PHENOMENAL CAVE CLIMATES.

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Abstract: In Australia, as in other parts of the world, there are caves which display unusual and often spectacular physical phenomena. Many of these caves have unusual or extreme climates, often involving massive energy flows or long term storage of huge quantities of heat. In this paper some caves which display interesting climates are described. Theories and observed data which describe the phenomena are presented. Some cave climates can affect cave safety.

Introduction.

Caves are often assumed to have static climates, with the temperature at the annual mean and the humidity as close to 100 percent as may be. This is probably the case for deep, sealed, caves, most of which are unavailable for observation, but most caves that we visit have at least one entrance and few of them have a climate that fits the norm. The operation of a number of physical processes in caves gives each cave a different climate.

On the surface we are familiar with the wind associated with cyclonic and anticyclonic weather systems, and the changes of weather as air masses of differing temperature and humidity pass over us. The daily and annual temperature and humidity cycles complete what we know as weather and climate.

Underground a different set of processes controls the conditions although these may ultimately relate to the surface conditions. In this paper the climates of a number of caves are described as examples of the range and variability of cave climates that are to be found in Australia, and as examples of the physical processes that are involved.

Method

Cave climates were observed by making measurements at a series of positions underground of the temperature, humidity, and velocity of the air, the temperature of water and the temperature and the state of dryness of the walls. Above ground, measurements were made of the air temperature and humidity, wind speed and direction, barometric pressure and rainfall. Additional measurements of surface radiation and vertical atmospheric temperature profile have also been necessary. These measurements had to be made at intervals as short as a couple of minutes over a period as long as several years. It is fortunate in the cases of most caves that only a small number of these measurements were necessary to monitor the cave's climate once the processes that were operating had been identified. A method [4,5] of hourly averaging of measured parameters and subsequent

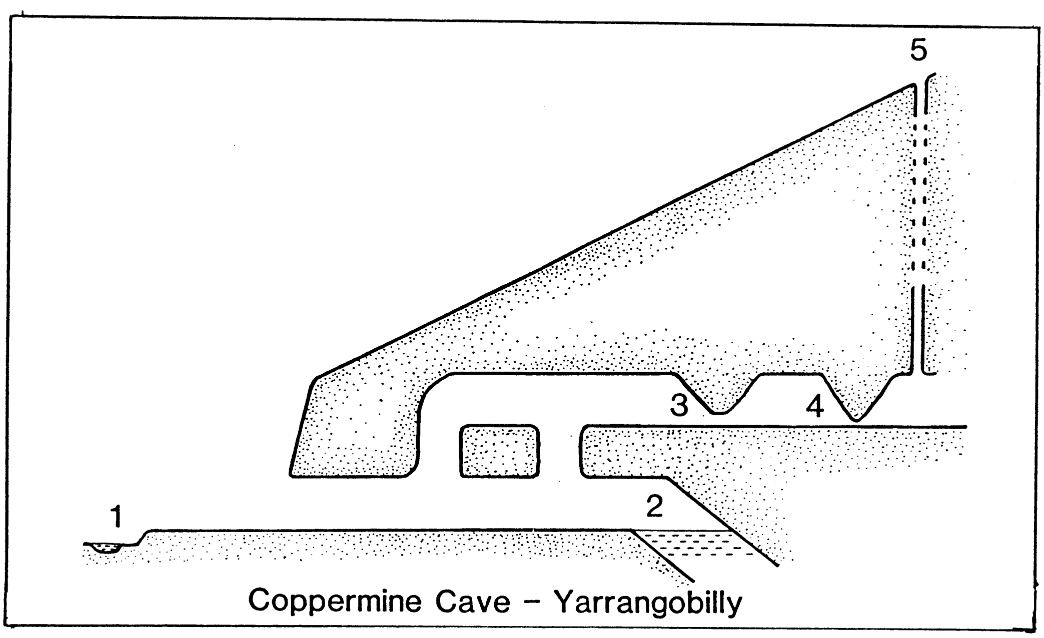


Figure 1. A simplified elevation of Coppermine Cave. 1 the Yarrangobilly River, 2 the stream resurgence, 3 the constriction at the locked bar, 4 the final impasse, 5 the hypothetical upper entrance.

multiple linear regression analysis proved useful in accurately determining the significant influences on the climates of caves that are dominated chimney effects. In such caves there are air flows caused pressure differentials caused by outside winds and by air density changes from air temperature and humidity variations.

