another indication of the existence of such structure was the murky water that is carried inside the cave from the inlet found close to the end of the main conduit; silty sediments should come from wide chambers where accumulation is related to low flow rates.

In conclusion, scientific diving techniques have provided a research tool for mapping the dimensions of the spring and collecting hydrological data. These data can provide a better definition of the flow regime of this spring which is an important reliable source of water for the local region.

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