3. The Borna Maggiore of Pugnetto (Lanzo Valley, Piedmont, North-West Italy): a horizontal cave, with water circulation

1. Introduction

The site of study is the hill of Truc d’le Tampe, in Western Alps (Lanzo Valley, Italy). This is a unique karst landscape, in a sector of the Alps without other karstlands, without glaciers even during the glaciations (Motta, 2014; Motta, 2015). The hill is made of calcschist with marble lenses. Within of this rock, the fractures enlargement by dissolution, together to processes of cave breakdown has created four caves: the well-known Borna Maggiore (1501 Pi/TO, 375551E 5014621N, 820 m a.s.l.), which was intensively studied since very long time; Tana del Lupo (1502 Pi/TO), Creusa d’le Tampe or Borna Minore (1503 Pi/TO), Tana della Volpe (1504 Pi/TO).

Karst breccia made of marble and calcschist fragments, with large interstices and voids, partially covers the lower part of slopes of Truc d’le Tampe. Soil with a thick epipedon covers in turn the breccia (fig. 1). Juberthie et al. (1980) has described ecologically this interstitial habitat as Milieu Souterrain Superficiel or Underground Superficial Compartment (MSS), and Juberthie et al. (1981) has reported this habitat also in karst breccia.

The Truc d’le Tampe represents an important spot of hypogean biodiversity in the Western Italian Alps. It hosts several caves protected by law (European Habitat Directive 43/92, S.C.I. IT 1110048), because they are the winter shelter of several species of bats, such as *Myotis emarginatus*, *M. myotis*, *Rhinolophus ferrumequinum*, *R. hipposideros*. These caves host many important endemic invertebrates also. Among these, it’s worth to mention the coleopterans *Dellabeffaella roccai*, the most specialized Leptodirinae in Piedmont (Arnò and Lana, 2005), and *Sphodropsis ghilianii ghilianii*; the orthopteran *Dolichopoda ligustica septentrionalis*; the isopod *Alpioniscus feneriensis caprae*; *Troglohyphantes bornensis*, a cryophilic, steno-endemic spider.

Fig. 3.1: The excavation for recovering of a trap shows the aspect of MSS and overlying soil, near to station 1, on the slope lower down of Borna Maggiore.

2. The study area

2.1. Geomorphology

In order to know the cave geomorphology better, we have made a survey of the sets of joints and faults, and we have measured the vertical distance between floor of cave and surface of hill (fig. 3.2). Truc d'le Tampe, the hill that contains the cave, has a true karst area, with sinkholes and a doline. In spite of this, inside of the cave, karstic forms of corrosion virtually do not exist. The Borna Maggiore is a joint-plane cave developed at the intersection of several sets of fractures. They are: fault planes F1 (from 336° / 71° to 310° / 76°) that separate rocks with bedding joints S1 (60°- 84° / 33°- 60°) from other with S1 165° / 59°; joint planes J1 0° / 80°; J2 (124°- 130° / 50°). The cave is almost horizontal, because the soluble rocks (calcschist and marble) that host the galleries rest above a confining unit made of permeable, but non-cavernous phyllite. The cave has four parts (fig. 3.3).

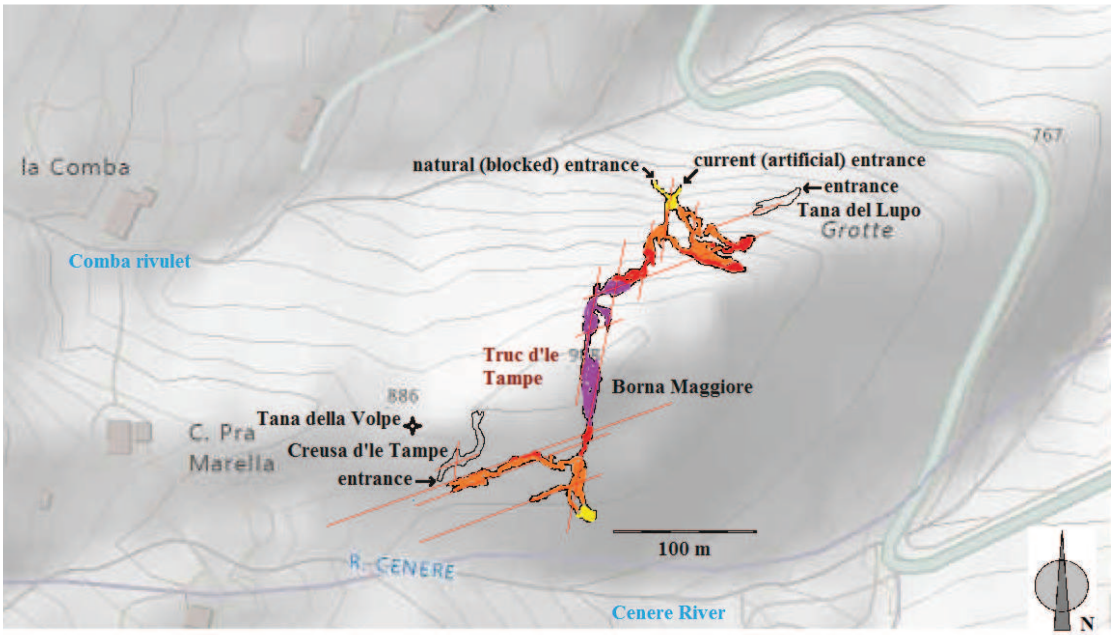


Fig. 3.2: Position of the caves and major sets of joints and faults (red lines). The colors represent the vertical distance between the floor of Borna Maggiore and the surface of hill. Yellow: 0-20 m; orange: 20-40 m; red: 40-60 m; violet: 60-80 m.

1. Madonna Branch and Main Branch from entrance as far as the fork between Madonna Branch and Fountain Branch: they are dry and horizontal galleries with some chambers created by fall of rock masses from ceiling. Prior to removal, by the mineral collectors, were abundant plates of large crystals of calcite grown underwater and opal concretions (Balbiano d'Aramengo, 1993). Therefore, the cave development is probably due to a water stream that has enlarged a passage close to the water table. During some periods the corrosion process (in phreatic conditions) has enlarged the galleries; otherwise in the cave the conditions were suitable for a calcite and opal precipitation. Today, this part of the cave is always in vadose zone. The water is dripping in main gallery for its entire length (sometime at least), but the dripstone are little developed (even before the devastation

because of collectors). This suggests that the condition vadose of gallery is quite recent. At the end, Madonna Branch is very close to the topographic surface.

2. Both the Fountain Branch, with its perennial source, and the parallel short branch, with its intermittent waterfall, are typical galleries of back flooding, with the morphological features of epiphreatic condition (ceiling channels…). The current aspect is also the result of successive process of cave breakdown.

3. The water flowing in Fountain Branch after a few meters sinks in Lower Branch, that is parallel and below the Fountain Branch. This branch becomes after a few meters virtually impassable (Muratore, 1925 and 1946). The Lower Branch is an epiphreatic passage that links the bottom of Fountain Branch to the active cave. The underground stream of Lower Branch flows exactly below the floor of Fountain Branch, and probably continues, going near to the lowest part of the Borna (Left Galleries). The corrasion is the main process of erosion in Lower Branch, because the floor is made of calcareous phyllite that is little soluble and very soft.

4. Left Galleries are the lowest sector, underneath the entrance gallery. The largest chamber, floored by collapse debris, once hosted a cave lake (Muratore, 1925 and 1946), probably linked to the watertable.

2.2. Discussion of the geomorphologic data

The proximity between cave ceiling and surface of hill, the independence of the path from the external morphology (Fig. 2) and the temperature of the fountain rather constant (annual excursions of temperature: 4.6°C; average: 10.1°C) are evidences that the Borna is a through cave (i.e., a hydro-geological tunnel). The autogenic drainage is secondary: only the small closed basin at 886 m a.s.l. (Fig. 2) is an actual karst seep, with a true sinkhole (Tana della Volpe, 883 m a.s.l.).

Probably, the main reason of the genesis of Pugnetto caves is the slight difference in height between Cenere Valley and Comba, a parallel and tributary valley (near Pugnetto). The rocks of the watershed have secondary and tertiary porosity. Therefore, a karst aquifer carries a canal seepage loss of the Cenere River to Comba Rivulet, going at shallow depth under Truc d’le Tampe, the watershed that separates the two valleys. The losing stream is the part of Cenere River above 880 m a.s.l., which flows parallel at the major set of joints of Fountain Branch. The yield of the cave stream is usually < 1 l/s, i.e. a simple canal seepage loss. Nowadays the Borna Maggiore not contains allochtonous pebbles that can come from Cenere River (the rocks coming from upstream are easy to recognize, because they are only serpentinite and gneiss, without calcschist). Therefore, never a watercourse arrived directly in the cave from outside. This explains why, although a lot of collectors have dug everywhere in the cave, they have never found fossils. The absence of large Mammals and old artifacts probably derives from the absence or obstruction of entrance in the past, and (more recently) from the absence of karst shafts that act as natural traps.

Once, probably the main stream flowed through the Madonna Branch, which ends at less of 20 meters to hill surface. When this branch was active, the cave had a hump in half (with a narrow that shows still today the siphon feature) and probably the water, through the Left Galleries, came in those times to Tana del Lupo (at 70 m from the Borna entrance, 7 m below), which was the outflow cave. The natural entrance of Borna Maggiore (a narrow tunnel blocked for safety; the current entrance is artificial) is a secondary passage of the autogenic drainage.

40 meters over the Borna, the Creusa d’le Tampe is very close (horizontal distance of about ten meters), and it follows the same fracture set of Fountain Branch. This cave may be

all that remains of a similar and oldest hydro-geological tunnel, or a cave system of the autogenic drainage, together to the Tana della Volpe.

3. Monitoring

To know the dynamics of thermic exchanges, it is obvious that we need first to know the temperature of the cave and its variations, both temporal as spatial. In this paper, in particular, we will present four data groups.

Data of ground temperature. The sensors are seven I-buttons Hygrochron - DS1923 that were into the shallow ground, relatively far from the walls and very far from the active watercourse (Fig. 3; G1 is at the cave entrance, in twilight zone). The sensors have a nominal accuracy of 0.0625°C; they have measured the temperature every three hours. The period of analyses is from 27 May 2012 up to 6 February 2013 (Fig. 4). The Hygrochron have also a humidity probe, but almost all of these measures have had a fails because of inappropriate working conditions (long period of high humidity). Therefore, we believe unreliable the few data obtained.

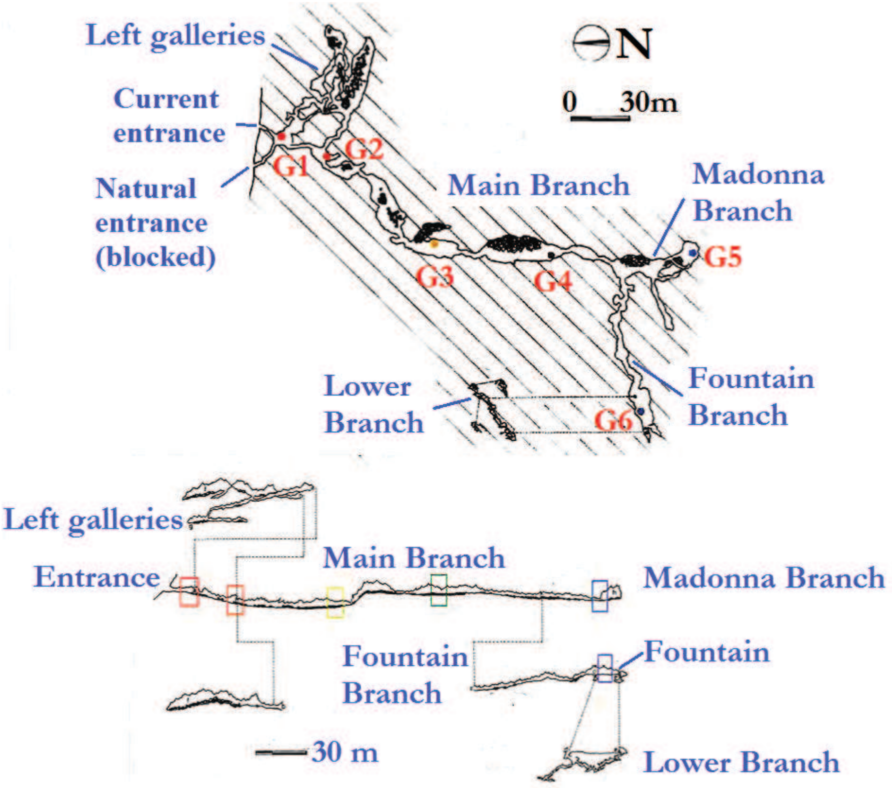


Fig. 3.3: I-buttons arrangement.

Seasonal (31 July 2013, 30 October 2013, 28 January 2014, 8 May 2014) **distribution of temperature and relative humidity**. The measures are made by a Delta Ohm thermohygrometer HD9216 through the longitudinal section of the cave, with a interval of 10 m (interval that seems appropriate for the temperature variability within this cave), in the lowest point of the floor within the ground (Pt100 TP9AP probe placed at 60 mm depth), in the air (air probe HD9216S at 1.5 m above ground level), in dripping water (TP9A probe). The temperature precision is ± 0.1°C plus linearization error (0.04°C) ± 1 digit. The humidity precision for the complete instrument is ± 2% in the range 5%...90%, +4% / -2% in the range 90%...98%. A long support has kept the air probes away from the operator some meters, so as to avoid the risk that the human body changes the measures.

Air temperature measured in cross sections, according to a rectangular mesh grid of 0.5 m, with an air probe HD9216S.

Moisture distribution within rock surfaces. The measure instrument is a dielectric moisture indicator T650 Trotec (penetration depth 20-40 mm), and its aim is to recognize the saturation state of the rock (dry / damp / wet).

4. Data Analysis and Discussion

4.1. Analysis of the I-button data

First, we have done the validation of the data and the aggregation at monthly level. In Motta and Motta (2014) we have published the analysis of the I-buttons data together to the data of the other caves studied by CaveLab. Table 3.1 reports the data of two I-buttons placed within the Borna Maggiore.