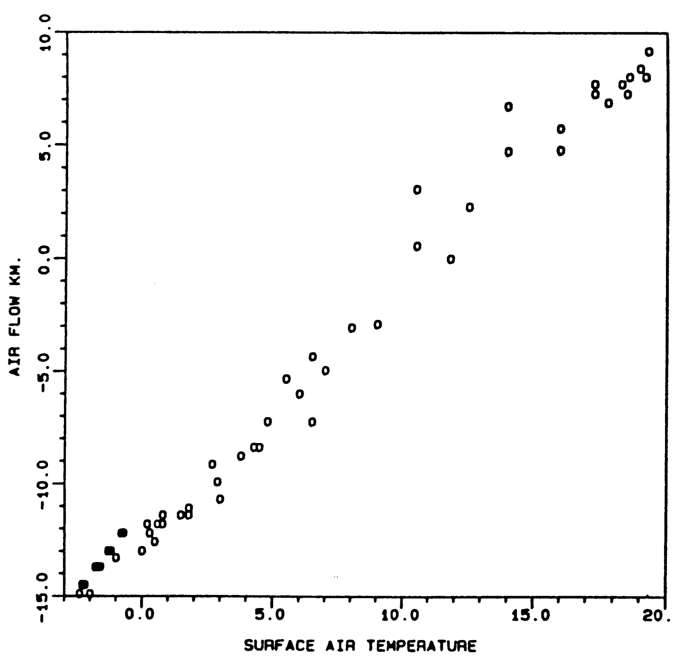


Figure 2. A plot of hourly average temperatures against the air flows for the corresponding hours in Coppermine Cave. 13th - 16th April 1979.

Results

(1) Coppermine Cave at Yarrangobilly (Figure 1), is a long tunnel cave formed by a stream that drains a large catchment. Only the exit which is at river level is accessible and the cave is eventually blocked by a narrow constriction. At this constriction there is a strong air current which is also obvious at a squeeze where there is a locked bar. Measurement and analysis of the air flow and the surface weather conditions [2,3,5] have shown that the air flow in this cave depends on the temperature of the air outside the cave. Figure 2 shows the strong relationship between surface air temperature and air flow in the cave.. The obvious conclusion is that the cave has another entrance much higher than the known entrance, which puts this cave into the category of chimney caves. These caves have a top and bottom entrance and the air flows through the cave in a direction that depends on the difference of density of the air inside and outside the cave. As temperature is the major factor in changing density, and the temperature outside the cave changes with the daily cycle, the airflow changes with time of day and season of the year.

In winter the section of the cave near the entrance becomes very dry and quite cold as the winter air cools the walls by evaporating water from them. In summer the cave gets very humid with water dripping off the roof and walls and the temperature rises. On average the cave, at about 10 degrees Celsius, is warmer than the mean surface temperature (6.8 at Kiandra) perhaps because of the geothermal capture of heat, (the Snowy Mountains area has a greater geothermal flux than most of Australia [1]) and in spite of the expected net evaporation of water caused by the air current.

(2) Mammoth Cave, Jenolan is a large system with several abandoned stream levels and a single known entrance by the ephemeral McKeowns Creek. The northern section of the cave is connected to the known entrance by a small unique constriction known as the Cold Hole (Figure 3). At times air flow of the order of 15 cubic metres per second passes through the Cold Hole to the rest of the cave. Analysis of the variation of the air flow shows that a chimney effect is operating. This has been established by correlating the air flow inside the cave with the temperature outside the cave.

Further north in the cave at a place called the Breeze Hole about one third of the air flows into the nearly vertical Waterfall Passage. Figure 4 shows a record of the airflow at the Cold Hole and the Breeze Hole and the surface air temperature measured on the 4th and 5th of December 1977. As with Coppermine Cave there is no other known entrance. Inside the cave it is apparent that there is more than one other entrance, and that the other two thirds of the air escapes through an upper entrance.

In winter, the sustained airflow dries out the lower sections of the cave making passage along the Central River Level quite pleasant.

If the Breeze Hole is blocked the pressure drop across the blockage can be about 30 Pascals. It is obvious that the air can find no other way past the blockage. The pressure drop corresponds to a chimney of 1000 metre-degrees. That is if the difference between the internal and outside air temperatures is one degree then the chimney must be 1000 metres high. A more probable but equally spectacular case is 10 degrees temperature difference and 100 metres high.

