The cave is warm in winter! Role of geothermal gradient on the Chamois Cave climate

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Abstract: The Chamois Cave (Alpes-de-Haute-Provence, France) opens at 1360 m asl., above the Coulomp spring. The Hormones Gallery extends on 2.5 km and ends by windy fissures below the Baussebérard Mountain (2088 m). Measurements of temperature and relative humidity (RH) allow establishing their seasonal distribution. The draft regime is driven by a chimney-effect between the entrance area and Baussebérard Mountain. Seasonal amplitude is more than 2 °C. During summer, the chilly draft (4 °C) from altitude is breathed in and warms up 2.7 °C during its underground traverse. If 1/3 of this warming is due to compression (1° / 100 m for dry air gradient), the 2/3 remaining, i.e. 1.7 °C, are attributed to the effect of geothermal heating. During winter, the draft reverses; the cave is then under the influence of the low altitude thermal conditions, i.e. warmer. RH measurements show that the air is never saturated (87-93 %). Part of the origin of this dryness results from the warming by compression during summer subsidence but most of it results from the especially dry conditions of the cave environment. Since the area is covered with thick marly limestone with diffuse permeability, the cave is in fact little influenced by the thermal effect of infiltration. Consequently, the abstraction of geothermal flow by infiltration is low and most of the thermal exchange occurs between the air flow and the cave walls. Chamois Cave displays a rare thermal behavior, only present in mountain caves that are isolated from altitude infiltration by low-permeable covers (marls, glaciers…), on the contrary to the general trend displaying cold temperature even at depth due fast infiltration of water originating in altitude. The very low RH in Chamois Cave also allows developing of rare sulfates because of the evaporative atmosphere.

Key words: Chamois Cave, Underground Coulomp, cave climate

Résumé : La grotte est chaude en hiver ! Effet du gradient géothermique sur le climat souterrain de la grotte des Chamois (Alpes-de-Haute-Provence, France). *La grotte des Chamois (Alpes-de-Haute-Provence, France) s'ouvre à 1360 m d'altitude, au-dessus de la source du Coulomp. La galerie des Hormones s'étend sur 2,5 km et se termine sur des fissures ventilées à l'aplomb du sommet de la montagne de Beaussebérard (2088 m). Les mesures de température et d'humidité permettent d'établir leur distribution saisonnière. Le régime du courant d'air correspond à un tube à vent classique, entre la zone d'entrée et le sommet de Beaussebérard. La grotte est plus chaude en hiver, avec une amplitude thermique saisonnière de plus de 2 °C. En été, l'air glacé aspiré en altitude entre à 4 °C et s'échauffe de 2.7 °C lors de la traversée de la montagne. Si 1/3 de cet échauffement est lié à la compression (gradient de 1° / 100 m en air non saturé d'humidité), les 2/3 restants soit 1.7 °C sont dus à l'effet du gradient géothermique. En hiver, le courant d'air s'inverse ; la grotte est cette fois influencée par les conditions thermiques de l'aval, plus chaudes. Les mesures d'humidité relative (HR) montrent que l'air n'est jamais à saturation (87-93 %). Ceci est l'effet d'une part de l'échauffement par compression lors de la subsidence estivale, mais surtout l'ambiance très sèche de la cavité. Recouverte de plusieurs centaines de mètres de marno-calcaires à perméabilité diffuse, le réseau n'est que très peu soumis à l'influence thermique des eaux d'infiltration, qui est habituellement le principal facteur de refroidissement, surtout en région de montagne. De fait, le flux géothermique n'étant que faiblement évacué par les eaux d'infiltration, c'est l'air qui devient le fluide s'échauffant au contact de l'encaissant rocheux. La grotte des Chamois représente une situation thermique peu commune, seulement présente dans les cavités de montagne se développant sous une couverture peu perméable (marnes, glacier…), à l'opposé de la situation habituelle où les températures sont froides jusqu'à grande profondeur sous l'effet de l'infiltration rapide des eaux d'altitude. Les conditions d'HR très basse ont par ailleurs permis le développement de sulfates rares sous l'effet de l'atmosphère favorisant l'évaporation.*

