Proceedings in
Advanced Research in Scientific Areas

The 5th year of International Conference on Advanced Research in Scientific Areas

ARSA 2016

7. - 11. November 2016

Slovak Republic

Published by: EDIS - Publishing Institution of the University of Zilina
Univerzitna 1
01026 Zilina
Slovak Republic
Editors: Ing. Michal Mokrys; Ing. Stefan Badura, Ph.D.
ISBN: 978-80-554-1284-9
cdISSN: 1338-9831
eISSN: 2453-6962
DOI: 10.18638/arsa.2016.5.1
Pages: 183
Printed in: 100 copies
Publication year: 2016

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Paper Citation Example: In (Eds.) S. Brown, S. Larsen, K. Marrongelle, and M. Oehrtman, Proceedings of The 5th International Virtual Conference on Advanced Research in Scientific Areas (ARSA-2016), Vol. 5, pg #-#. Zilina, Slovakia.

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Mechanical engineering
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Health sciences

Preliminary data on the temperature distribution in a ponor (Andrassa, Ligurian Alps)

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Abstract—**The aim of the study is to illustrate the thermal dynamics of a ponor, the Andrassa cave (Italy). We examined the hygrothermic Spring and Winter conditions. These first data provide some interesting indications on the circulation of air into the cave. Indirectly, the temperature distribution in the air and ground indicates the direction of air flow, even when the flows are too slow for direct measurements. According to bibliography, the ponor morphology is expected to lead to a circulation "air bag", where the winter temperature is determined by a convective circulation fuelled by the entrance. Instead, the evidence shows that the water (of oozing and surface runoff) in Andrassa cave influence the ground temperatures more than air. This probably happens in all caves with an important water flow. If confirmed, this would be a strong limit to the number of caves that have actually a circulation "air bag".**

Keywords- Temperature distribution, Humidity, Air circulation, Karst, Ponor, Cave, Ligury

I. INTRODUCTION

Understand the thermic dynamics of the caves, is critical to evaluating particular sectors of caves as refuge (steno-endemic species, winter refuges of bats colonies...) [8]. Moreover, in touristic caves the air circulation by thermic imbalances is fundamental, not only, obviously, to the comfort or even the survival of visitors, but also for the reduction of the environmental impact that is related to the visit (heat and humidity), which can destroy the delicate ecosystem of the caves.

A goal of the research project "Thermic dynamics of underground systems" (Earth Dept., University of Turin) is to investigate also the caves where air movement is too slow for measurements with anemometers. The idea is to discover the air circulation through the analysis of its effects, i.e. the thermic imbalances and their annual variations. The study examines four sectors: the ground at 1 cm deep; the air at 50 cm above the ground; the oozing water (internal temperature of tubular stalactites); the flowing water.

The Andrassa ponor (western Liguria, WGS 84 coordinates N 44° 12' 8" and E 22.8° 22' 42.3", 221 m a.s.l.) has a very simple structure: a single entrance, absence of side branches, and longitudinal profile with constantly, downward trend. The model of air circulation named "air bag style" [7] says that in a cave of this kind, the air should have only convective movements (due to temperature difference between the cave and outside air), which lead to the following seasonal temperature conditions.

1. During the summer the air in the cave is more cold (i.e., more dense) than outdoor air, so the latter can enter the cave only to a limited extent. Therefore the thermic stratification in the cave is reversed: the deep air is the colder; after a short transition zone, at the entrance the air temperature reach quickly the outside value.

2. During the winter, the air in the cave is hotter. The outdoor air enters, flows along the floor and heats up, then slides along the ceiling, before of coming out.

3. In transitional seasons little air circulates, with direction that varies, depending on the temperature variation of the outside air.

However, the Andrassa (like many other caves) has a water circulation, i.e. an additional source of heat exchanges. Being a ponor, frequently water flows on the bottom. Throughout the year, largely of the cave fall lots of water dripping. The "air bag" model still applies? If the heat transfer between air, water and rock changes dramatically the air circulation, the "air bag" model (commonly applied to all single caves entrance) would not be applicable to caves in which, in addition to air, the water normally enters (by oozing, or by underground rivers).

