Characteristics of the Underground Atmosphere

J. Haast

Many of the familiar roadside signs advertising caves open to the public carry the phrase, "Come underground and cool off". This is reasonable advice, for during the heat of summer the temperature of these caves is indeed pleasantly cool. If the principal tourist season were in the winter instead of the summer, however, the signs would probably read, "Come underground and warm up", for in winter these same caves are far warmer than the surface. Cave temperatures are nearly constant throughout the year.

1. Controls of Cave Temperature

The air movement in and out of a cave is so slow that within a few hundred meters of the entrance the cave air ordinarily takes on the same temperature as the wall rock.

The temperature of the deep parts of limestone caves is therefore controlled by the temperature of the limestone, which is, in turn, approximately equal to the average annual temperature of the surface.

The daily and seasonal temperature fluctuations of the surface tend to diminish as the heat moves down through the rock into the cave. A 30℃ temperature fluctuation between day and night is reduced to a fluctuation of less than 1℃ at a depth of 57 centimeters below the surface.

Likewise, a fluctuation throughout the year of 30℃ is reduced to 1℃ at a depth of 11 meters. Because caves commonly lie deeper than 11 meters, they ordinarily have annual temperature variations of less than 1℃.

The surface temperature on which the cave temperature depends is chiefly determined by the latitude of the cave and its altitude above sea level. The average temperature of caves near the southern border of the United States is about 20℃, and that near the northern border is about 5℃.

The effect of altitude is illustrated by two Colorado caves near on another and at approximately the same latitude. Fly Caves, at an altitude of 3630 meters, has a temperature of only 2℃. This indicates a gradient of about 6℃ per thousand meters. The temperature of middle-latitude limestone caves for which the location and altitude are known can be approximated by the following equation :

$$℃ = 38 \cdot 0.6L - 0.02h$$

where L is the latitude in degrees and h is the altitude in meters.

A formula for approximating the depth in meters, x, at which a temperature change of 1℃ results in limestone from a cyclic surface temperature change lasting T years is

$$x = 3.18 \sqrt{T} \ln N$$

where $\ln N$ is the natural logarithm of the surface temperature fluctuation N in ℃.

Probably the oldest climatic event that might conceivably be recorded in a cave is the last cold stage of the Pleistocene ice age. Assuming that the cycle of which it was a part began 40,000 years ago and that the average low temperature reached was 10℃ lower than that at present, the above formula indicates that the temperature effect of this last glaciation would now equal 1℃ at a depth of 1464 meters.

The deepest cave so far discovered in the world, Pierre St. Martin Cave, France, is 1474 meters deep. Thus, the temperature near the bottom of the Pierre St. Martin presumably reflects the average annual temperature of the region as it was as long as 40,000 years ago.

2. Caves Containing Perpetual Ice

A northern cave that lies at a high altitude will have a below-freezing temperature if the average annual temperature of the surface is less than 0℃. Such caves, because they commonly contain ice all the year round, are called *ice caves*.

Cold-trap caves in limestone are relatively rare, because limestone caves seldom have the required relationship between passages and entrances. Lava tubes, on the other hand, almost always have the necessary shape, because their entrances are holes formed by the collapse of part of the ceiling. One can visit interesting groups of lava-tube ice caves of this type in Lava Beds National Monument, California, and Craters of the Moon National Monument, Idaho.

3. Relative Humidity

The air of most caves is saturated with water vapor - in other words, the relative humidity is 100 percent. This is so because the ceilings, walls, and floor are all moistened by seeping water, which the air must pass by as it moves slowly through. The constant temperature of the inner part of the cave permits this high humidity to be maintained indefinitely.

Near the entrances to caves, however, the humidity may be lower, partly because the outside humidity is usually lower, and partly because the cave temperature differs from the outside temperature. A fall in temperature increases the humidity, and a rise in temperature decreases it.

In the summer, warm air entering a cool cave soon becomes saturated without absorbing water from the cave walls. In the winter the air becomes warmer as it enters the cave, and for a short distance its humidity falls. Deeper in the cave, however, the humidity of this warmed air slowly rises to the saturation level.

The opposite effect occurs in caves from which air currents flow outward. In the summer, the humidity may be low just inside the entrance, where the outward-moving saturated air first becomes warmed.

4. Air Currents Caused by Barometric Change near Entrances

The parts of caves near entrances are ventilated by an exchange of air with the outside. This exchange varies as a function of the constantly changing pressure of the outside atmosphere. Surface barometric pressure changes are of two types, periodic and nonperiodic.