Mots clefs : *grotte des Chamois, Coulomp souterrain, climat souterrain*

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Introduction

Cave climate and especially cave temperature have been widely studied for centuries and more extensively recently (BADINO, 1995; LISMONDE, 2002; and references therein). In temperate regions, water circulation across karst massifs is usually high enough to extract the geothermal heat flux (LUETSCHER & JEANNIN, 2004). Consequently "*le montagne carsiche hanno la temperature delle acque che le attraversano"* (karst mountains have the temperature of waters that cross them; BADINO, 1995), temperature gradients are similar to the adiabatic gradient of humid air (LUETSCHER & JEANNIN, 2004), and basically for the caver, caves are cold! However, in some peculiar cases, temperature gradient might be higher and reveals the influence of the geothermal heat flux which is usually not perceptible.

In this paper, we present the Chamois Cave context, the temperature measurements methodology and results, and we discuss the seasonal and spatial distribution of temperature. Parameters responsible for this distribution are discussed with a special emphasis given to the high temperature gradient and the role of geothermal heat flux.

Cave and context

The Chamois Cave (Castellet-lès-Sausses, Alpes de Haute-Provence, France) opens at 1'360 m asl. in the Grand Coyer massif, between the upper segments of the Var and Verdon valleys (AUDRA et al., 2009). The Chamois Cave develops more than 10 km for a depth of 326 m (+284 / -42) (fig. 1). It gives access to a 1 km segment of the Underground Coulomp, the largest underground river in France (1 m^3/s). This underground river gives origin to the Coulomp spring, the largest in the Southern Alps, which pours out below the cave in a scenery waterfall. A sequence of thick marly limestone from Upper Cretaceous (Turonian-Coniacian-Santonian) begins with bedded limestones, where the cave develops, at the top of black marls. The air circulation in the cave can be considered as a simple "chimney effect". The upper apertures are still unknown, but several shafts have been climbed up at the remotest part of the cave leading close to the summit at about 2'000 m asl. The lower apertures correspond to a delta of galleries close to the entrance at around 1'360-1'400 m asl. Since there is no significant air inflow in between, we can consider the cave as a simple tube with one opening at each extremity. In summer, the draft is subsiding and it reverses in winter. The Underground Coulomp is the largest underground river in France; however the main flow route is located in a distinct part of the cave which is not concerned by the draft transit. Beside the river passage, most of the cave is dry. This is due to the topographic and geological settings and to the cave structure. Most of the cave develops below a narrow crest in a thick sequence of marly limestones dipping perpendicularly to the main passages. As a consequence, most of the water infiltrating above the cave is guided toward west, next to the cave. The catchment area is limited to the East by a high cliff preventing for any water contribution to the cave itself. Infiltrations are small and not frequent; the cave owes its origin to allogenic input and to a remote recharge.

Methodology

To measure Temperature (T), a first field campaign was carried out in August 2011, in summer conditions (i.e. subsiding draft) using a mercury thermometer with reading precision of ±0.1 °C. A second campaign was done at the end of November 2011, in winter conditions (i.e. rising draft). T and Relative Humidity (RH) were measured with a Brannan Compact Sling Psychrometer, where temperature is red on both dry and wet bulbs thermometers and % RH is later calculated using a spreadsheet (PONTHUS, 2000). Reading precision of T values is expected to be ±0.5 °C and calculated RH to be about ±5 %. Measurements were done at 13 stations spread along the main axis of the cave between the Chamois cave entrance and the end of Valette Highway.