To estimate the annual data despite the short observation period, we use only the monthly mean temperatures of January 2013 and July 2012 with their standard deviation (both calculated on the basis of daily data), and the average of the thermic daily excursions recorded during two months already mentioned (tab. 3.2). The table shows as well:

- the average of the monthly values already mentioned; given the relative stability of the hypogeous thermic conditions, it can be an estimate of the average annual temperature;

- the difference in value; it does not indicate the annual thermic excursion (indeed, January and July are almost never, the coldest month and the warmest, see Fig. 1 of Motta and Motta (2014), but it gives an idea of the difference between the seasons anyway.

Tab. 3.1: January 2013 temperature parameters, in °C.

Distance from entrance	Mean	Monthly excursion	Daily excursion (average)
3 m	2.38	1.69	1.50
230 m	9.34	0.00	0.00

Tab. 3.2: Values (°C) of July 2012 and January 2013. Annual average estimated by January and July values mediated.

I-button	Distance from entrance	Mean		Difference	Annual mean	Standard deviation		Daily excursion	
		January	July			January	July	January	July
G1A	3 m	2.38	7.76	5.38	5.07	1.69	0.20	1.50	0.06
G1B	3 m	2.95	7.82	4.87	5.38	1.13	0.16	0.41	0.05
G2	30 m	5.40	7.09	1.69	6.25	0.39	0.06	0.14	0.01
G3	90 m	6.54	7.50	0.96	7.02	0.21	0.04	0.03	0.00
G4	150 m	8.21	8.40	0.19	8.30	0.04	0.00	0.02	0.00
G5	230 m	9.34	9.40	0.06	9.37	0.00	0.00	0.00	0.00
G6	350 m	9.21	9.29	0.08	9.25	0.02	0.04	0.01	0.01

To determine more accurately the position of the maximum and the minimum of the thermic curve and have a better estimate of the average and the annual thermic excursion, we calculated with the method of least squares the equalization of the thermic curve formed by 3-hours data with the sine function (1):

$$T = T_m + e_a \sin [2\pi (t - t_0 - \varphi_a)/365.2422] / 2 + e_d \sin [2\pi (t - 0.25 - \varphi_d)/24] / 2 \qquad (1)$$

where T is the temperature laid down in time t (expressed in average of days since midnight 0.00 from 01.01.1900; the t_0 = 40988.6347$\underline{2}$ value corresponds to the spring equinox of 2012).

We thus obtain the values of:

T_m, estimate of average temperature (°C),

e_a, estimate of the annual excursion (°C),

e_d, estimate of the daily excursion (°C),

φ_a, estimate of the average of time (in days) since summer solstice until the moment when the thermic curve reaches the maximum value, and of time since winter solstice until the moment where the thermic curve reaches the minimum value. In other words, this parameter indicates the "phase delay" of the position of the maxima and minima of the sine curve of equalization of the thermic curve compared to the solstices.

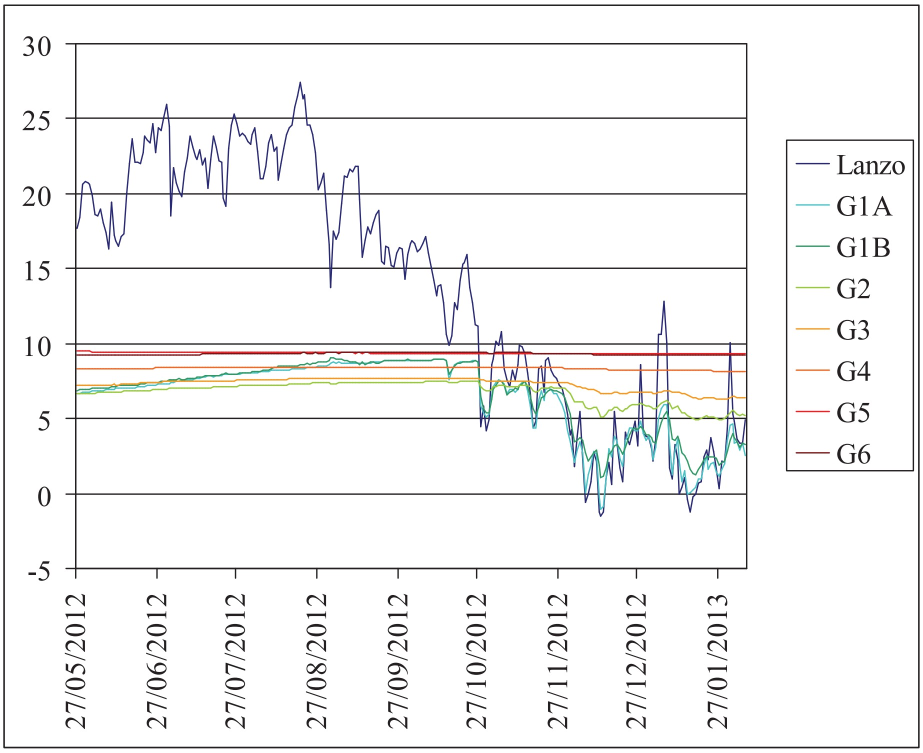
φ_d, estimate of the average of time (in hours) since midday until the moment when the thermic curve reaches the maximum value, and of time since midnight until the moment when the thermic curve reaches the minimum value.

Table 3.3 shows the parameters obtained from (1).

The daily excursions that are estimated by this technique are systematically lower than those calculated by an average measured, because the sinusoidal curve no approximates exactly the curve derived from the daily data.

Tab. 3.3: Values of T_m, e_a, e_d (°C), φ_a (days), φ_d (hours).

I-button	Distance from current entrance	T_m	e_a	φ_a	e_d	φ_d
G1A	3 m	7.89°	2.36°	129.6 d	0.014°	20.5 h
G1B	3 m	7.79°	2.38°	116.1 d	0.025°	19.3 h
G2	30 m	6.98°	0.91°	105.8 d	0.002°	9.8 h
G3	90 m	7.39°	0.57°	98.3 d	0.004°	12.2 h
G4	150 m	8.31°	0.33°	82.4 d	0.002°	26.5 h
G5	230 m	9.39°	0.12°	339.5 d	0.001°	26.7 h
G6	350 m	9.25°	0.28°	103.5 d	0.001°	24.0 h



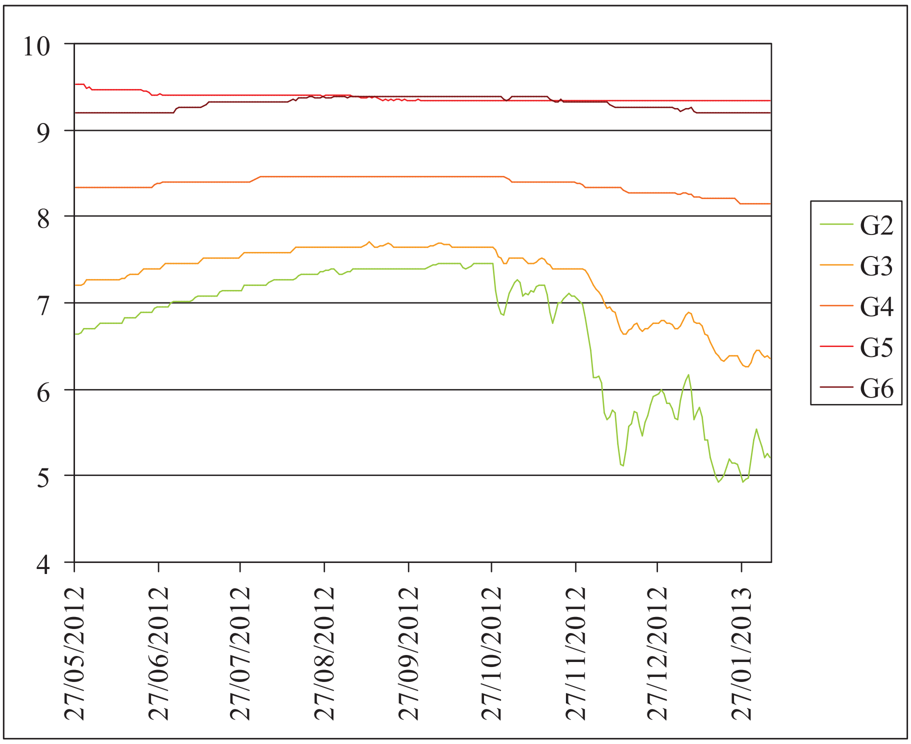


Fig. 3.4: Temperature (°C) measured by I-buttons, respectively at 3 (G1A and B), 30, 90, 150, 230, 350 m from current entrance, and temperatures recorded by weather station ARPA of Lanzo. The second graph reports only the data recorded in the innermost part of the cave for a better understanding.

4.2. Discussion of the data collected by the I-buttons

Motta and Motta (2014) have proposed a subdivision of the caves studied by CaveLab (in Western Italian Alps) in four groups, on the basis of their thermic condition inside (tab. 4).

Tab. 3.4: Groups of thermic conditions of the caves.

Group	Averages	Daily excursions	Annual excursions
A	8.5 - 10.5°C	Very weak or absent (< 0.05°C)	Very weak (< 0.6°C)
B	6 – 9°C	Very weak (0.02 - 0.10°C)	Weak (2 - 5°C)
C	7.5 - 10.5°C	Variable (0.20 - 1.00°C)	Relatively high (5 – 13°C)
D	3 – 8°C T < 0 °C in January	Moderate (0.05-0.35°C)	Relatively high (5 – 13°C)

According to this classification, Borna Maggiore inside is in the Group A: the thermic conditions are almost stable over time, on a daily scale (excursions < 0.05°C), as on an annual scale (excursions < 0.6°C). The variable-temperature zone (up to 30 m from entrance) is in the group B. So, the whole Borna Maggiore is an insulated environment where a temperature change, even at a level over the year, occurs much attenuated and with great delay.

The daily excursions are very low already at the entrance and below the nominal accuracy of the probes at a depth of 30 meters (July) and 90 m (January; tab. 3.1 and 3.2).

The temperature oscillation in the course of the month is linked to weather changes on the outside, and is much low in hypogeal environment (Fig. 3.5). The evidence is the relatively low standard deviation of the data at monthly scale (tab. 3.2).

The causes that reduce this variability are almost the same of those that depress the daily excursions: this explains the good linear correlation between the two variables (according to Fig. 2 of Motta and Motta, 2014).

Inside, the Borna Maggiore has higher daily temperature in July than in January, while the same cave at the entrance has the opposite phenomenon. This phenomenon is not simply a consequence of variability in thermic conditions: the standard deviation of the data is higher in January than in July, although in July the daily excursion is higher that in January.

The equation (1) well portrays the annual thermic oscillations. Only in autumn, and only in the variable-temperature zone (G1A, G1B, G2 and G3 sensors) during some periods the temperatures are quite colder of the temperatures equalized by (1). In other words, during autumn, the temperature curve within the cave near the entrance evidences many sudden lowering (Fig. 5 and 6). This can be explained by variations of the flux of air coming from the outside (see paragraph of discussion of a hypothesis of thermic dynamics), and/or with variations induced by greater or lesser dripping resulting from the precipitations, which increase the deep percolation.

The water budget estimated for the soil on the hill over the cave (Fig. 7) indicates that in autumn the rainwater overcomes the groundwater storage; therefore during or immediately after the rains, much more water infiltrates and drips than in previous months. In winter, this effect should decrease when the soil freeze and becomes waterproof; in spring, as a rule, the water temperature is quite similar to inner temperature of the cave.

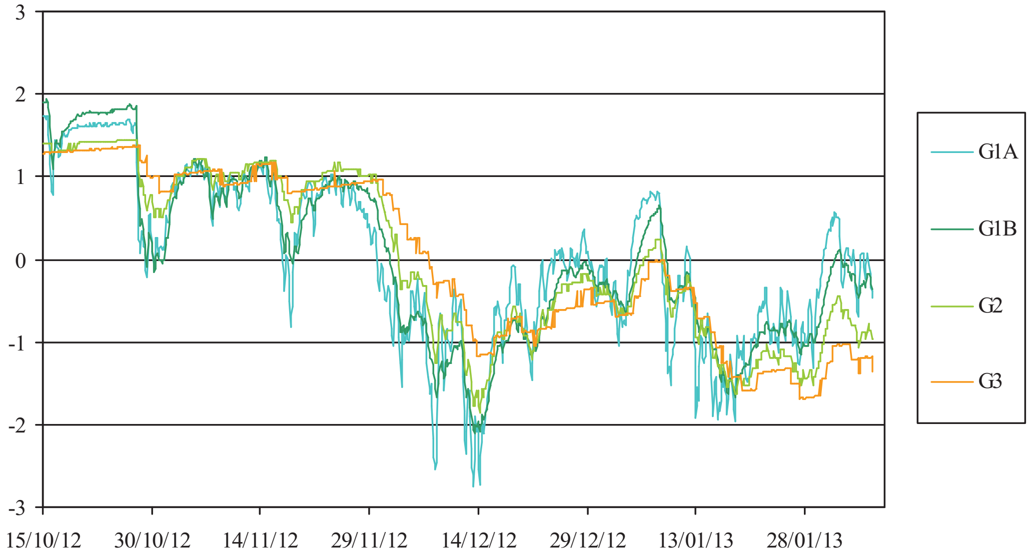


Fig. 3.5: The comparison of standardized data $x' = (x - \overline{x}) / \sigma$ recorded near to the entrance (G1) and more inside (G2, G3), evidences a oscillation more and more low toward the inside.

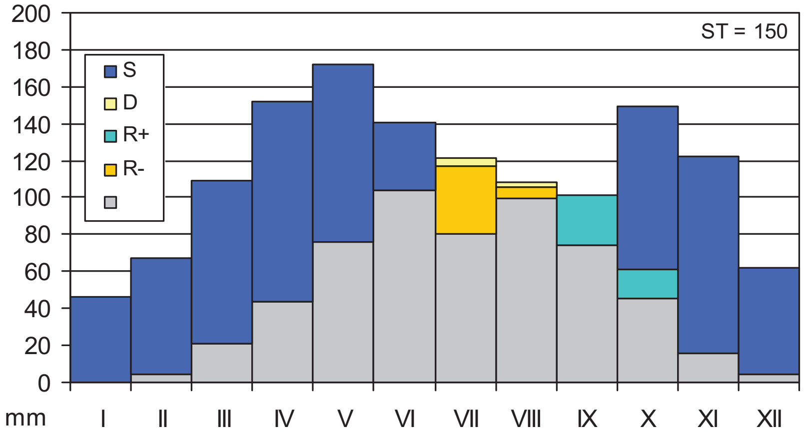


Fig. 3.6: Thornthwaite diagram obtained by data of ARPA Piemonte, weather station of Lanzo (about 6 km from Borna Maggiore), corrected for the difference in altitude. The deep blue indicates water surplus, the pale yellow indicates drought.