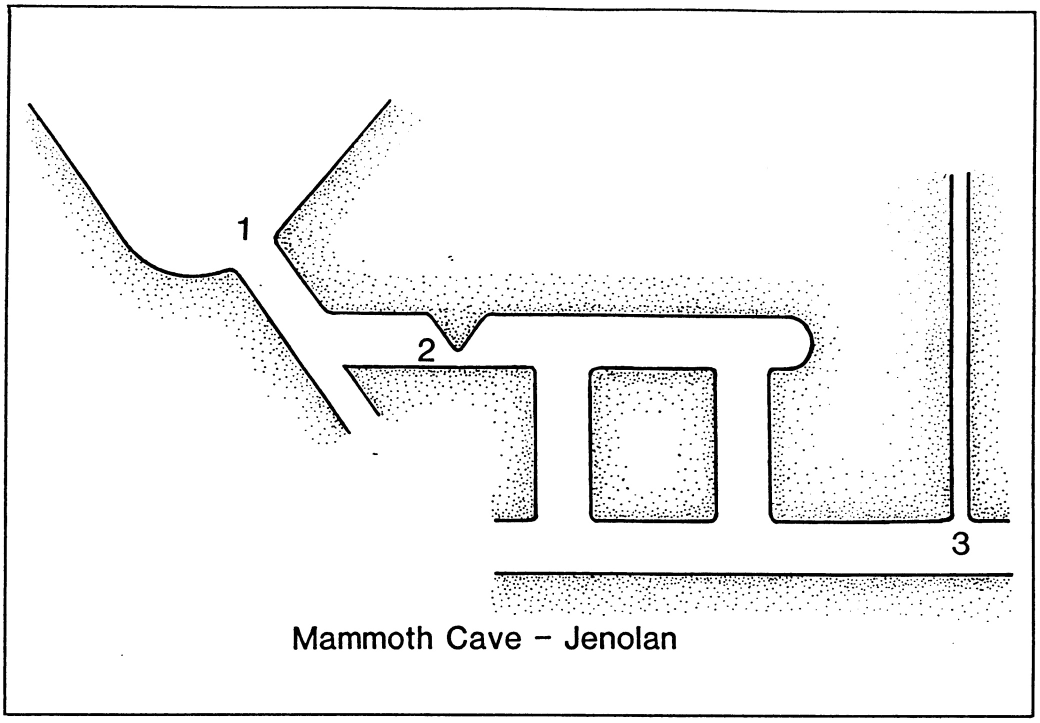


Figure 3. A simplified elevation of Mammoth Cave. 1 the entrance by McKeowns Creek. 2 the constriction known as the Cold Hole. 3 the Breeze Hole which leads to the Waterfall Passage and the hypothetical upper entrance.

Neither of the two postulated upper entrances to Mammoth Cave has been found in spite of the fact that on a cold winter's day below zero Celsius there should be a column of fog rising from each of the entrances as about 20 cubic metres per second of air at 18 degrees Celsius and nearly 100 percent humidity flows out of the unknown entrances. This heating and humidifying of cold air extracts heat from the cave at a rate of over one megawatt.

(3) Cutta Cutta, Katherine. Now this analysis of Cutta Cutta Cave is based on measurements made on 29th July 1981, and the published meteorological summaries from Katherine airport. It would have been better to have measurements from the cave at other times in the year, but in this case the available data is sufficient to identify a probable physical model of the cave.

The Katherine Aero. meteorological station has a mean annual temperature of 27.5 degrees Celsius but the deep cave temperatures are around 32 degrees Celsius.

This is at least partly because the rainfall occurs in the hottest months and the heat is carried into the ground with the water, whereas for most of the year the surface has a very high rate of heat loss by evaporation. The cave temperature is quite impressive, for if the humidity is high it will reduce healthy cavers to lethargic wrecks in minutes.

The amazing thing about Cutta Cutta (see Figure 5) is the temperature. The tourist section of the cave in July had a low temperature of 22 degrees with 68 percent relative humidity. This is quite comfortable in an area where the mid afternoon temperature outside averages 30 degrees. By contrast the nearby Turkish Bath Cave is over 30 degrees and 100 percent humid.

The locals speak of the Turkish Bath Cave as being anomalous but it is Cutta Cutta that is amazing, maintaining a temperature 10 degrees below the earth temperature and a humidity below saturation. One shudders to think of the size of the air conditioning system that would be needed to cool a whole cave by 10 degrees.

Here we will digress to mention a few details of human physiological response to extremes of temperature and humidity.