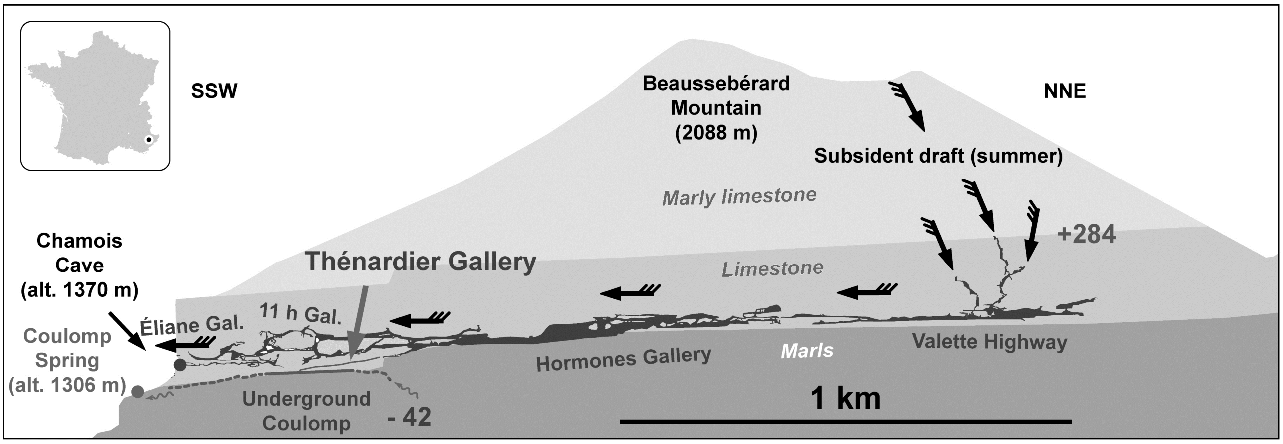

Fig. 1: Cross section of the Chamois Cave, showing its development at the contact of a marly basement and a limestone covered with a thick sequence or marly limestones. In summer, strong draft entering at high altitude crosses the cave systems toward the lower entrance ("chimney effect").

Results

Results are presented in fig. 2. Along the measurement profile, the temperature (T) ranges from 4.3 to 7.8 °C. Coldest T is found in the upper part where draft coming from the top of the mountain enters the cave passages. Warmest T are recorded close to the lower entrances. Additionally, an 8.5 °C temperature was measured in a confined passage in the lowermost part of the cave, which is not influenced by the draft (Thénardier gallery, fig. 1). RH measured in winter along the measurement profile ranges from 86 to 94 %.

Discussion

In summer, cold draft arrives from the top of the mountain, from an entrance probably located at about 2'000 m asl. It enters the (known) part of the cave at 4.3 °C and gradually warms up to 7.1 °C while going down to the entrance. The trend curve clearly shows the difference between confined areas and draft inputs. The draft enters Valette Highway before its end making this place to be the coldest (fig. 1, 2). On the contrary, the end of Valette Highway is confined and consequently slightly warmer. The curve also shows a minimum in the middle of Hormones Gallery. A small water tributary might explain this, since no significant draft input is present. The trend curve, corresponding to T gradient along the profile, shows a warming gradient of 2.7 °C / 100 m.

Such a gradient is extremely high in cave, which usually ranges from 0.25 °C / 100 m in wet and deep caves to 0.8 °C in dry caves (Luetscher & Jeannin, 2004). Since air is not saturated in vapor, the dry air adiabatic gradient due to air compression during subsiding is ≈ 1 °C / 100 m. The 1.7 °C additional part of the T gradient is due to another process, i.e. the warming by contact with rock walls. Moreover, if one considers the lower part of Valette Highway, which is flat, the warming of air has nothing to do with compression in this area. Usually, in mountain caves, air temperature is mainly influenced by infiltration having fast transfer, and being cold because of their high altitude origin. These cold infiltrations, together with the presence of the phreatic zone, intercept and export the heat flux of the geothermal gradient and consequently caves are generally colder than the mean local annual temperature, even at great depth.