4.3. The data collected in the four seasons

Figure 3.7 reports the map of temperature and humidity values, collected in the survey done along the longitudinal section.

Sometimes ceilings are dry, but commonly are wet. The dripping from ceiling, being abundant and in sharp rising after periods of rain, suggests that infiltration water is more than that of condensation. Besides, all the measurements of the internal water contents in the dripping ceilings have pointed out that the rock has the same wet inside. The temperature of this water has always turned out colder than the temperature of surrounding air (Fig. 3.7). We can reasonably think that this is mainly due to a low starting temperature of the infiltration water.

4.4. Discussion of data collected in the four seasons

On the basis of air temperature and relative humidity, we have calculated the values of absolute humidity (Fig. 3.8). No part of the cave is exactly dry or moist throughout the year as the rest of the cave. During the winter, because of the cold, the cave dries considerably near to the entrance, and the decrease of humidity is remarkable along the whole Main Branch. In spring, the first 60 meters from the entrance are still quite dry (see Fig. 3.8, May). In the autumn, however, the distribution of the absolute humidity is remarkably homogeneous. Within the Fountain Branch the absolute humidity remains constant and high year-round, due to the rather constant flux of liquid water. Within Madonna Branch the absolute humidity is like to the Fountain Branch but with even higher values during summer, for the warmest air.

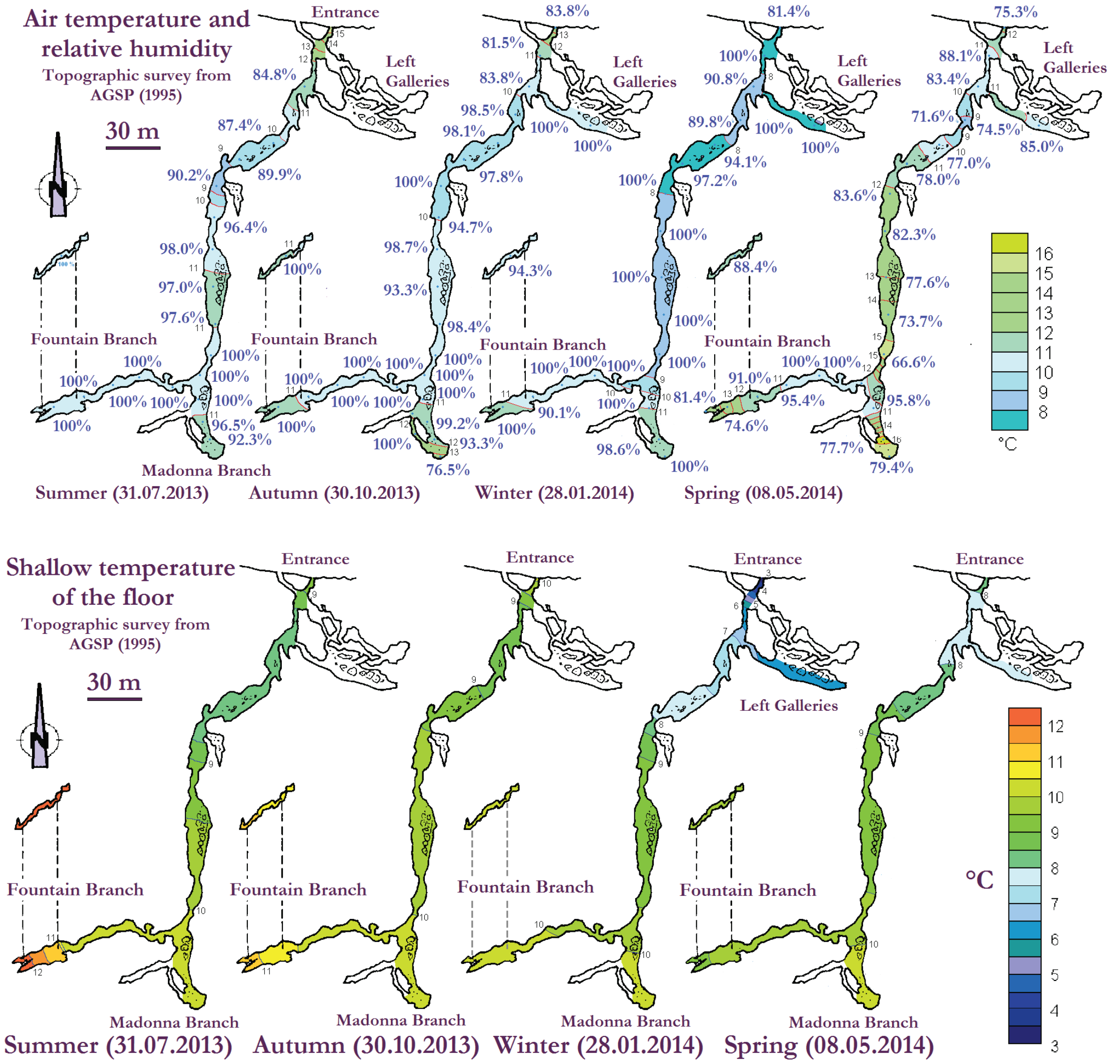


Fig. 3.7: Seasonal distribution of temperature and humidity, inside Borna.

The distribution of air temperature (Fig. 3.7) evidences clearly that an air circulation tends to homogenize the temperature. Some depressions of the cave, however, remain "cold holes" (Badino, 1995): the main gallery to 40-120 m from the entrance and the galleries on the left, especially in winter. On the contrary, evidently the last chamber of Madonna Branch is a trap for the warm, humid air: in fact, both temperature and absolute humidity have high values respect to the soil temperature.

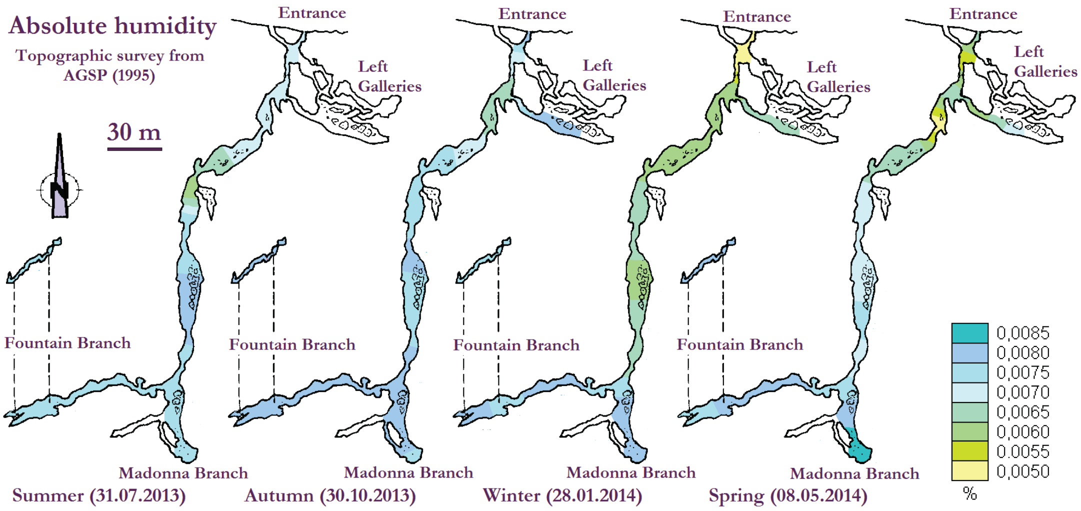


Fig. 3.8: Map of absolute humidity (kg/kg) calculated from distribution of temperature and relative humidity of Fig. 3.7.

The relative humidity is extremely variable. Often the air is saturated with moisture inside of Fountain Branch (the branch with the water stream), but elsewhere, including the inner parts of the cave, it is normally very below the 100%, even when drip abounds (in spring) and in spite of the bottom and walls of the cave are normally wet. In spring, the season of maximum uniformity of temperature (i.e. maximum of air circulation), the relative humidity is very variable in the very same branch, perhaps depending by condensation/evaporation phenomena caused by passage of air through alternation of chamber and narrow.

The distribution of ground temperature (Fig. 3.7) shows two areas of temperature variation:

the first 140 meters from the entrance, where the temperature gradients suggest that the temperature variations are probably linked to the penetration of outer air, or are linked to temperature or to quantity of dripping water;

Fountain Branch, where the change in temperature follows the variation of the temperature of the spring water, and evidently derives from it.

In the rest of the cave the temperature varies very little, also within Madonna Branch, which is located at a distance from the surface comparable to that of the cave zone with seasonal variations in temperature. This proves that the dripping undoes the effect of the air circulation (the air temperature ranges, albeit weakly, with the seasons) on soil temperature. In other words, despite the presence of a circulation of air, the effect of heat carried by the dripping water is preponderant when compared to air, starting from 140 m from the entrance. The result is normally a cooling of the floor, because the water of oozing is 0.6°C colder respect to air (average of 44 measures in the four seasons).

4.5. Temperature distribution in the cross-sections

The cross-sections of 8 May 2014 (Fig. 3.9) show small, but significant differences of air temperature (0.2°C < ΔT° < 1.1°C).

The thermic distribution in the entrance (section A) indicates a hot air flow at the time of the survey. The section at the level of the main floor has a homogeneous temperature area, surrounded by an area of strong temperature gradient: a true air current. A “cold hole” (Badino, 1995) is at the bottom left, where is one of the passages leading to the Left Galleries, with a temperature almost homogeneous of 6.6°C.

In the sections B, C and D, all in narrows of the cave, the air is more and more hot towards the ceiling; it is still possible that a warm air current flows against the roof of the cavity. It isn’t possible that the ceiling heat the air, because dripping water is colder than of air. In B and D, the soil seems to slightly heat the air.

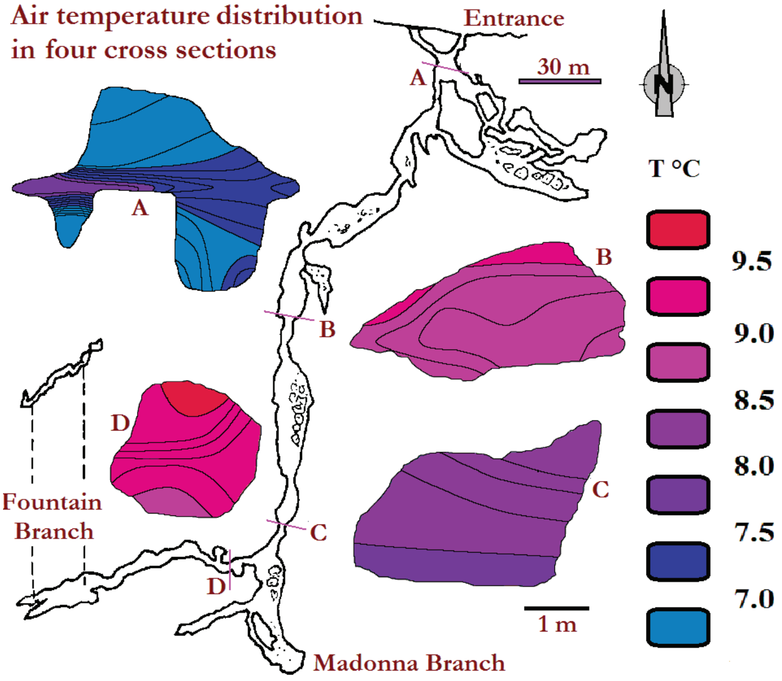


Fig. 3.9: Air temperature in four cross sections (May 8, 2014). The graphic scale of the map is at the top, the cross section scale is below it. Map of the cave re-drawed from Eusebio (1995).

The cross-sections of 15 January 2015 show the typical thermic distribution of the winter (Fig. 3.10).

The A section is not far from entrance (very close to A section in Fig. 3.9), in variable-temperature zone. The arrival of outer air makes cold the floor; but the ceiling stays warm, so the air is warmer than the air during the spring. In other words, this section explains the phase delay of annual thermic curve already mentioned.

The B section is in Main Branch (very close to B section in Fig. 3.9). Here, the air coming from outside (lower part of the section) is colder only of 0.5°C. The temperature and moisture distribution on the ceiling surface shows that the water coming from the autogenic drainage heats the ceiling, maybe because this water warms up sinking in the path between the hill surface and the cave. The floor temperature is homogenous and it is mainly determined by the water temperature (also this water comes from autogenic drainage).

The C section is located in the Fountain Branch, at some meters from its beginning (close to D section in Fig. 3.9). The air is warmer than both ceiling and floor, but this is not due to a heat flow coming from water course at the end of the branch, because the temperature of this water course is in the same moment only of 8.3°C.

The D section is in last chamber of the Madonna Branch. The water coming from the ceiling is slightly warmer (up to 11.2°C) and makes the air temperatures quite homogenous (10.5 – 11.0°C).

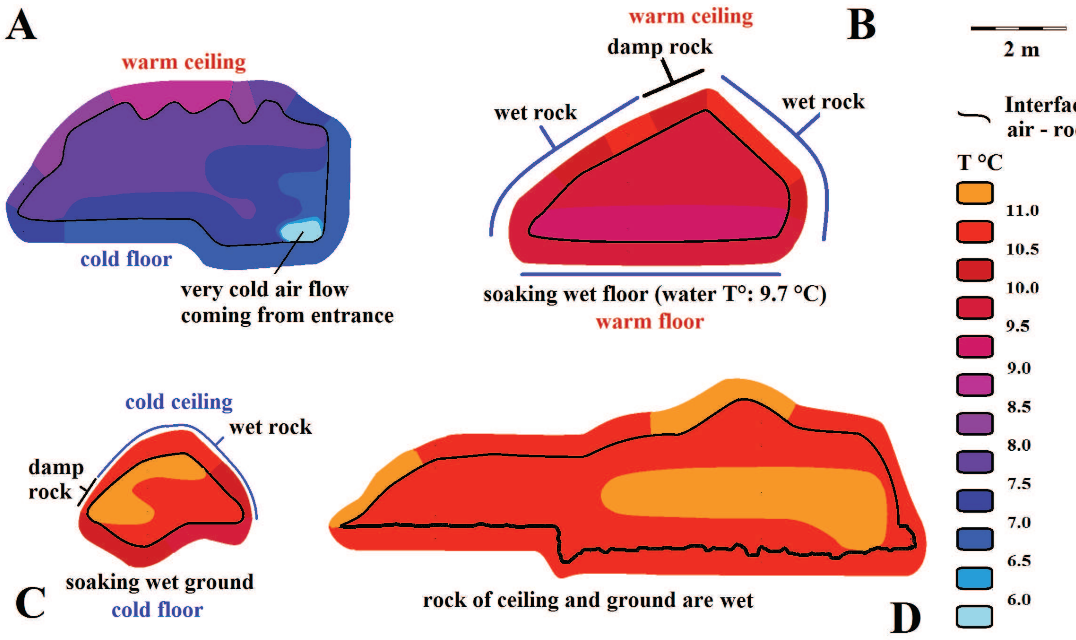


Fig. 3.10: The cross sections of air temperatures, rock temperatures and moisture surveyed on January 15, 2015.