Basic Human Thermoregulation

Core temperature just less than 40 C. Skin temperature about 32 C. This is maintained at metabolic energy levels ranging from 70 watts asleep up to 800 watts during exceptional levels of physical activity. To transfer this

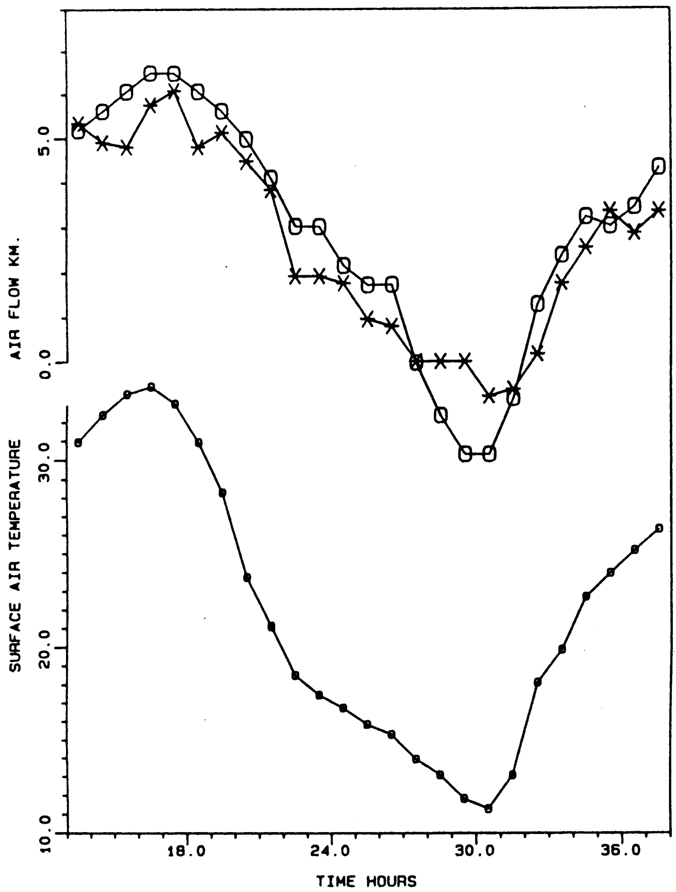


Figure 4. A plot of the measured air flows at the Cold Hole (o), and the Breeze Hole (*), and the surface air temperatures on 4th and 5th December 1977. This illustrates the strong relationships between these variables.

amount of heat to the skin to dissipate it and maintain the all important core temperature may require the constriction of peripheral circulation if heat losses are great, with a consequent drop in skin temperature, or alternately the transport of large volumes of blood if heat losses are not large enough and there is a rise in skin temperature above 32 C. This involves the heart in pumping ever greater quantities of blood through a decreasing temperature gradient.

A moist body loses heat by evaporation and by sensible heat loss (convection). For the human with 32 C skin temperature the skin may be dry or moist depending on the rate of sweating. For a given air velocity over a body the heat loss can have a wide range of values depending on the sweating rate.

What does it all mean? It means that there are limits to human comfort, or in extremes, to human survival. These limits depend on the air temperature, air velocity, air humidity, level of incident radiation (incoming or outgoing) and metabolic rate.

An air temperature of 32 degrees and 100 percent humidity does not allow the skin to dissipate heat without an elevation of its temperature, and is only comfortable at the lowest of metabolic rates. Any exercise will cause distress and extreme levels of exercise can induce collapse, heart failure and death.

So what is amazing about Cutta Cutta Cave? The amazing thing about Cutta Cutta is the cave climate. By means of a chimney circulation that only operates when outside conditions allow cooling, the cave transports heat, from convective transfer and from evaporation so that the cave is very comfortable for humans. The lower reaches of the cave give fair warning to cavers about the nature of the climate in other caves in the area.

The humidity is so high in the lower reaches of Cutta Cutta that the termites do not even build tunnels but just walk down the walls. In the transitional areas one can see termite tunnels that stop as they reach the high humidity area and the termites march on in the open.

For areas such as Katherine or Camooweal there is a danger of abseiling into caves if such action commits cavers to a high effort return. The rate of metabolic heat production when say climbing a ladder may be too high, causing hyperthermal collapse. It is important in such conditions to have facilities for long periods of rest to recover thermal equilibrium during the climb out.