Accordingly, the thermal gradient is generally between 0.3 and 0.4 °C / 100 m (Badino, 1995). In Chamois Cave, thanks to the quasi-absence of infiltration along the profile, the cave is dry and not significantly influenced by infiltration cooling. Moreover, along the measurement profile, most of the cave is perched on marls with no significant phreatic zone. Consequently, heat interception by both infiltrations and phreas is not significant. The geothermal gradient heats the rock walls, which in turn transfer this heat by convection to the draft. As a consequence, draft acts as the main cooling fluid. Such thermal characteristics, where the geothermal gradient is sensitive,

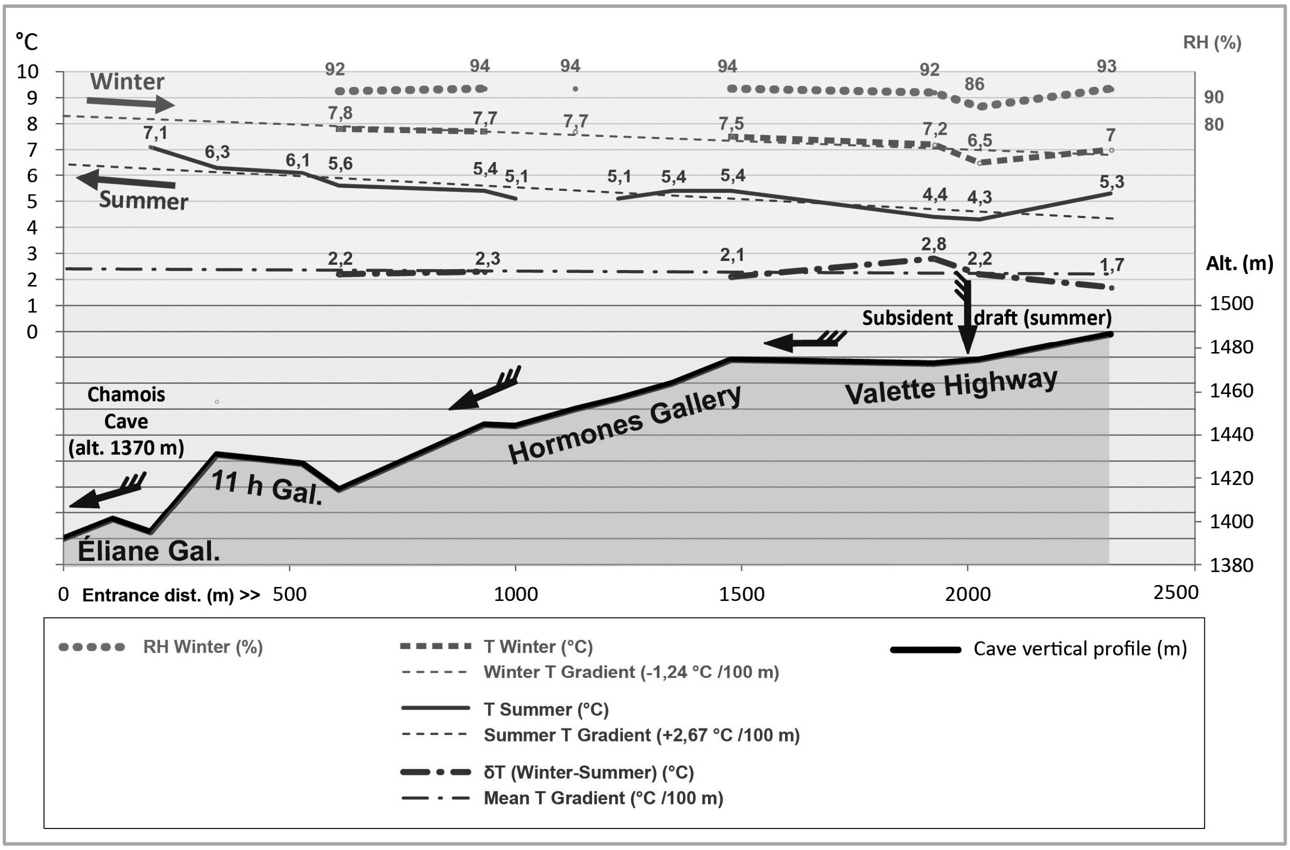

Fig. 2: Synthesis of T and RH data along the measurement profile in Chamois Cave. In summer, cold draft coming from the top of the mountain enters the upper part of the cave. RH was measured in winter conditions, T in both summer and winter conditions. Dotted lines show the trend of T evolution along the cave profile. Thermal amplitude between summer and winter (δT) is shown on the lowest curve.

are not common in mountain caves and are only present when infiltration is limited, either by impervious covers, or prolonged frost such as in Castleguard Cave, Canada, where heating reaches about +3 °C (Atkinson et al., 1983), or after long recession (Lismonde, 2005).