4.6. Discussion on a hypothesis of thermic dynamics

One possible explanation of the thermal oscillations inside the cave is that are linked directly to the outer atmosphere, even past the variable-temperature zone. In fact, the caves with more entrances in different conditions, have convection air flows, because "the mass of air inside the cave, for difference of density, tends to fall, and so comes out from lower openings during the summer, and draws the hot air from openings above the cave; for the same reason will tend to exit from the top during the winter, sucking cold air from lower entrances. The result is a temperature graph that follows a sinusoidal portion of outdoor temperatures during a season (summer for the upper entrance, winter for the lower entrance), and follows internal stabilized temperatures during other season" (Melacarne, unpublished).

This phenomenon can happen at Pugnetto actually, only if this cave has at least a second entrance in different thermal conditions for altitude or exposure.

Based on current knowledge on the cave, the existence of unknown openings appears not likely. Moreover, in caves that have two entrances, like the Grotta Ghiacciata del Mondolè, the distribution of temperature and relative humidity is similar to that of Borna Maggiore (compare fig. 3.7 with 3.11), but the gradients are big along the whole cave, so there is a strong air circulation (Balbiano d'Aramengo, 1993).

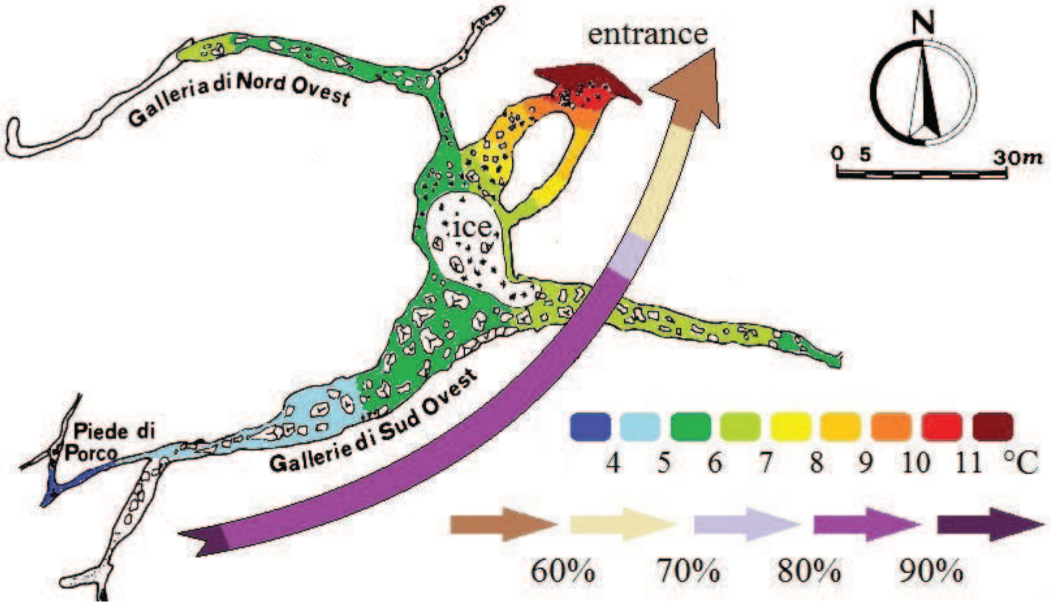


Fig. 3.11: Temperature (map colors) and relative humidity (arrow colors) within a cave large like the Borna Maggiore, but with several entrances at different height (Grotta Ghiacciata del Mondolè, 102 Pi/CN, Balbiano d'Aramengo, 1993). During summer in the Gallerie di Sud Ovest a strong current flows. The air is less and less humid towards the main entrance. At the time of data collection the temperature range of the waters is 0°C ... +1.5°C. Data collected by E.V. Motta, L. Motta, M. Motta in September 2002.

5. Conclusions

The cave has a remarkable and never-ending thermal imbalance (fig. 3.12) between Fountain Branch (warm) and entrance (cold). Therefore, the temperature oscillations of the outside air cannot be the only reason of the variations of the inner climate. The temperature distribution suggests three heat flows, all linked to the matter flows: the water stream of the Fountain Branch, the air entering from the entrance, the dripping water from the ceilings.

Two heat flows are acting always: the correspondents matter flows are the air currents, and the water stream of the Fountain Branch. The first is obviously very important near to the entrance (i.e., in the variable-temperature zone), and it acts as far as some 60 meters from the entrance. The second is important only in Fountain Branch: the evidence is its big seasonal variation of the temperature, compared with the closest galleries. In turn the temperature of the water flowing in Fountain Branch is following the average temperature of the aquifer recharge area. An important component of the thermal dynamics of Borna is therefore the thermal imbalance because of the change of exposure among Cenere Valley, where the infiltration area is a sunny and south-facing slope, and the shady entrance, in a north-facing slope.

It would be very interesting to know how varies the water temperature of the source respect to the temperature of the outdoor atmosphere. For further clarify this point, and both the influence of water temperature on the air and soil, in October 2014 we installed new synchronized stations that measure air, soil and water temperature.

The third heat flow, linked to the drip water, is important in the cave whole, but only during the period of bigger infiltration (starting from the periods of water surplus in the soil). This heat flow is the main reason of delay of thermic variations compared to the outside variations, and makes the cave climate very similar to a climate of a soil. Near to entrance, the thickness of rocks between cave ceiling and hill surface is little, so the infiltration water has a temperature close to that of air. In autumn, the water surplus of soil causes sudden increases of drip water in the cave after the rains, causing strong thermic oscillations of the inner climate.

Air traps, like the Madonna Branch (warm air) or as the depressions of the floor in the Main Branch (cold air), have further the microclimates even more.

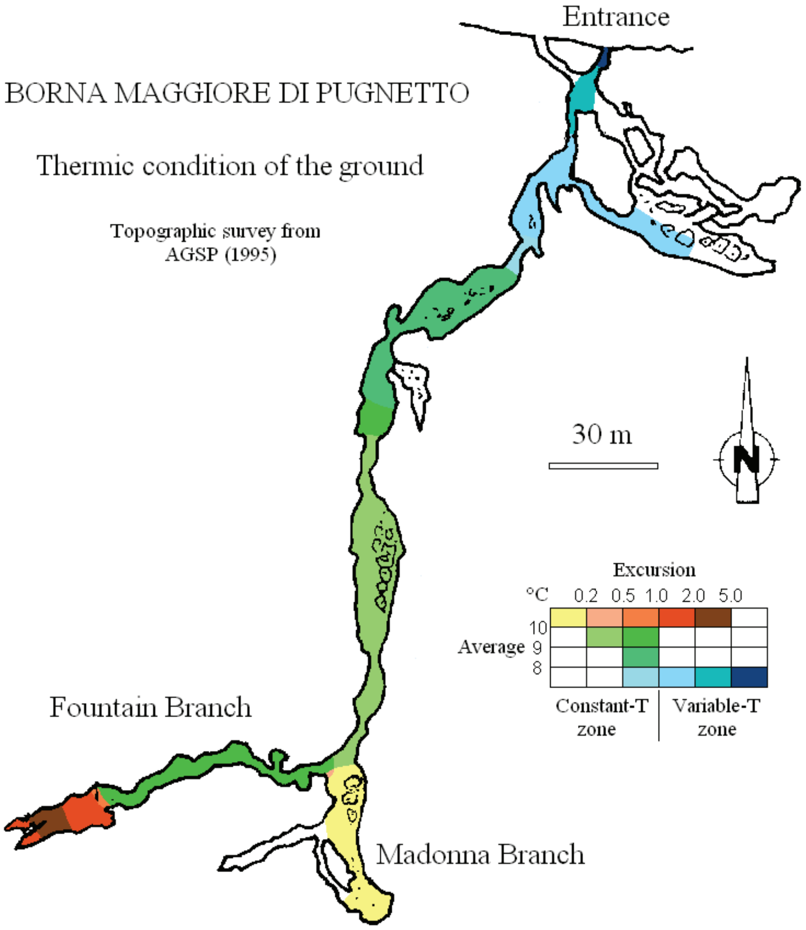


Fig. 3.12: The Borna Maggiore has two variable-temperature zones, but with different features: near the entrance, the temperature average is the lowest of the cave; near the stream, the temperature average is the warmest. Also the constant-temperature zone has several sectors, with different temperature average: the Madonna Branch is warmer than Main Branch part of this zone.

In any case, a special feature of the Borna is that a variable-temperature zone, where air temperature fluctuates with the seasons, is located near the entrance, as well as at the end of the cave (Fountain Branch). This makes the Borna Maggiore like a cave open at the air circulation at both ends.

In other words, this cave hasn’t a relaxation distance (*sensu* Wigley and Brown, 1971)from the cave entrance, where the variables reach asymptotic values.

Probably the thermal dynamics of Borna Maggiore is present in all the numerous caves (e.g. resurgences like in Piedmont: Grotta delle Camoscere 105Pi/CN, Grotta W del Bandito 1003Pi/CN, Tana della Dronera 151Pi/CN…) with a entrance open to air circulation, while the bottom is open only to water (phreatic) circulation.

The Borna Maggiore is an environment thermally very stable as all karst systems, but with strong diversification in several thermal zones, both along the gallery axis, and in cross section. Similar conditions may favour the life of stenothermic arthropods. These animals in many parts of the cave can find a stable temperature all year round, and moving itself for a few decimetres they can exploit temperature differences between ground and air, finding exactly the optimum of temperature. On the contrary, probably eurythermic species prefer the variable-temperature zone near to the entrance.

The presence of some deep depressions of the floors, contributes to habitat heterogeneity within the cave. In fact, within these depressions the air is motionless, and thus it tends to become cold at the bottom (Fig. 3.10, A section). This creates a suitable habitat for cryophilic species, which can take advantage of these “cold holes”. On the contrary the bats during the winter can take advantage of the warm air that is near to ceiling. Also the relative humidity being variable, and so the animals can find relatively saturated or dry environments. This variability in term of micro-habitats, together at the proximity to glacier in past, is probably the cause that determines the peculiar biodiversity that we can observe in the Pugnetto site.

6. The Underground Superficial Compartment (MSS) next to Borna Maggiore

6.1. The climate

The climate is that one typical of low altitude in the Piedmontese Alps. The regime is hypomesaxeric (fig. 3.13). The thermic regime of soils is mesic; the moisture condition is almost anywhere udic.

The nearest station is Lanzo Torinese (ARPA Piedmont). The 2012, year of measurements, has been normal, except for rainfall, bigger and concentrated in April and November (fig. 3.14).

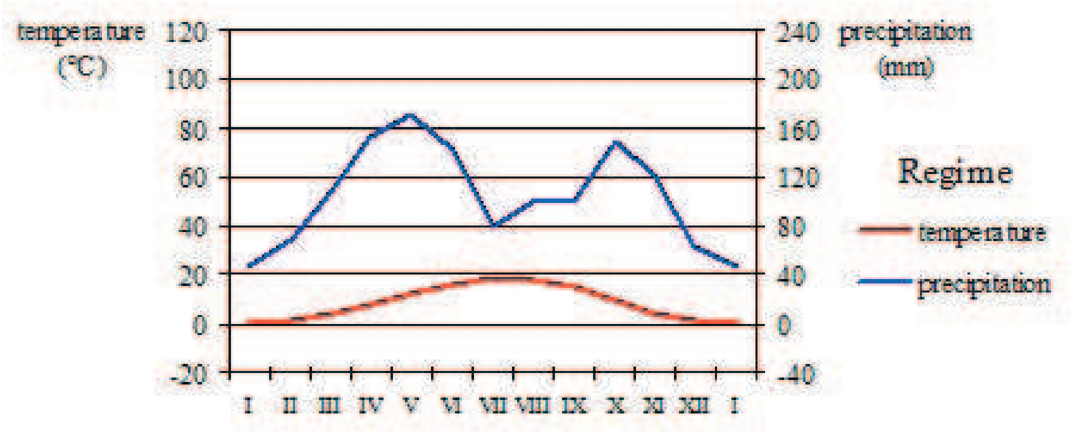


Fig. 3.13: Ombrothermic diagram of Pugnetto, from data of Biancotti et al. (1998).

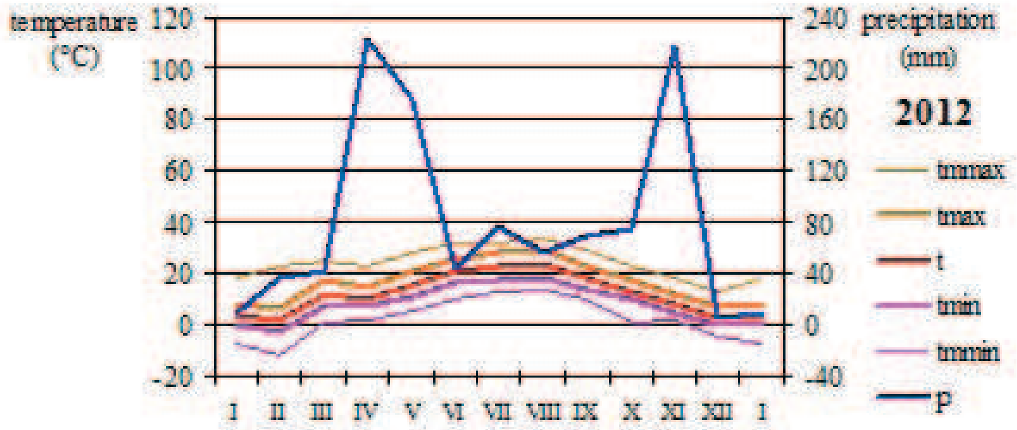


Fig. 3.14: Temperature and precipitation distribution at Lanzo Torinese in 2012 (ARPA data).