II. GEOMORPHOLOGY

The Andrassa entrance (or Andrassa del Cane, i.e. Dog's pit) opens on the bottom of a karst ravine, at the geological boundary between the dolomitic limestone of Middle Trias (medium permeability) and the arenaceous limestone of Middle Miocene (very permeable), just downstream from the western edge of the Manie plateau. The latter is a cockpit karst, born in a period of tropical climate, during the Early Pleistocene. The original plateau, much larger, included the cave area [3]: it was a big cockpit, whose was the ponor Andrassa [10]. Today Manie plateau is greatly reduced, so, only the easternmost part of the cockpit (so-called Andrassa Plains) keeps the original morphology [1]. The western part is a little valley, with a watercourse active only during exceptionally rainy periods [2], the Rian Andrassa.

The Andrassa cave has the typical morphology of a ponor: an initial pit, of 12 m deep, that is followed by several chambers (sometimes flooded), connected by steep slides. The cave is oversized compared to habitual runoff, because when the cave was the ponor of the entire cockpit, the hydrogeological basin was about double that of today. The accessible part of the cave is 210 m long and drops to -56 m.

Reference [6] proved that the water of Andrassa arrives at Acquaviva spring (65 m a.s.l., Sciusa Valley), in a time ranging between 80 hours (during a very strong drought), 18 hours (at the first flood after the summer drought, with vadose zone saturated) and 15 hours (at last flood after the winter period, with epiphreatic zone completely flooded). On the basis of changes in discharge, turbidity, hardness and tracers concentration, [5] says that the entire path of the water follows the geological boundary between dolomitic limestone (bed) and arenaceous limestone (roof). The inaccessible part of karst system is long at least 1700-1800 m (with a difference in altitude of 100 m). After an initial part with narrow passages and chambers similar to the accessible part, it should be almost horizontal, partially clogged with silt and sand, with large chambers (maybe not completely submerged) at the arrivals of other underground rivers (including one coming from the cave of Mala, 768 Li-SV). In other words, it should be an epiphreatic or phreatic gallery, maybe not completely flooded, but certainly with no actual atmospheric circulation.

Four different types of sediments are found in Andrassa.

1) Silty clays, coming mainly from erosion of the soils of the cockpit. These sediments fill the depressions, arising from an after-flood settling within the basins perpetually (or almost) full of standing water.

2) Sand with gravels, arising from floods, increasingly common towards the end of the cave.

3) Twigs, and blocks made of dolomitic limestone, arising from exceptional floods.

4) Angular blocks of arenaceous limestone, arising from the cave breakdown processes.

The sedimentation type shows that the ponor is active, even if water enters through the entrance pit only during major floods. After heavy rains, the distal end of the cave remains completely flooded for weeks. Exceptionally, also remains flooded Great Chamber (fig. 2).

The dynamic of groundwater flow can be summed up as well.

1) In an ordinary flood, the outer rivulet (Rian Andrassa) collects water overflowing from the Andrassa Plains. This water is intercepted by sinkholes immediately upstream of the entrance to the Andrassa Cave, or, by the entrance pit of the cave. The narrow passages of the Andrassa are cluttered with sediment; therefore the water cannot drain completely, so a part the cave is full of water.

2) During exceptional floods, fluvial processes lead sometimes into the cave pebbles, sand and twigs.

3) After the rains, a large amount of dripping water enters in the cave from the vadose area (particularly at the beginning of Great Chamber). This process has settled several stalactites, travertine dams, and flowstone deposits.

4) During lean periods, the water is only in isolated pools and in areas of persistent oozing, but the floor remains wet everywhere.

III. DATA COLLECTED

The work presents the data of a first campaign of measurement. We have measured:

1) temperature and relative humidity in air at 1 m from the bottom;

2) temperature of ground;

3) temperature of standing water;

4) temperature of dripping water within of soda-straw (tubular stalactites).

The measurements are performed at 2 m from the operator. The light was only a two-led lamp, in order to avoid unwanted sources of heat. The method and instruments (error of ± 0.1 °C for temperature and ± 1 % for relative humidity) are the same used in Borna Maggiore cave [9].

IV. WINTER DATA ANALYSIS

Fig. 1 and 2 show the distribution of temperature on January 5, 2016.