Nonperiodic changes in barometric pressure are those related to the weather, such as, for example, the pressure changes that accompany the passage of a storm front. These are superimposed upon the daily fluctuation, and the cave pressure adjusts itself to conform to the resultant effect of both. .

5. Chimney and Reverse-Chimney Effects

In some caves that have two entrances, one higher than the other, a fairly strong air current issues persistently from one entrance or the other. These caves are called *blowing caves*. They normally have an annual cycle, in which air blows out of the lower entrance all summer and out of the upper entrance all winter.

In the winter, a blowing cave functions in the same way as a chimney. Cold air enters the lower entrance, is warmed inside the cave because their the temperature equals the average annual temperature of the surface, and rises to emerge from the upper entrance.

6. Breathing Caves

In a few caves, the air moves inward for a few minutes and then outward for a few minutes, as if the cave were breathing. Burton Faust studied this effect at a cave in Virginia now known as Breathing Cave.

While waiting in a small passage near the entrance for the remainder of his party to come out, Faust noticed an unusual reversal of the air current in the passage and lighted a candle to study the effect further. The candle was first deflected by the moving air toward the interior of the cave and then, after standing upright for a moment, was deflected toward the entrance. This cycle subsequently repeated itself again and again.

The air in the jug acts as a spring, compressing and expanding with a certain resonant frequency. A breathing cave is rather like a gigantic, very irregular jug, but its great size makes the oscillation of the air mass inside the cave much too slow to produce an audible note. A formula for approximating the breathing cycle of a jug-shaped cave operating as a simple Helmholtz resonator is

$$T = 0.019 \sqrt{lV/S}$$

where T is the period of the breathing cycle in seconds, S is the cross-sectional area of the necklike breathing passage in square meters, l is the length of the passage in meters, and V is the volume of the cave beyond in cubic meters.

Breathing Cave seems to be much more favorably arranged for this phenomenon than a cave that depends on random wind movement across its entrance. The irregular but constantly inward movement of the air into North Passage in May suggests that this passage serves as the beginning of a chimney in which cool air moves into the north part of the cave, is warmed, and goes out through a higher exit. Usually, therefore, the air moves between the entrance and North Passage, past the mouth of Breathing Passage, either inward or outward depending on the season.

The arrangement of the junction is like that of the mouth of a whistle or an organ pipe. The steady breath of air in an organ pipe provides vibratory energy when the lip of the pipe mouth deflects it first one way, then the other. The air current provides the energy, but the resonance of the pipe determines the frequency. Precisely the same thing happens in Breathing Cave, except that the dimensions are so large that the oscillation, instead of being measured in cycles per second, must be measured in cycles per hour.

7. Ebb and Flow Springs

The water flow from some large springs in limestone regions exhibits a curious pulsating action. Every few hours a surge of water about 10 times the base flow erupts from the spring. The process that triggers this ebb and flow is not yet definitely known, but enough has been learned about the phenomenon to ascribe it tentatively to an intermittent syphon.

In most cases, Study of ebb and flow systems necessaril has been restricted to measurements of changes in the flow of outside springs, but in research in progress under the direction of S.R. Ulfeldt at Big Spring, California, effects in Lilburn Cave, 700 meters away from Big Spring and about 10 meters higher, have also been observed and compared with those taking place simultaneously outside.

In early phases of the study at Lilburn Cave, speleologists inside the cave clocked a slow rise of ponded water succeeded by a sudden flushing, while others at Big Spring noted a steady increase in flow followed by an abrupt flood.

To extend the period of observation and to increase the precision of the time correlation between events at Big Spring and at Lilburn Cave, Ulfeldt set up a permanent water-level gauge at the spring, and for special observation periods installed pressure transducers in the cave pool and at the spring, both recording electronically on a single chart.

Flushing may occur in the system when water enters the cave too fast to be handled by spillover at the apex of a syphon. the water then rises in the cave until it impinges against the ceiling at the apex, a syphon action is established, and the water in the cave reservoir is rapidly drawn down to a level where air again enters the system from the air-filled part of the cave and breaks the syphon.

The intervals between the surges might be related to variations in the height of the U-tube oscillations. The maximum amplitude of these is about 25 percent of the total water-level fluctuation in the cave.

When the oscillations are high, the water may impinge against the ceiling early and establish a syphon more quickly, thereby reducing the time interval between surges.

This type of ebb and flow action is not unique to the system at Lilburn Cave, California. At Ebb and Flow Spring, Missouri, an almost identical relation is observed between the length of time preceding a group of surges and both the surge height and the number of surges in the group.