6.2. Data collection

The CaveLab members had placed within the MSS, at several depth, 10 I-buttons Hygrochron - DS1923 (nominal accuracy of 0.0625 °C; measurement every 3 hours): 4 in two stations (1 and 2) lower down of Borna Maggiore, at a distance of about 100 m from the cave entrance; 4 at the foot of the small crag of cave entrance (30 meters from the entrance; 3 and 4 stations); 2 at the 5 station, near the Borna Minore. We have validated the data of the period 27 May 2012 - 6 February 2013, and then we have gathered the data at monthly level.

6.3. Data analysis

Average values

Monthly average temperature and standard deviation (both calculated from daily data) at several measuring depth for July 2012 and January 2013 are in tab. 3.5. The average between January and July of T° and of the standard deviations, to the depth of 60 cm (where the thermic condition is quite stable), is the best representative datum of the annual average (not available for the short time of measurement).

Monthly average temperature and standard deviation (both calculated from daily data) at several measuring depth for July 2012 and January 2013 are in tab. 3.5. The average between January and July of T° and of the standard deviations, to the depth of 60 cm (where the thermic condition is quite stable), is the best representative datum of the annual average (not available for the short time of measurement).

In all stations, with increasing depth °T in January grows, in July decreases. January and July have a gradient quite similar in value and opposite as sign. For example, in 4 station, between 40 and 80 cm depth, in January the temperature rises of 1.8 °C, in July decreases of 2.3 °C; in 5, from 60 to 80 cm in January, °T rises of 1.3 °C, in July decreases of 1.3 °C.

The standard deviations of daily values of January and July decrease significantly with increasing depth, i.e. to greater depths the temperature remains more constant during the month.

Tab. 3.5: Temperatures into MSS (°C).

Station		**Average of January**			**Average of July**			**Average of Jan.-Jul.**
N°	*Depth* **Position**	*40 cm*	*60 cm*	*80 cm*	*40 cm*	*60 cm*	*80 cm*	*60 cm*
1	***wooded slope***		1.5	2.3		15.5	15.1	8.5
2	***wooded slope***	4.6	5.0		14.0	13.7		9.3
3	***foot of crag***		6.4			15.5		10.9
4	***foot of crag***	3.3	4.2	5.1	16.0	14.8	13.7	9.5
5	***foot of crag***		4.5	5.8		16.1	14.8	10.3
Station		**Standard deviation of January**			**Standard deviation of July**			**Average of Jan.-Jul.**
N°	*Depth* **Position**	*40 cm*	*60 cm*	*80 cm*	*40 cm*	*60 cm*	*80 cm*	*60 cm*
1	***wooded slope***		1.01	0.82		0.84	0.54	0.93
2	***wooded slope***	0.74	0.68		0.29	0.25		0.47
3	***foot of crag***		0.50			0.54		0.52
4	***foot of crag***	1.23	0.89	0.63	0.70	0.33	0.22	0.61
5	***foot of crag***		1.05	0.66		0.63	0.26	0.84

Annual excursions

The monthly averages of daily maximum, minimum, and medium temperatures of each sensor are in figures 15-18. The three curves are almost perfectly overlapping for each depth.

On the slope below the Borna Maggiore, at all depths the curves are very similar to each other. In station 1 (fig. 3.15), the maximum of difference between 60 and 80 cm is 1.4° C; in 2 (fig. 3.16), this maximum between 40 and 60 cm (i.e. at an even lower depth) is only 0.6 °C. Altitude and exposure of the two stations are very similar, but in 1 steepness and grain size of the MSS are lower. The temperatures distribution is significantly different in the two stations. In station 1, in August °T > 16 °C, and in January T ≈ 2 °C, i.e. an excursion of about 14 °C; in 2, the excursion is lower (15 °C in August and 5 °C in January).

In other stations, the lowering of the annual thermic excursion with the depth is significant. This is normal also in any soil, but in the latter the excursion is less.

In station 4 (fig. 3.17), from 40 to 80 cm of depth the difference between August and January changes from almost 14 °C at about 9 °C. Close to autumn equinox °T ≈ 13.5 °C at all depths. The station 5 (fig. 3.18) is similar to 4, with a difference between August and January of about 13.5° at 60 cm of depth, 10° at 80 cm. Close to autumn equinox °T ≈ 14,7 °C both at 60, and both at 80 cm of depth.

The comparison of average monthly temperatures of the various stations at 60 cm of depth is in fig. 19. The maximums are always in August (17.0 °C - 14.3 °C). The minimums in 5 and 1 are in January (in the others perhaps also in February, because in this month the measurement ends). In January, 1.5 °C < °T < 6.5 °C. The thermic excursion is between, 15° C (1) and about 12° C (5); the excursion varies greatly from station to station, particularly at the foot of the crag. All have the same value (almost 14° C) close to autumn equinox.

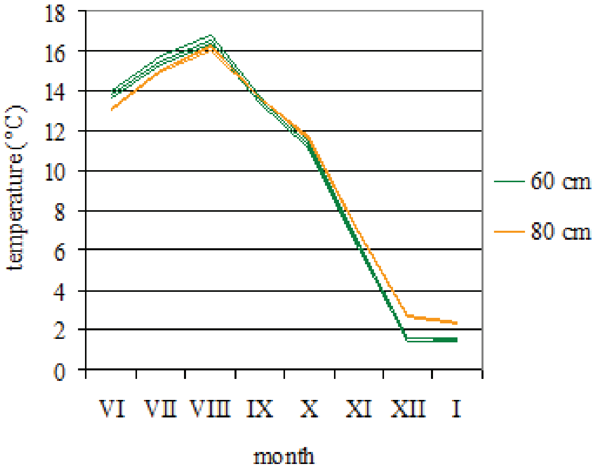


Fig. 3.15: Station 1: average value, for each month, of daily maximum, minimum and medium temperatures.

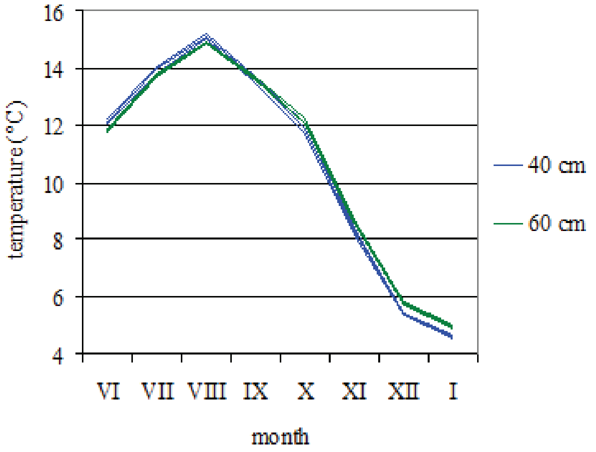


Fig. 3.16: Station 2: average value, for each month, of daily maximum, minimum and medium temperatures.

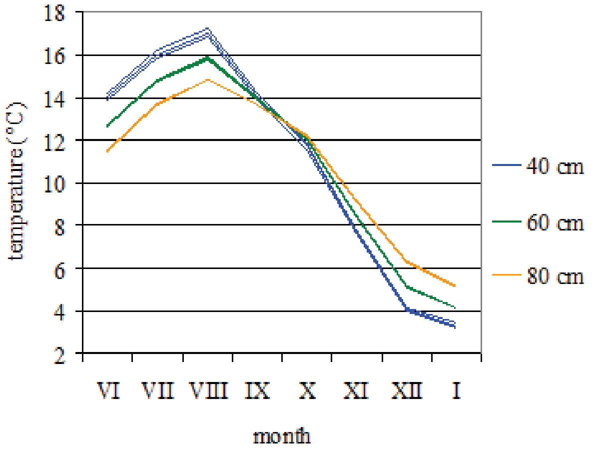


Fig. 3.17: Station 4: average value, for each month, of daily maximum, minimum and medium temperatures.

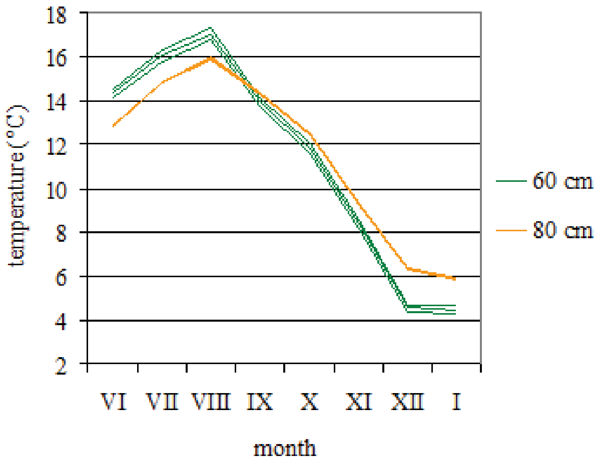


Fig. 3.18: Station 5: average value, for each month, of daily maximum, minimum and medium temperatures.

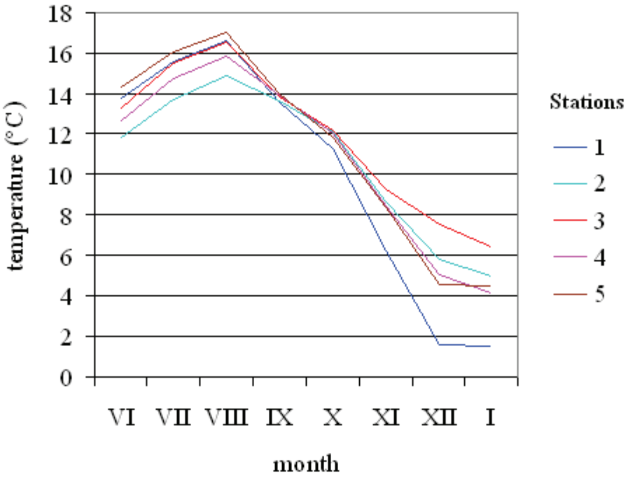


Fig. 3.19: Temperature at 60 cm depth.

Daily excursions

There is only one common feature in graphs of monthly average of daily excursions of each sensor (fig. 3.20-23): the thermic excursion decreases with the depth.

In 1 (fig. 3.20), at 60 cm the thermic excursion decreases from July (almost 0.5 °C) to December (< 0.2 °C). At 80 cm, the daily excursions show small seasonal variations, from 0.2 °C (October) to 0.1 °C (already in November).

In 2, the daily excursion at 40 and 60 cm is similar (fig. 3.21), with a maximum in October (0.35 °C at 40 cm, < 0.2 °C at 60), and with no obvious seasonal variations.

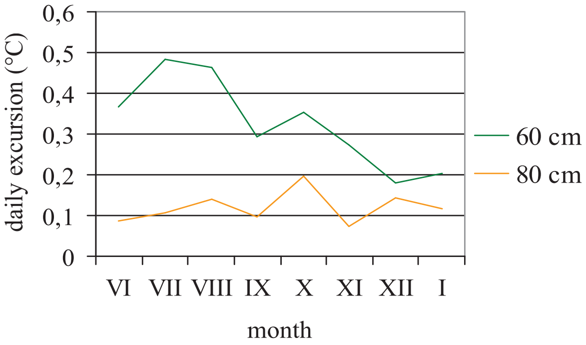


Fig. 3.20: Daily excursions in station 1.

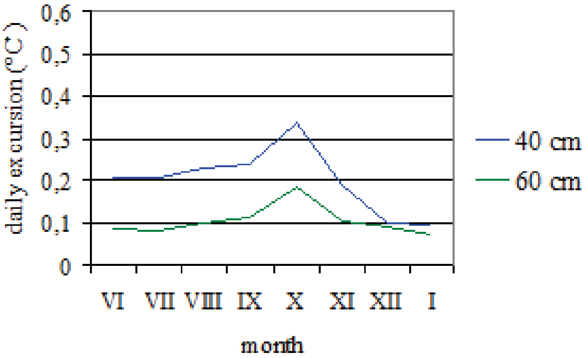


Fig. 3.21: Daily excursions in station 2.

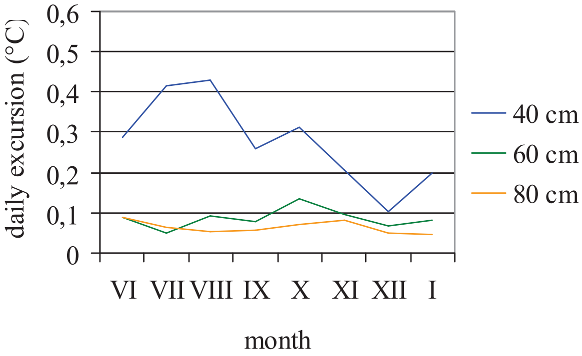


Fig. 3.22: Daily excursions in station 4.

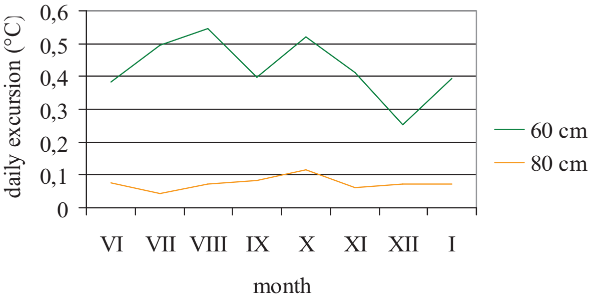


Fig. 3.23: Daily excursions in station 5.

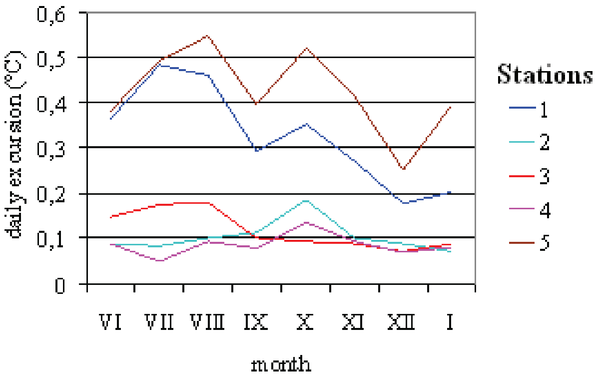


Fig. 3.24: Daily excursions at 60 cm depth.