Ground and water temperature are very similar from the entrance until of 92 m. More far, oozing water is much hotter. The water temperature is close to that of resurgence (Acquaviva spring), normally 14.1 - 15.4 °C [6]. Standing water is always colder than that of dripping, perhaps because it is largely coming from the underground: arriving quickly from the outside, it is colder than water of vadose zone. The air temperature increases rapidly at the entrance, then stabilizes on 11.8 - 12.5 °C up to 52 m away from the entrance; more far, it oscillates between 13.7 and 14.2 °C regardless of the distance from the entrance. This oscillation do not follows the sequence of chambers and narrow passages: we can thus exclude that is due to either compression or expansion of air mass (moreover it is unlikely, because the air movement is imperceptible).

Fig 3 shows the difference of temperature between air and other materials. It is clear that water dripping influence ground more efficiently than air.

The tendency towards saturation with the depth (fig. 4), despite the increased air temperature (fig. 5), indicates a progressive increase of absolute humidity, tied to strong evaporation. The undersaturation near the entrance despite the lowest air temperature (fig. 1), conversely, indicates that the cave, during the measurements, takes in air from the outside. The absence of evidence of exit streams of air indicates that probably the same joints that carry water of oozing into the cave (together to snails, seeds…) at the time of the measurements aspire hot air from the cave, compensating the entry of cold air in the cave from the entrance (fig. 6).

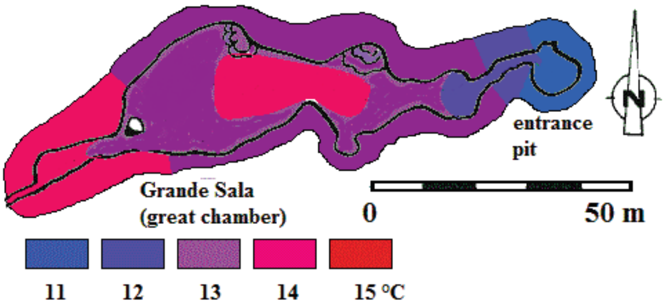

Figure 1. On the January, 5 2016, the distribution of ground temperature (colors outside the cave boundary) differs from the one of air temperature (colors within the cave contours), showing a thermic imbalance due to airflows. Cave map redrawn from [4].

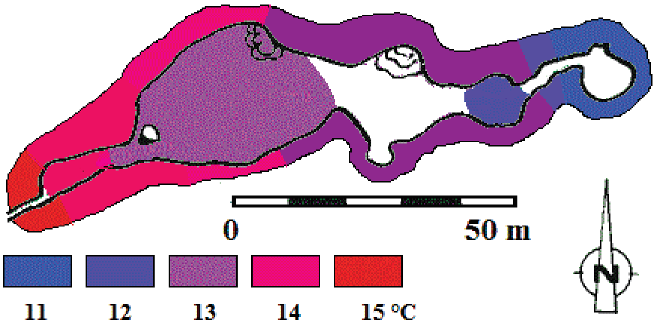

Figure 2. Temperature distribution of dripping water (colors outside of the cave boundary) and of surface water (colors within the cave boundary; the part in white is dry) on January 5, 2016. The water reaches the same temperature of the resurgence (Acquaviva spring) in little more than a hundred meters from the entrance.