(4) Eagles Nest, Yarrangobilly. From one extreme to another, the Eagles Nest System at Yarrangobilly is a complex system with a closed doline which will encourage the formation of frost hollow events in cold weather. Cold air from the doline feeds, with the circulation assistance of a chimney system, a rockpile heat storage system (Figure 6). The cold weather cools the zone where a large available surface area of rock acts as a rock pile heat storage system. If the outside air temperature rises, cold air flows from the storage zone into the doline until the densities balance. In summer at 35 degrees ambient one can walk into the bottom of the doline and encounter 5 degree temperatures. In winter the cave features ice formations and even in summer in the cave there is a wind tunnel where temperatures of two degrees may be encountered. The other entrance, West Eagles Nest, continually discharges air from the cold rockpile but reheats it to about 9 degrees with collected geothermal heat. Figure 7 shows the strong response of the Y1 chimney to outside air temperature changes and the persistence of outward flow from the Y2 entrance.

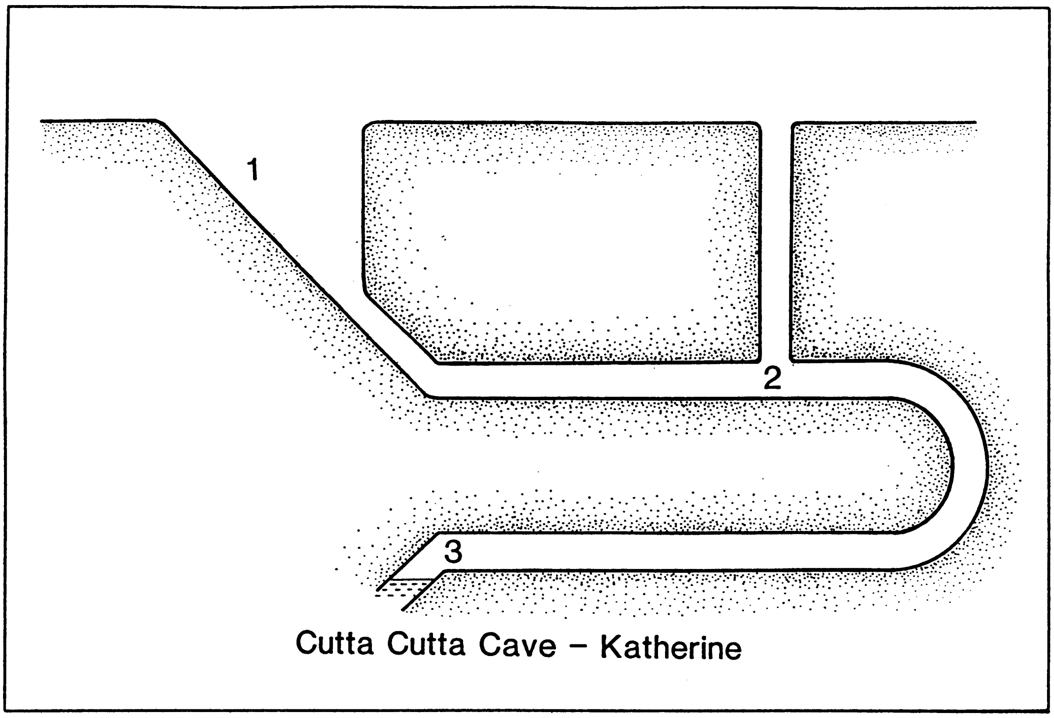


Figure 5. Simple section of Cutta Cutta Cave. 1 entrance doline. 2 chimney to surface at the end of the tourist section. 3 end of lower section featuring high temperature and humidity. When the outside air temperature is low, air enters at 1 and exits through the chimney at 2.