In 3, at 60 cm the daily excursions are very low, between < 0.18 °C in August and 0.07 °C in January.

In station 4 the curve changes at the different depths (fig. 3.22). At 40 cm descend by 0.43 °C in August to 0.10 °C in December; at 60 cm the values are much lower, with a maximum in June to 0.14 °C and two minima in July and December; at 80 cm the variations range is minimal, with a maximum in November of just 0.08 °C, and two minima in August and December of about 0.05 °C.

Also station 5 has several curves at different depths (fig. 3.23). The probe at 60 cm depth measures about 0.55 °C in August, a bit more than 0.25 °C in December. The curve of 80 cm depth is different, with maximum in October of only 0.12 °C and minimum in July (0.05 °C).

The comparison of monthly averages of daily excursions at 60 cm depth is in fig. 3.24. The excursions are very variable even at the same depth, both as values and both as aspect.

By comparing the data with those of pluviometric station (Lanzo Torinese), we note that the influence of the rainfall is very important. In 1, at 60 cm depth the thermic excursion reached a maximum of 3.27 °C, a value some six times the seasonal variation, in a rainy day (10/28/2012), when it rained in Lanzo 8.4 mm. With heavier rains the effect is probably greater than: in example above mentioned, the temperature fell by 10.83° C at 5:14 (solar time) of 10/27/2012, to 5.62° C at 10:14 of 10/30/2012. In the same period, with a precipitation at Lanzo of 31.4 mm, the air not was become greatly cold, only 2.4 °C of cooling.

This suggests that the rain water can percolate quickly and easily in the MSS, causing a sudden lowering of temperature, and an irregularity of daily thermic cycle, both in the days of precipitation, and both in those immediately following.

6.4. Comparison with the thermic data of adjacent caves

Table 2.6 gives thermic data of caves, detected in same time periods of MSS stations.

The mean values are very different from those of the MSS. The difference between July and January, proves that the annual excursion of cave climate is always much lower than that of MSS climate. About the daily temperature excursion: in winter, when in the caves near the entrance is maximum (0.3-0.6 °C), in the MSS is minimal (0.2 °C at only 40 cm deep); in summer, when the daily excursion in the caves is generally < 0.05 °C, in the MSS is so low only at 80 cm depth, while already at 60 cm is > 0.5 °C.

Obviously, in both environments, as increases the depth and isolation with the outside, °T variation is less and less, like the annual and daily excursions (Motta and Motta, 2014).

However, the data suggest that existing thermic processes in these environments are very different. For instance, in MSS the monthly standard deviation at daily level (i.e. the value uniformity) is proportional to daily excursion (fig. 14): the values of the same month, of all stations and all depths, are aligned along a straight line. For different months, as January and July, the values are aligned on different lines. The same happens in Borna Maggiore (fig. 3.25), but the angle between the lines of January and July is less, and the line of January is over that of July instead of under.

The comparison between the daily excursion in open air, in MSS (at 60 cm depth) and in caves, is in Fig. 26. The three environments differ not only because of the characteristic width of thermic excursion, but also for variations of excursion width in hot and cold months.

Tab. 3.6: Thermic data of Borna Maggiore (Motta and Motta, 2015) and Borna Minore (Motta and Motta, 2016).

Probe position	**Average (°C)**		**Standard deviation**		**Daily excursion (°C)**	
	Jan	***Jul***	***Jan***	***Jul***	***Jan***	***Jul***
Borna Maggiore						
Entrance tunnel	3.0	7.8	1.13	0.16	0.41	0.05
Before first chamber	5.4	7.1	0.39	0.06	0.14	0.01
After siphon narrow	6.5	7.5	0.21	0.04	0.03	0.00
Breakdown chamber	8.2	8.4	0.04	0.00	0.02	0.00
End of Madonna Branch	9.3	9.4	0.00	0.00	0.00	0.00
Spring (Fountain Branch)	9.2	9.3	0.02	0.04	0.01	0.01
Borna Minore						
Entrance	3.5	8.7	1.10	0.13	0.30	0.01
Entrance	2.7	8.4	1.32	0.12	0.38	0.01
Entrance	2.6	8.2	1.33	0.10	0.57	0.01
Inside	8.7	8.7	0.18	0.05	0.02	0.01

6.5. Conclusions

The MSS environments have a reduced thermic variability in the annual and daily cycles. Figures 3.25 and 3.26 suggest that the thermal dynamics of each environment is very different from that of others. The annual excursions of MSS at the foot of crag are different than on the slopes. The MSS has thermal characteristics different from both caves and true soils, although genetically it is linked and contiguous to both.

Obviously, the main factors that determine MSS temperature are air temperature, solar radiation, and precipitations. The rains influence the climate of MSS studied more quickly and much more intensely than a soil climate.

The MSS seems an optimal refuge for cold-sensitive invertebrates. At the foot of the crag, the MSS temperature is even better than at the entrance of a cave.

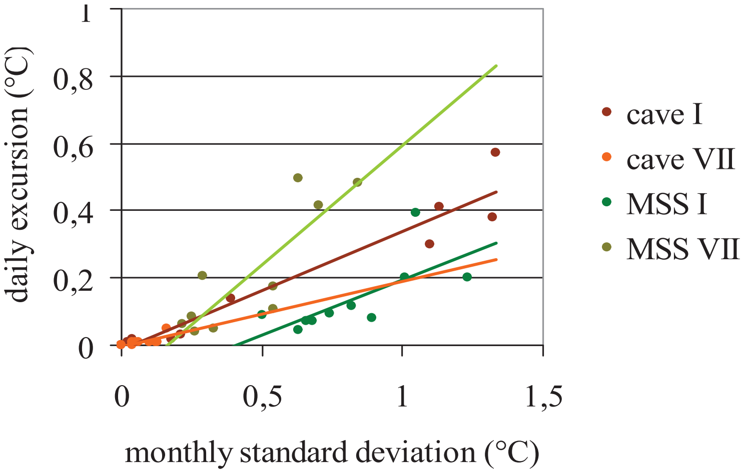


Fig. 3.25: Daily excursion versus monthly standard deviation in January (cave and MSS I) and July (cave and MSS VII).

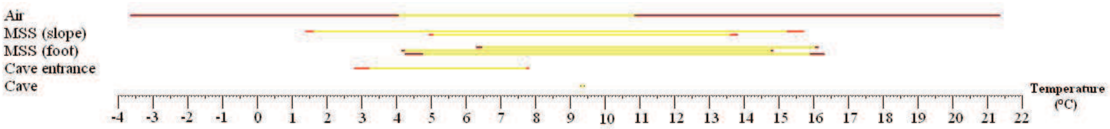


Fig. 3.26: Daily excursions in the coldest month and warmer. Air: open air; MSS slope: 1 and 2 stations; MSS foot: 3 and 4 stations; cave entrance: stairway of entrance tunnel in Borna Maggiore. Cave: end of the branch of Madonna of Borna Maggiore.

4. The Arma do Principà (Rocca Carpanea karstic plateau, Ligury, NW Italy): a dry, horizontal cave

1. Introduction

According to the usual ventilation models, in a dry and horizontal cave the ventilation should be roughly constant and low throughout the year and be directly proportional to the proximity to the entrance. The temperature should be correlated with the external one, with attenuated thermal variations.

2. The study site

2.1. Geomorphology

Arma do Principà (synonym: Arma inferiore do Principa'a, Arma do Martin) opens at the edge of Rocca Carpanea, a karstic plateau similar (but very small) to the Manie plateau. WGS 84 coordinates: 44° 11' 56.015" N, 8° 18' 53.663" E, 255 m a.s.l. Like Andrassa, this cave follows the geological boundary between "*Dolomia di San Pietro dei Monti*" that is a dolomitic limestone of medium permeability, and "*Pietra di Finale*" that is an arenaceous limestone of high permeability. The cave has the features of a formation in phreatic zone, followed by a further development in vadose zone.

The cave is 30 m long. It has a first chamber, followed by a narrow tunnel. Both are into twilight zone. A second chamber is the end of the cave.

Fig. 4.1: The twilight zone.

2.2. Climate

Calice Ligure – Ca Rosse is the closest climatic station (WGS84 44° 11' 44.628" N, 8° 18' 7.38" E, 50 m a.s.l.; fig. 1.3).

The 2017 was the warmest of the period 2011-2017, with annual mean 15.2 °C (average of 2011-2017: 14.8 °C), but has the coldest day (January 6, 0.9 °C), the minimum of temperature (January 7, -4.5 °C), the hotter day (August 8, 28.6 °C), the maximum of temperature (August 22, 37.8 °C). The 2017 is also the driest year (388.6 mm, versus 1008.2 mm of 2016, the more rainy year).

3. Short-term data

The measurement method of relative humidity (fig. 4.2) and air temperature (fig. 4.3) is like to this of Andrassa. The measurement of ground temperature also, but the depth of measurement is 0.12 m. We have measured also the surface temperature of the vault and the floor, by an IR-thermometer PCE-Instruments 889B (measuring ranges: -50 / + 1000 °C, resolution 0.1 °C, accuracy ±1 %, response time <150 ms, ratio of measuring distance to spot size 30:1, adjustable emissivity, depending on the material 0.1 ... 1.0, spectral range 8 ... 14 µm: PCE-Instruments, 2017).

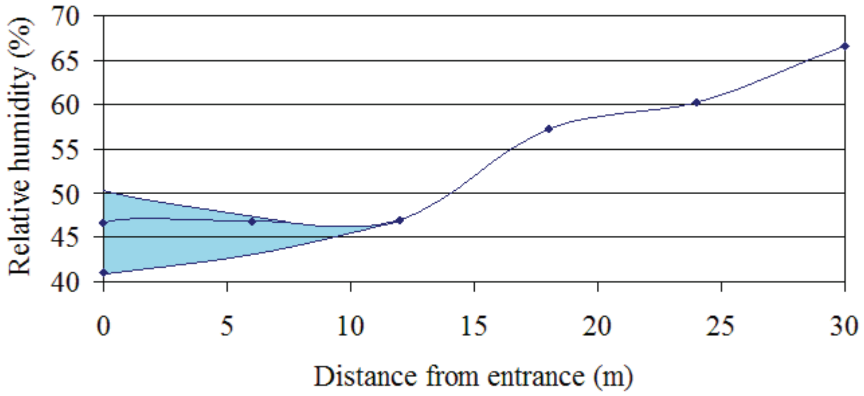


Fig. 4.2: Relative humidity on December 8, 2017, at twilight. The pale blue area represents the variation from 16:30 until 17:30.

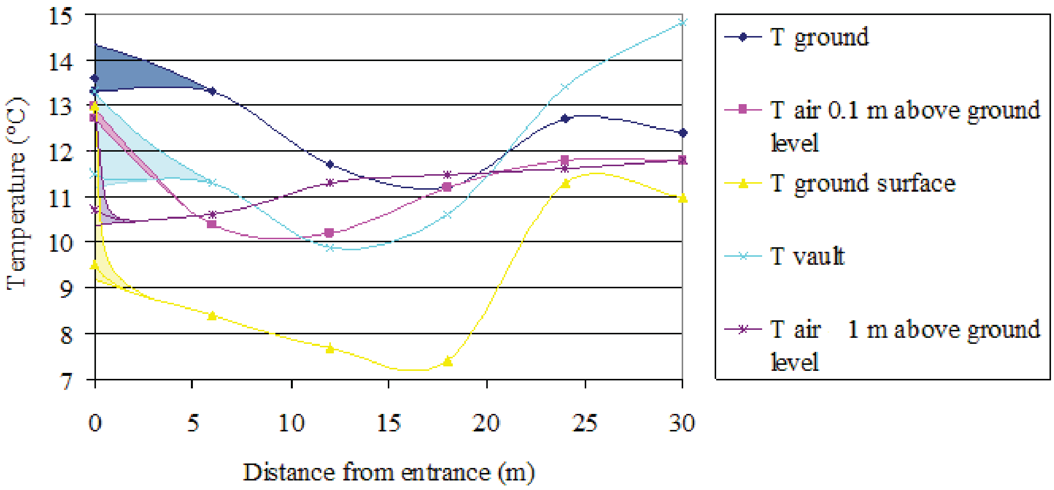


Fig. 4.3: Temperature on December 8, 2017. The colored areas represent the variations from 16:30 until 17:30.

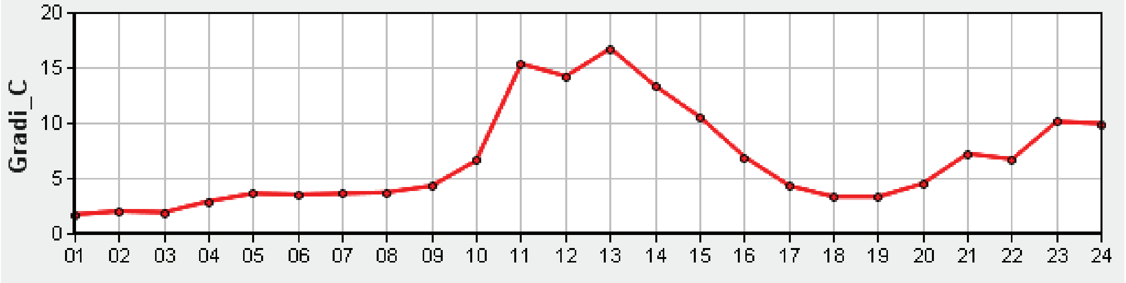


Fig. 4.4: Average of air temperature at Calice Ligure – Ca Rosse climatic station on December 8, 2017 (graph calculated online at Arpal website, www.cartografiarl.regione.liguria.it/). Average 30 years: 14.8 °C

4. Discussion

Both the ground temperatures have similar distribution: a cooling from the entrance to end of twilight zone, and a maximum at the centre of the second chamber. The distribution of vault temperatures is similar, but the maximum is at the cave end, which has the highest ceiling of the cave. The air temperatures have smaller variations than rock and ground.

The air is quite dry, and the relative humidity increases toward the cave end. Therefore, as the air temperature is almost the same, the absolute humidity increases, i.e. the air is less dense. One meter above ground level, the density in twilight zone is quite constant, in the second chamber decreases strongly (fig. 4.5). This air may exit, travelling along the ceilings; but the roof of bottleneck between first and second chamber is much lower than the ceiling of second chamber. It is probable that the humid air remains trapped in the second chamber, and its renewal is limited: this should explain the sudden variation of ground temperature between bottleneck and second chamber.