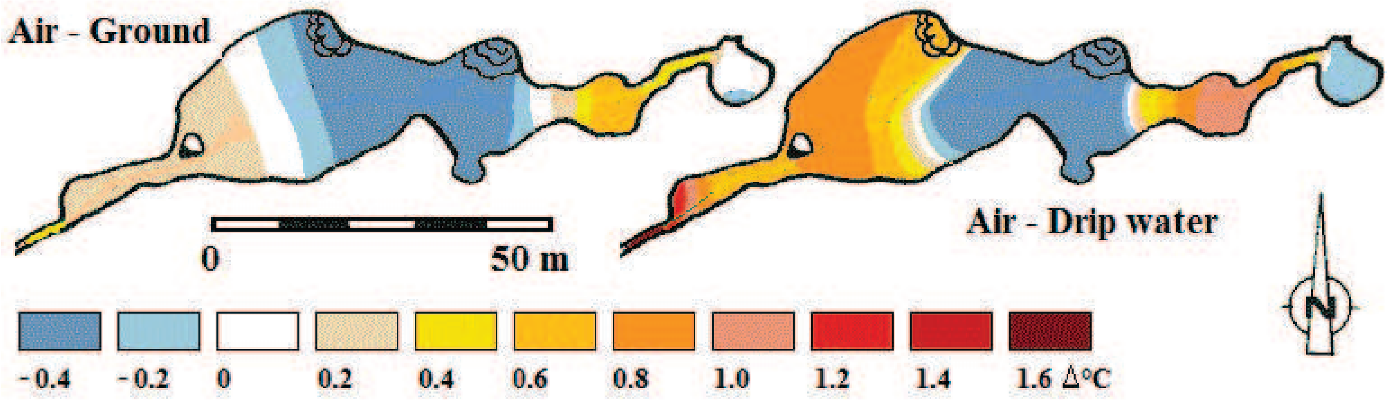

Figure 3. Thermic difference between air and ground, and between air and dripping water, on January 5, 2016.

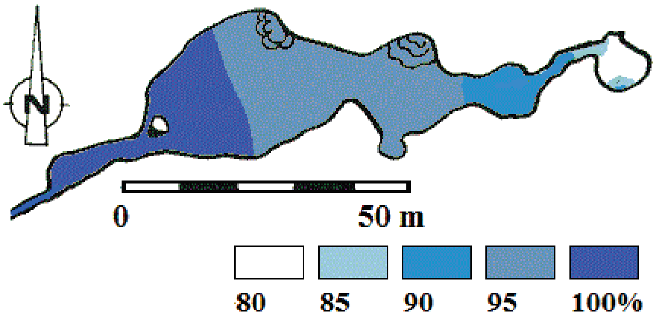

Figure 4. Distribution of relative humidity (%) on January 5, 2016.

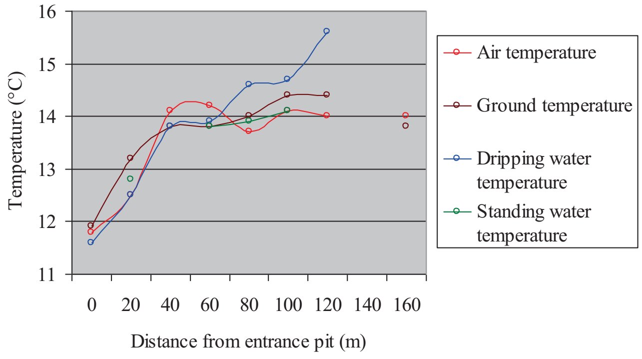

Figure 5. Temperature variations on January 5, 2016.

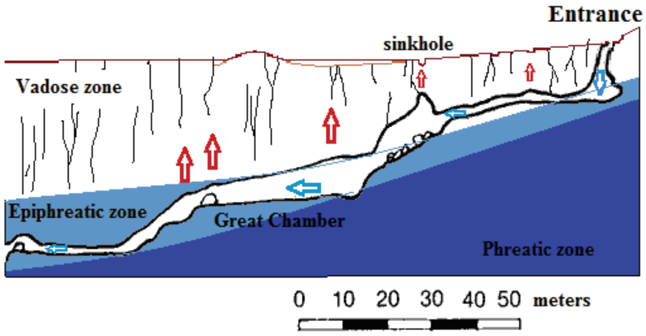

Figure 6. Schematic section of Andrassa ponor (section of cave from [4]; topographic profile from an original GPS survey). The arrows indicate the likely circulation of air in winter (red: hot air; blue: cold air).

V. SPRING DATA ANALYSIS

The distributions of temperature and humidity of the figures 7-11 indicate that:

- the air of initial pit is warmer than the outside. It is also warmer than ground and water dripping;

- the first part of the cave shows a progressive lowering of temperature difference between air, ground and water. At 52 m from the entrance air, ground and water are in thermic equilibrium, at 13.6 – 14.0° C (value close to the annual average);

- at 72 m from the entrance, where the cave has a steep step with abundant runoff, the temperature of air newly increases respect to ground and water;

- in the Great Chamber, at 92 m from the entrance, the air is colder than ground and water;

- more next, with the depth, the temperature of the air becomes more and more similar to that of dripping water, but becomes higher of ground temperature;

- at 112 m from the entrance, the air is warmer of ground, water and air upstream.