During winter, draft is reversed and lifts from the lower entrance to the top of the mountain. In November 2011 airflow direction followed the winter ascending trend, even if the outside temperature was not so cold (daily minimum at 5 °C with significant higher temperature during the day that was bright). As a consequence, the cave temperature in the entrance is still “warm” from summer effect and has not been significantly cooled by cold winter air. The air cools from 7.8 at the entrance to 6.5 °C at the upper extremity. This cooling is very regular and discrete measures perfectly fit with the trend straight line, with a negative gradient of -1.2 °C / 100 m. Since draft is rising in this season it cannot be responsible of local cooling: the lowering of the curve in Valette Highway corresponding to the upper series likely results from the arrival of small infiltrations. The confinement of the last segment of Valette Highway also clearly shows a 0.5 °C higher temperature. The cooling trend of -1.2 °C / 100 m is partly due to the decompression during its lift (RH measures shows that air is not saturated in vapor) and partly to thermal exchanges between air and rock.

Relative humidity has been measured only in winter so far. It shows that the air is never saturated in vapor, with a rather constant value of about 92-94%. A rise of vapor tension would be expected while air cools during its travel across the cave. Such unexpected stability is possibly the result of the Hormones Gallery influence, which is extremely dry and where dimensions and exchange surfaces in huge boulders accumulations maintains the dryness of the air, at least at the beginning of winter when the measures have been done.

The seasonal measures show that the temperature is about 2 °C warmer in winter all along the measurement profile, with a mean T of 7.5 °C for winter and 5.5 °C for summer. This important result arises from the seasonal origin of the draft, with an influence of cold draft from high altitude in summer and of “warmer” draft from lower altitude lifting in winter. The amplitude is maximal in exchange sites (2.8 °C in Valette Highway where upper series branch from the main passage) and minimal in confined areas (1.7 °C in the upper part of Valette Highway).

The 4.3 °C summer temperature of the highest part of the cave, which is only at 1’470 m asl., appears to be unusually cold. It shows that air entering at high altitude (about 2’000 m, with summer daily temperatures ranging from 15 to 30 °C) strongly cools down during its descent into the cave. This cooling must be due to exchange with the surrounding rock previously cooled during winter. The origin of such a cold storage remains unknown (large volume of rock cooling?). The presence of large volumes of snow or ice in the unknown upper part of the cave is unlikely, because of the absence of large snow shafts and of the direction of the airflow in winter that rises from inside.

Conclusion

Chamois Cave climate is typically controlled by a chimney effect. Temperature measurements along its main axis show that in summer cold draft subsiding from altitude makes the cave about 2 °C colder than in winter where draft is rising. Confined areas have lower amplitude and warmer temperature than “opened” areas. The air is never saturated in vapor, even in winter. Such conditions are mostly expressed in Thénardier Passage (8.5 °C / 88 % HR) where strong confinement allows the growing of rare sulfates speleothems (see Audra and Nobécourt in these Proceedings). Draft is warming when subsiding in summer. We hypothesize that this warming is explained for less than 1/3 (<1 °C / 100 m) by the compression of subsiding air and for more than 2/3 (>1.7 °C / 100 m) by the thermal exchange between air and walls that are heated by the geothermal flux. Such dry conditions not only result from this drying subsiding air but also from the peculiar topographic and geological setting, which restrict infiltration. The cave temperature is only locally influenced by infiltration. Consequently, we hypothesize that the parameters controlling cave temperature are air flow and mainly the geothermal gradient. Such thermal characteristics, where geothermal gradient is sensitive because of restricted infiltration, are rare in alpine caves where cold infiltration is generally fast and abundant.

We plan to further measure HR in summer conditions, and to detail T measures. T data loggers are already recording.

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