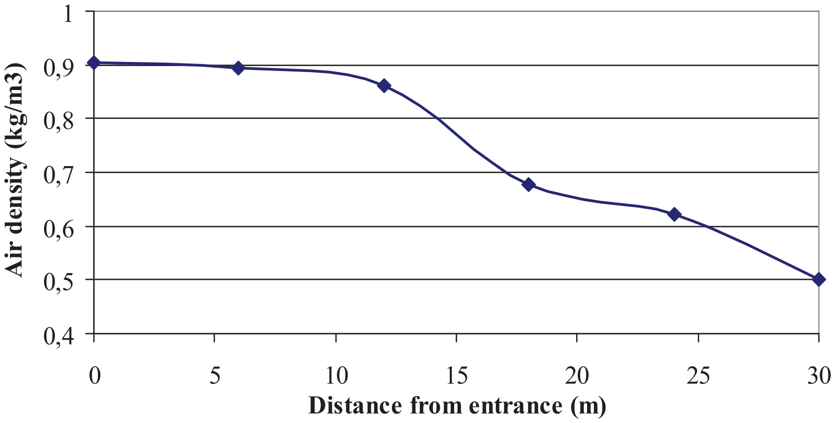


Fig. 4.5: Air density on December 8, 2017, 1 m above ground level.

5. Conclusions

In Arma do Principà the morphology, i.e. the sequence of chambers and tunnels, seems more important than horizontal development for the temperature distribution. Some authors (e.g. Badino, 1995) state that the influence of bottlenecks is very limited, because of Venturi effect; instead this result suggests that, as several architects stated, sudden restrictions to section of air pipe, like the partition walls of houses, hinder effectively the ventilation. So, the big chambers act as humid (or warm) air trap.

5. A cave can be a climatic indicator?

Every soil scientist knows that the thermal oscillations of the soil are much less wide than those of the air. Every speleologist well knows that the temperature of the caves is much more stable than the outside, because the caves are isolated and the sun rays enter only in the twilight zone. So it's obvious that thermal oscillations are extremely small in the cave ground. The today's global change is too rapid for a good study by the analysis of the standard climatic data, which require thirty years of observations. By using a climate indicator that has less oscillation amplitude, it is possible reduce the amount of time it takes to obtain a significant data, and thus follow rapid changes such as those of global warming. Among the climate indicators of this type, the cave ground appears very interesting, especially in the glacier-free areas.

For effective use as a climatic indicator, the cave ground must have special characteristics that make it representative of the external climate. In general, the temperature of the cave ground depends on four possible thermal fluxes.

1) *The geothermal flow.* The water circulation normally shields from this flow the karst caves (Badino, 2005). It is noteworthy in caves created by hydrothermal karst (e.g. Frasassi in Italy) and in some volcanic caves.

2) *The air circulation.* This flow ensures the dependence of the temperature of the cave from the outside temperature next to entrance, and is therefore necessary for the use of the cave ground as a climatic indicator. Multi-entrance caves have strong ventilation, but generally of opposite direction in winter and summer. The areas that feed the ventilation have altitude and microclimate different, and are their climates that determine the climate of the cave. The relationship between internal and external climate is, so, too complex for a good use as a climatic indicator. In the single-entrance caves the air circulation is weak, but sufficient to guarantee a continuous relationship between internal and external climate.

3) *The water circulation.* When there is abundant water flow, its effect on temperature is greater than that of air circulation (e.g. Andrassa and Pugnetto). The temperature of the groundwater is close to the average temperature of the aquifer refill zone. Therefore, the heat flow varies greatly, depending on water discharge and depending on the season. Therefore the climatic significance of this temperature is rather uncertain, if we not know exactly the underground drainage system, in particular the origin area of the water. So, the caves (or sectors of the caves) with an abundant water flow are bad climatic indicators.

4) *The heat conduction between the outer surface and vault of the cave*. This heat flow has some importance only in very shallow caves, or in caves without circulation of water and air: for example, a cave completely isolated from the outside environment, as a touristic cave with the entrance artificially closed by doors.

In conclusion, a karst cave, at least a hundred meters long, with a single entrance, with thermal dynamics as stable as possible, is the best candidate for use as a climatic indicator.

Further studies are necessary to establish the optimum duration of the period of observations, in order to obtain a data with significance comparable with the thirty-year series of the climatic stations.

6. The recommended data for to define the climate of a single-entrance cave

Climatic parameters of karstic caves

The climate dynamic of a cave is obviously different from the outside environment. There are phenomena of condensation and change of state (Badino, 2010), but there aren't true precipitations as rains and snowfalls. As environments are small, it is always sensitive and relatively fast the exchange of heat between air, water and rock.

The outside temperature can change the temperature of the air inside the cave either through the ventilation, or by the diffusion of the heat (which happens in turn mainly for local convective movements, and it appears like a propagation of heat waves).

Every temperature change of the water induced from the outside take place as a consequence of the temperature variations in the infiltration area, but it is convenient divide the water circulation in two types:

- *oozing*: the water that feeds the dripping must pass only through the vadose zone, so its temperature depends on the temperature that had when was on outside surface (as rain, runoff, etc.), and depends on temperature and thickness of the rock layer between surface and dripping point;
- *groundwater*: The water comes from the recharging area of the aquifer, which is at bigger altitude than the cave and therefore generally cold.

Normally, the water percolation influences strongly the temperature variations of the rock. If the cave is very superficial there is also conduction processes, and in this case the changes in soil temperature are the factor influencing the temperature variations of cave rock. Generally they propagate like heat waves, and induce very slow but also very persistent temperature variations.

Obviously in the caves there are important heat exchanges between air, water and rock. Also phase changes of the water can vary the temperature. In deep caves, geothermal flux can also be important (Badino, 2005) and, rarely, the inlet of water or hydrothermal vapors.

According to this, slightly different parameters from those defining the external climate should define the climate of the caves.

1) The temperature measurements commonly performed belong to three types: long-term data collected with data logger, for a period of time of months or years; short-term data, i.e. data collected with portable instruments along longitudinal sections or a network; spot data.
2) The air temperature measurements must always be at the same height on the ground as in the external measurements, but a standard height may be impossible in low caves or be senseless, if the measurement is very close to the vault. It is very important to specify the distance between entrance and point of measure, as this distance often determines the speed of interaction with the external environment. Normally at the entrance there is an area of rapid response of the temperature to the variations of outside temperature. This area can progressively end inward (at the "relaxation length" of Wigley and Brown, 1971, i.e. the distance from entrance where the variables reach asymptotic values), or abruptly end for the prevailing dynamic interactions of the interior of the cave (e.g. Andrassa). The cross sections of temperature distribution within Borna Maggiore show that, at the same height on the ground and at the same distance from the inlet, the temperature can vary greatly. The cause may be the different distance from the side wall, or simply a local flow of air.

It follows that the air is the material in which the measurements have the least repeatability.

3) The water temperature (both drip water and runoff water) is not usually measured. However this is very useful to define the interactions air-water-rock, i.e. to understand the causes of seasonal variations of temperature. The water in fact strongly influences the temperature of the other materials, because of its high thermal capacity, on average four times bigger than the rock and 4000 times bigger than the air per volume unit (Badino, 1995).
4) The temperature of the ground is more stable than that of air, so this temperature is the most useful to define the average annual temperature using a short period of observations. Because of the interactions with air and water, it is mandatory specify the depth of measurement. In surveys of the areal distribution of temperature, the main limit is the possible shortage of easily drilling points to carry out the measurement with constant depth (due to rocky floor, calcareous crusts, and ground rich in large pebbles). The most practical depth of measurement could be 0.15 or 0.2 m, possible for most penetration probes on the market.
5) Sensors placed in a perforation, used rarely, allow the measurements of rock temperature.
6) Often a single instrument allows to simultaneously measuring relative humidity and air temperature (with different sensors). The normal instruments available on the market cannot get long-term data, because the sensors can not work long in a very humid environment.
7) The temperature and relative humidity data allow the calculation of the absolute humidity. For this operation it is necessary to know (and therefore, to measure) also the atmospheric pressure.
8) Direction and intensity of the air currents are important parameters, which are directly measurable if they have sufficient intensity. In this case, the good choice of measuring points is fundamental, taking into account that any narrowing of the runoff section generates the Venturi effect (increase in current speed).

Data availability

The speleologists seldom measure climatic parameters, and often the data have little value, because (perhaps for the common belief that in the caves the climate is absolutely homogeneous and constant) the report does not specify sufficiently the date or position (distance from the inlet, height on the ground...). Untrustworthy data are, for example, generic indications of the presence of air currents (without date and/or without direction), temperature measurements without indication of the position respect to the entrance, etc. For example, throughout Piedmont (a region comprising hundreds of caves), reliable data are available only for the Caves of tab. 6.1.

The only organic measurements of climatic data in caves of the Italian Western Alps are:

1) collection of meteorological data at the Bossea scientific station (GSAM and Politecnico di Torino, 1990);
2) measurement of temperature in the voids inside the cave debris, carried out in 22 Piedmont caves by the CAVELAB of the University of Turin, in order to define the habitat of cave spiders (tab. 6.2; Motta and Motta, 2014).

Only the series of Bossea is long enough to constitute a possible climatic indicator (although very influenced by the strong water circulation of the cave). The necessity of further sampling or permanent stations of measurement, possibly inside the ground, is evident.

Tab. 6.1. Temperature data of Piedmont caves available.

Cave	N°	Altitude (m a.s.l.)	Period	Material measured	"Normal" T (°C)	Ventilation	Ice	Font
Rio Martino	1001 Pi/CN	1530	Year	Air	6	Chimney effect	In Winter up to underground river, 100 m from entrance	1
Piaggiabella	160 Pi/CN	11 entrances between 1927 and 2525	Year	Air	2-3	Chimney effect	In Winter and Spring near to entrances	1
Arma inf. Grai	120 Pi/CN	1030	Year	Air	11-12	Absent		1
Balma del Mondolè	102 Pi/CN	2071	Summer	Air	2.2-2.9	Chimney effect	Perennial (from water), between 30 and 50 m from entrance	1
				Water	0-2			
Mottera	242 Pi/CN	1325	Year	Air	6-7	Chimney effect, very strong	In Winter in a chamber at 150 m from entrance	1
Bossea	108 Pi/CN	836	Year	Air	8.5	Absent		1,2,3,4
				Water	7			
Monticello d'Alba		208	Year		8-15	Yes		5
Buco della Bondaccia		690	Winter	Air	9.5	Cold air trap		6
			Summer	Air	9 – 9.5			
Caverna delle streghe di Sambughetto		660	May 1965	Water	6			

Fonts: 1: AA.VV., 1995. 2: Cigna, 1958. 3: Ghibaudo and Peano, 1983. 4: GSAM and Politecnico di Torino, 1990. 5: AGSP and Balbiano d'Aramengo C., 1993. 6: Cella and Ricci, 1984.

Tab. 6.2. Values of July 2012 and January 2013. Annual average estimated by January and July values mediated.

Caves	Average		Difference	Annual average	Standard deviation		Daily excursion	
	January	July			January	July	January	July
Ghiaccio	-0.50	0.36	0.86	-0.07	0.35	0.07	0.05	0.03
Partigiano, inside	6.01	8.11	2.11	7.06	0.48	0.07	0.10	0.02
Partigiano, entrance	4.23	8.82	4.59	6.53	0.87	0.16	0.22	0.02
Argentera, inside	5.36	10.59*	5.23	7.97	0.74	0.63*	0.97	0.61*
Argentera, entrance	0.86	11.93*	11.07	6.40	2.33	0.66*	2.19	0.98*
Bandito	8.56	8.63	0.07	8.60	0.01	0.00	0.01	0.00
Vernante	8.59	8.94	0.35	8.76	0.15	0.08	0.02	0.03
Bossea, inside	8.88	9.01**	0.14	8.94	0.02	0.02**	0.03	0.02**
Bossea, entrance	4.32	15.29**	10.97	9.80	0.93	0.65**	0.23	0.58**
Caudano, inside	9.32	9.38	0.06	9.35	0.00	0.00	0.00	0.00
Caudano, entrance	1.33	8.23	6.90	4.78	1.25	0.09	0.48	0.15
Pugnetto, inside	9.34	9.40	0.06	9.37	0.00	0.00	0.00	0.01
Pugnetto, entrance	2.38	7.76	5.38	5.07	1.69	0.20	1.50	0.06
Napoleone, inside	5.85	13.82	7.97	9.84	0.72	0.46	0.43	1.00
Napoleone, entrance	5.58	18.68	13.10	12.13	0.90	0.76	1.20	0.96
Dronera	10.43	10.80**	0.37	10.61	0.00	0.01**	0.00	0.01**

*) Values are only the first 15 days of the 2013.

**) Values that relate only to the third decade.

References

1 AA.VV, 1995, Atlante delle grotte e delle aree carsiche piemontesi: Regione Piemonte and AGSP, (A. Eusebio ed.), 206 p., Torino.

2 Arnò, C., and Lana, E., 2005, Ragni cavernicoli del Piemonte e della Valle d'Aosta: Regione Piemonte & Associazione Gruppi Speleologici Piemontesi, Torino.

3 Arpa Piemonte, 2016: Meteorological data of Lanzo Torinese station. [Online] Available from: http://webgis.arpa.piemonte.it/ geoportale/ [accessed on December 2, 2016]

4 Arpal, 2017: Meteorological data. [Online] Available from: http://www.cartografiarl.regione.liguria.it/SiraQualMeteo/script/PubAccessoDatiMeteo.asp?_ga=2.183257318.1506398574.1513098765-625821549.1481913880 [accessed on December 13, 2017]

5 Arpal, 2017: Meteorological data. [Online] Available from: http://www.cartografiarl.regione.liguria.it/SiraQualMeteo/script_annali/StazioneCMIRL.asp?stazione=ME00311 [accessed on December 13, 2017]

6 Agrillo, G., and Bonati, V., 2013, Atlante climatico della Liguria: Genova, ARPAL - Centro Funzionale Meteoidrologico di Protezione Civile, 130 p.

7 Ajassa, R., and Motta, M., 1991, Osservazioni sui suoli della zona dell'Altopiano delle Mànie - M. Capo Noli: Studi e Ricerche di Geografia, v. 14 n. 2, p. 194-213.