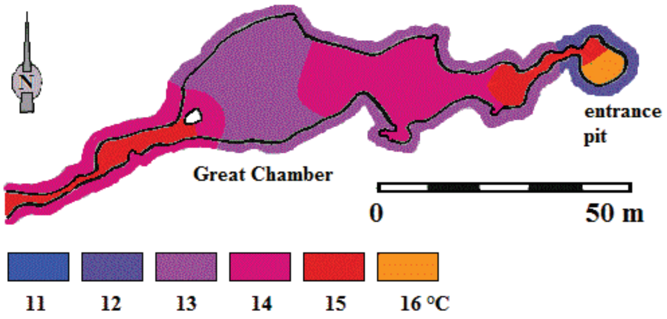

Figure 7. Temperature of air and of ground on April 13, 2016. Outside, the ground is at 13.0 °C, the air is at 13.1 °C.

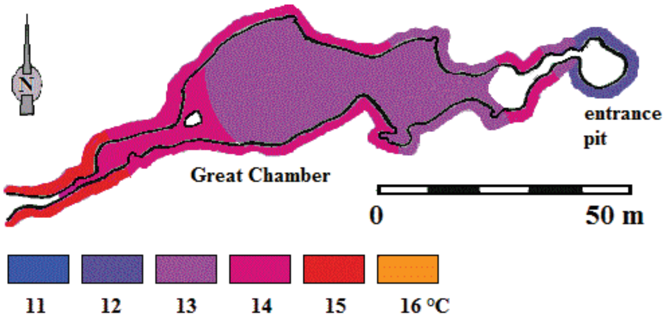

Figure 8. Water temperature (see caption of fig. 2) on April 13, 2016. The water temperature of the Rian of Andrassa (the rivulet outside) at the same time is 15.1 °C.

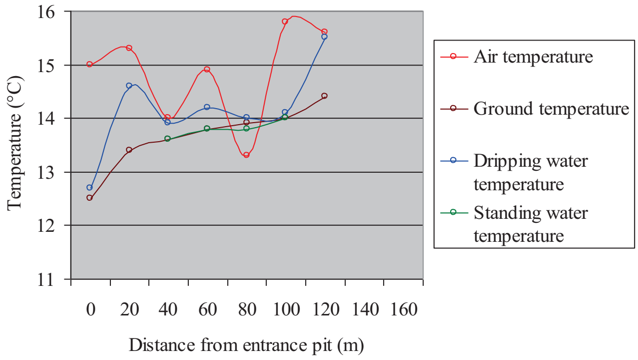

Figure 9. Temperature variations on April 13, 2016.

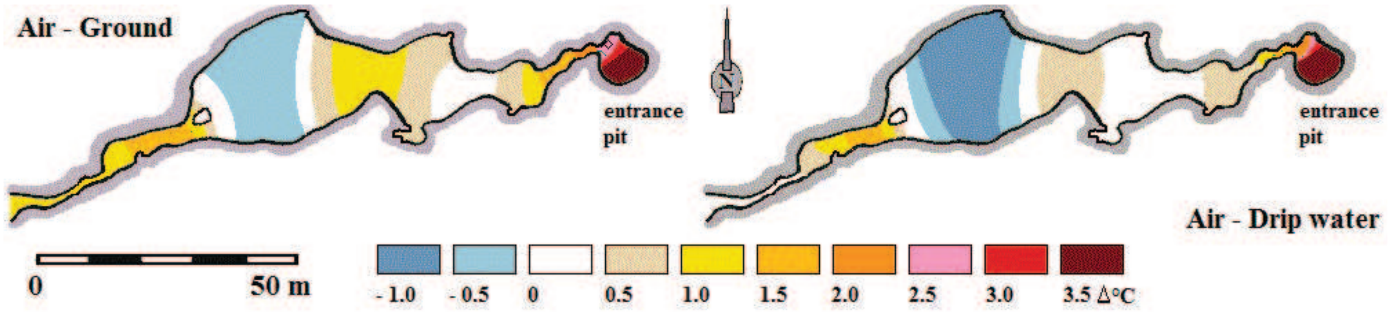

Figure 10. Difference of temperature between air and ground, and between air and dripping water, on April 13, 2016.

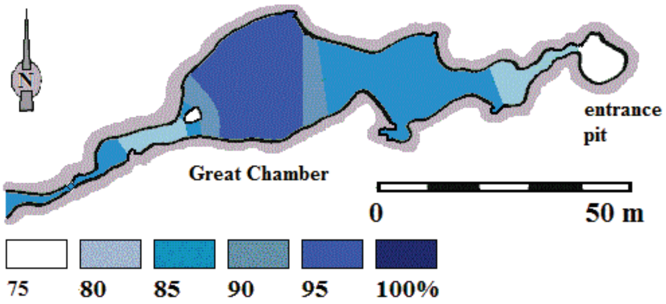

Figure 11. Relative humidity (%) on April 13, 2016. Outside, the air in front of the entrance, at 1.5 m above the ground, had RH = 67.6%

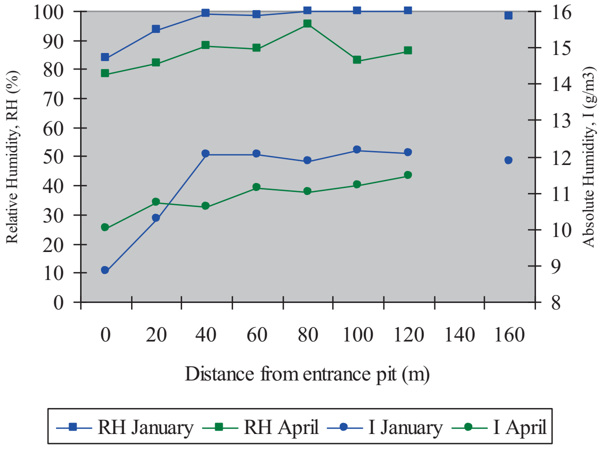

Figure 12. Comparison between the humidity conditions in January and in April.

VI. CONCLUSIONS

The study shows that the method is better to assess the air circulation than a method based only on anemometers. Indeed, despite not being present, during measurements, any air circulation perceptible (with empirical systems commonly employed by cavers as smoke...), the distribution of temperature and humidity (fig. 12) allows to easily reconstruct the air flow direction and the thermal imbalances. The results show that the Andrassa in winter has not a current of air coming out from the entrance, hence the absence of condensation into the entrance. The temperature of the floor of the cave is mainly determined by water dripping (i.e. from the average temperature of the vadose zone), not from the air. These circumstances make the cave more stable than one might assume with a hypothesis of circulation like "air bag". In spring the interior of the cave has remarkable thermic imbalances, not uniformly extended to the whole cave. They show that the dynamics of the cave is not simple, perhaps because of a lack of homogeneity of the heat flux conveyed by the oozing. From the deepest part of the cave comes out hot air, but probably not reaches the Great Chamber. Probably this air meets, before of the Great Chamber, some cracks through which it exits directly to the outside. In conclusion, although the Andrassa has the typical morphology for a circulation "air bag", does not has this kind of dynamic, due to factors that commonly found in many caves:

- large amount of dripping water from the vadose zone;
- outflow of water in the bottom;
- cracks that are air permeable.

This leads to suspect that in reality:

- the "air bag" model of circulation is not the rule for all caves developed downwards and with single entrance, but is limited to very dry and not very long caves;
- a substantial portion of the air circulation occurs through small joints (i.e. inaccessible);
- thermic imbalances of 1-2 °C are possible even very far from the entrance, without any relation with the arrival of air coming from the entrance;
- the air has frequently moisture < 100 % (due to thermal imbalances) even in caves with abundant water (besides, several authors believe that the genesis of stalactites is linked to a partial evaporation of dripping water).

As for the Andrassa, the additional ongoing studies on daily variations in temperature and on temperature distribution in summer and fall will certainly clarify the thermic dynamics further.

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