8 Arpal, 2016: Meteorological data. [Online] Available from:

9 http://www.cartografiarl.regione.liguria.it/SiraQualMeteo/script/PubAccessoDatiMeteo.asp?_ga=1.131054856.625821549.1481913880 [Accessed 25th November 2016].

10 Badino, G., 1995, Fisica del clima sotterraneo: Memorie dell'Istituto Italiano di Speleologia, v. IIS,7 n. II, 137 pp., Bologna.

11 Badino, G., 2005, Underground drainage systems and geothermal flux: Acta Carsologica, v. 34 n. 2, p. 277-316.

12 Badino, G., 2010, Underground meteorology - "What's the weather underground?": Acta Carsologica, v. 39 n. 3, p. 427–448.

13 Balbiano d'Aramengo, C., and AGSP, 1993, Le grotte del Piemonte. Guida per l'escursionismo: Via dalla Pazza Folla Ed., Cassolnovo, Pavia.

14 Biancotti, A., Bellardone, G., Bovo, S., Cagnazzi, B., Giacomelli, L., and Marchisio, C., 1998, Distribuzione regionale di piogge e temperature: Regione Piemonte, 80 p., Torino, Italy.

15 Biancotti A., Brancucci G., and Motta, M., 1990, Carta geomorfologica dell'Altopiano delle Mànie e dei bacini idrografici limitrofi: Studio Cartografico Italiano, Genova.

16 Biancotti A., Brancucci G., and Motta, M., 1991, Note illustrative alla carta geomorfologica dell'Altopiano delle Mànie e dei bacini limitrofi: Studi e ricerche di Geografia, v. 14, n. 2, p. 155-177.

17 Biancotti A., and Motta, M., 1989, Morfoneotettonica dell'Altopiano delle Mànie e zone circostanti (Liguria occidentale): Supplementi Geografia Fisica Dinamica Quaternaria, v. 1, p. 45-68.

18 Bixio, R., et al., 1987, Le nostre grotte – Guida Speleologica Ligure: Genova, Società Speleologica Italiana, 176 p.

19 Bögli, A., 1978, Karsthydrographie und physische Speläologie: Berlin, Springer, 292 p.

20 Botosaneanu L., and Holfinger J.R., 1991, Some aspects concerning colonization of the subterranean realm-especially of subterranean waters: a response to Rouch & Danielopol, 1987: Stygologia, v.6, p. 129-142.

21 Brancucci G., and Motta, M., 1989, Note illustrative alla carta delle zone geomorfologicamente instabili dell'Altopiano delle Mànie e dei bacini idrografici limitrofi (Liguria occidentale): Studi e ricerche di Geografia, v. 12, n. 1, p. 59-68.

22 Buecher R.H., 1999: Microclimate Study of Kartchner Caverns, Arizona.- Journal of Cave and Karst Studies, v. 61, p. 108–120.

23 Cachia M., De Marinis R., Maifredi P. and Pastorino M.V., 1974, Studio sulla circolazione delle acque sotterranee nella Valle del Rio dei Ponci. In: *Atti XI Congresso Nazionale di Speleologia, Memoria XI di Rassegna Speleologica Italiana*, Genova 1972, v. II, p. 251-263, Como.

24 Calandri, G., 1997, L'anidride carbonica nelle grotte della Liguria occidental: (ed.) Pensabene G., Atti XVII Congresso Nazionale di Speleologia, Castelnuovo Garfagnana, Firenze, 1st-15th September 1994, v. 2, p. 91-97.

25 Calandri, G., 2003, Caratteri chimico-fisici della sorgente Acquaviva (Finale Ligure, prov. Savona): Bollettino del Gruppo Speleologico Imperiese CAI, v. 33 no. 55, p. 3-9.

26 Capello, C. F., 1955, Il fenomeno carsico in Piemonte. Le zone interne al sistema alpino: C.N.R. Centro studi geografia fisica, Ser. 10, Vol. 6., Mareggiani, Bologna.

27 Cella G.D., Ricci M., 1984, La caverna delle Streghe: Labirinti, v. 5, p. 18-38.

28 Christoforou C.S, Salmon L.G., and Cass, G.R., 1996: Air exchange within the Buddhist cave temples at Yungang, China.- Atmospheric Environment, v. 30, p. 3995–4006.

29 Cigna A., 1958, Prime ricerche meteorologiche nella grotta di Bossea (Cuneo): Atti VIII congresso nazionale speleologia (1956), Memorie SSI e RSI, v. 4, p. 91-201, Como.

30 Cigna, A., 1968, An analytical study of air circulation in caves: International Journal of Speleology, v. 3, p. 41–54.

31 Colosio A., 2017, Studio dei fattori che influenzano gli scambi termici in un inghiottitoio carsico (Altopiano delle Manie, Liguria): Ph. thesis Un. Turin, 178 pp.

32 A. Eusebio (Ed.), 1995, Atlante delle grotte e delle aree carsiche piemontesi: Regione Piemonte & AGSP, Torino.

33 Faimon, J., Troppova, D., Baldık, V., and Novotny, R., 2012, Air circulation and its impact on microclimatic variables in the Cısarska Cave (Moravian Karst, Czech Republic): International Journal of Climatology, v. 32, p. 599–623.

34 de Freitas C.R., Littlejohn R.N., Clarkson T.S. & S. Jernigan J.W. & R.J. Swift, 2001: A mathematical model of air temperature in Mammoth Cave, Kentucky.- Journal of Cave and Karst Studies, 63, 3–8.

35 Gestionale speleologico ligure, 2017: Pozzo delle Cento Corde. [Online] Available from: http://www.catastogrotte.net/Navigator-view-137.html?q=corde&order=recordupdate&desc=1 [accessed on December 12, 2017]

36 Gestionale speleologico ligure, 2017: Arma do Prinsipa'a. [Online] Available from: http://www.catastogrotte.net/Navigator-view-171.html?q=corde&order=recordupdate&desc=1 [accessed on December 13, 2017]

37 Ghibaudo M., Peano G., 1983, Il regime del collettore di Bossea e le correlazioni intercorrenti fra l'idrologia e la climatologia della grotta (prime osservazioni): Mondo Ipogeo, p. 77-80.

38 P. M. Giachino, D. Vailati, The subterranean environment. Hypogean life, concepts and collecting techniques, WBA Handbooks, Verona, 2010.

39 GSAM, Politecnico di Torino, 1990: Atti della Stazione Scientifica di Bossea, 136 p., Torino.

40 Isaia M., Pantini P., 2008, A new species of Troglohyphantes (Araneae, Linyphiidae) from the Western Italian Alps: The Journal of Arachnology, Vol.35, 427–431.

41 Isaia M., Paschetta M., Lana E., Pantini P., Schonhofer A.L., Christian E., and Badino G., 2011, Subterranean Arachnids of the Western Italian Alps (Arachnida: Araneae, Opiliones, Palpigradi, Pseudoscorpiones): Monografie XLVII, Museo Regionale di Scienze Naturali, Torino.

42 Isaia M., Paschetta M., Chiarle A., Badino G., Berto S., Bona F., Meregalli M., Motta M., Motta L., Vione D., and Vizzini A., 2013, CAVELAB, an interdisciplinary research project for the study of cave ecosystems and their potentialities for the study of global change: Abstract Book of XIX International Congress of Arachnology, Kenting, Taiwan, 23-28 June 2013, Thungai University, p. 201-202.

43 Juberthie, C., Delay, B., and Bouillon, M., 1980, Extension du milieu souterrain en zone non-calcaire: description d'un nouveau milieu et de son peuplement par les coléoptères troglobies: Mémoires Biospéologiques, v.7, p. 19-52.

44 Juberthie, C., Delay, B., and Bouillon, M., 1981, Sur l'existence du milieu souterrain superficiel en zone calcaire: Mémoires Biospéologiques, v. 8, p. 77-93.

45 Kowalczk, A.J., and Froelich, P.N., 2010, Cave air ventilation and CO_2 outgassing by radon-222 modeling: How fast do caves breathe?: Earth and Planetary Science Letters, v. 289, p. 209–219.

46 Lana E., 2001, Biospeleologia del Piemonte, Regione Piemonte & AGSP, Torino.

47 Lanza C., 1966, Aspetti antropici delle grotte del Piemonte, Rassegna Speleologica Italiana, v.18, n.3-4, p. 1-19.

48 Melacarne D., 2013, L'influenza del clima e della meteorologia esterna sugli ambienti sotterranei. Ph. thesis, Natural Sciences, University of Torino, A.A. 2012-2013.

49 Maifredi P., and Pastorino, M.V., 1969, Osservazioni idrogeologiche sulla sorgente dell'Acquaviva presso Finalpia: Atti Istituto Geologico Università Genova, vol. 7, no. 1, p. 59-69.

50 Massa S., 1971, Note meteorologiche (Grotta Andrassa e Tana di Spettari): Stalattiti e Stalagmiti, 1970-1971.

51 Melegari, G.E., 1984, Speleologia scientifica e esplorativa: Calderini, 474 p., Bologna.

52 Motta, L., and Motta, M., 2012, The protection Law and the Register of erratic Blocks in Piedmont (Italy), as Example of Protection of a widespread Geosite in a densely populated Region, Advanced Research in Scientific Areas 2012, Section 10 Natural Sciences, EDIS, Zilina, Slovak Republic, p. 1534-1539.

53 Motta, L., and Motta, M., 2013, Massi erratici, Regione Piemonte, Torino.

54 Motta, L., and Motta, M., 2014, Oscillations of temperatures in Piedmont caves remarkable for speleofauna, in Proceedings, International Virtual Scientific Conference (SCIECONF 2014), 2nd, Zilina: 9 th - 13 th June 2014, Publishing Society, p. 412-417.

55 Motta, L., and Motta, M., 2015a, The Climate of the Borna Maggiore di Pugnetto Cave (Lanzo Valley, Western Italian Alps): Universal Journal of Geoscience, v. 3 no. 3, p. 90-102.

56 Motta, L., and Motta, M., 2015b, Thermic characterization of the Underground Superficial Compartment near Pugnetto cave system (Lanzo Valley, Western Alps), in Proceedings, International Virtual Conference on Advanced Research in Scientific Areas (ARSA-2015), 4th, Zilina: 9 th - 13 th November 2015, v. 4, p. 216-221.

57 Motta M., 1987, Geomorfologia climatica e strutturale dell'altopiano carsico delle Manie e dei bacini idrografici limitrofi: PhD thesis University of Turin, 679 pp.

58 Motta M., 2015, The analysis of geomorphic indicators for the definition of the extension of Pleistocenic glaciers within alpine valleys: method and applications: Acta Naturalis Scientia, v. 2, n. 1, p. 7-17.

59 Motta M., 2016a, Handbook of recognition of Karst Microforms: Motta - Lulu Press, 101 p., Raleigh.

60 Motta, M., 2016b, Rischio Idrogeologico: Motta - Lulu Press, 184 p., Raleigh.

61 Motta, M., and Motta, L., 2016a: Preliminary data on the temperature distribution in a ponor (Andrassa, Ligurian Alps). [Online] Available from: http://www.arsa-conf.com/actual-conferences-and-papers/?pa=831&cmd=det [Accessed December, 2016].

62 Motta, M., and Motta, L., 2016b: The caves with single entrance have a circulation "air bag style" really? The hygrothermal conditions of Andrassa (Ligury, Italy). [Online] Available from: http://quaesti.com/actual-conferences-and-papers/?pa=278&cmd=det [Accessed December, 2016].

63 Motta M., 2014, The Definition of the Extension of Quaternary Glaciers within Alpine Valleys, and his Application to Study of Subterranean Fauna: QUAESTI 2014, EDIS, Zilina, Slovak Republic, 439-444.

64 Motta M., 2016, Handbook of recognition of Karst Microform: Motta - Lulu Press, 101 pp., Raleigh.

65 Motta M. and Motta L., 2014: Moyens de collecte des données climatiques dans les grottes. [Online] Available from: http:// www.speleo-doubs.com/congres2014 [accessed on December 10, 2016]

66 Muratore G., 1925, Grotte del Pugnetto, Rivista mensile Club Alpino Italiano, v.44, n.8, p. 192-197.

67 Muratore G., 1946 Grotte del Pugnetto, valli di Lanzo - Stura di Ala, Rivista mensile Club Alpino Italiano, v.65, n.1-2, p. 21-29.

68 PCE-Instruments, 2017: Misuratore temperatura PCE-889B [Online] Available from: https://www.pce-instruments.com/english/measuring-instruments/test-meters/digital-thermometer-pce-instruments-digital-thermometer-pce-889b-det_4591190.htm?_list=qr.art&_listpos=1 [Accessed on December 13, 2017]

69 Pflitsch A., and Piasecki J., 2003, Detection of an airflow system in Niedzwiedzia (Bear) Cave, Kletno, Poland: Journal of Cave and Karst Studies: v. 65, p. 160–173.

70 Ramella L., 1997, Italie, in: C. Chabert, P. Courbon (eds.), Atlas des cavités non calcaires du monde, Union Intérnational de Spéléologie, p. 68-70.

71 Russell M.J., and MacLean, V.L., 2008, Management issues in a Tasmanian tourist cave: Potential microclimatic impacts of cave modifications: Journal of Environmental Management, v. 87, p. 474–483.

72 Sacco F., 1928, Caverne delle Alpi Piemontesi, Le grotte d'Italia, v.2, n.3, p. 97-121.

73 Sindaco R., Savoldelli P. and Selvaggi A., 2008, La Rete Natura 2000 in Piemonte. I Siti di Importanza Comunitaria, Regione Piemonte, Torino.

74 Vigna B., 1986, Il carsismo piemontese, in: A. Eusebio, B. Vigna (eds.), Sintesi delle conoscenze sulle aree carsiche piemontesi, AGSP, Torino, p. 11-16.

75 Vigna Taglianti A., 1968, Considerazioni sulla coleotterofauna cavernicola del Piemonte, Archivio botanico e biogeografico italiano, v.44, n.4, p. 252–264.

76 White W.B., 1988, Geomorphology and Hydrology of Karst Terrains: Oxford University Press, 464 p., New York.

77 Wigley, T.M.L., and Brown, M.C., 1971, Geophysical applications of heat and mass transfer in turbulent pipe flow: Boundary-Layer Meteorology, v. 1, p. 300–320.