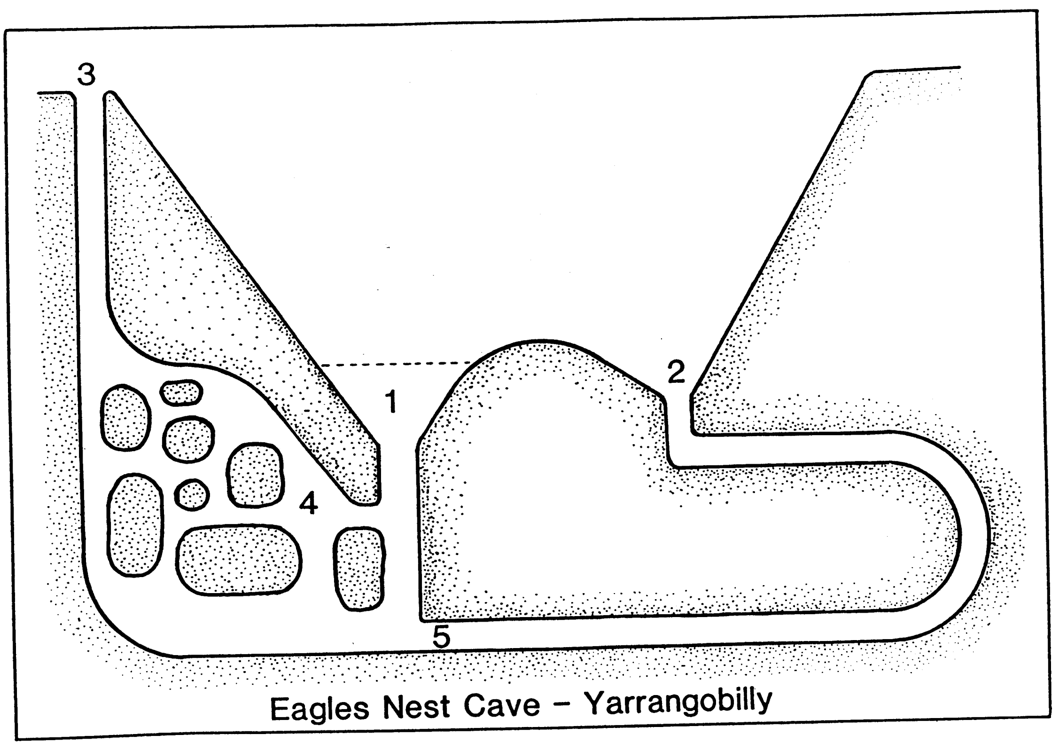


Figure 6. A schematic diagram of Eagles Nest Cave. 1 the Y1 entrance in the doline which is held below 5 degrees. 2 the Y2 entrance where the stream sinks and the air always flows out. 3 The Y3 entrance, the Eyrie, top of the system's chimney. 4 the heat storage area. 5 Hurricane Alley where the temperature is very low.

(5) Mullamullang, Nullarbor Plains (Figure 8) This cave and others in the Nullarbor area are barometric breathers. The volume of the cave is so great and the area of the entrance, by comparison, is so small that changes in the barometric pressure on the surface cause strong winds to blow in and out of the entrance. Figures 9 and 10 show the barometric pressure measured on the surface from the 16th January 1979 for more than two days, and the corresponding air flow in and out of the cave. These data were not gathered without some considerable hardship. The barometer had to be read at frequent intervals at the base camp so that I had to forgo all caving and most of my sleep for over 54 hours to record the readings. In the end everyone else left the area so the observations had to end. Imaging being so close to such a cave and not being able to explore it!

The velocity of the air flow is roughly proportional to the rate of change of the barometric

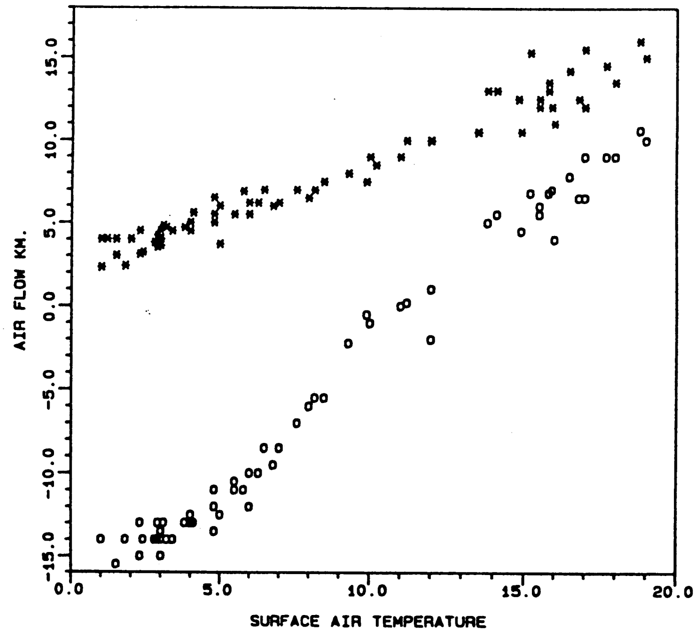


Figure 7. The hourly averages of the surface air temperature plotted against the air flows for the corresponding hours at the Y3 entrance (*) and the Y2 entrance (o).

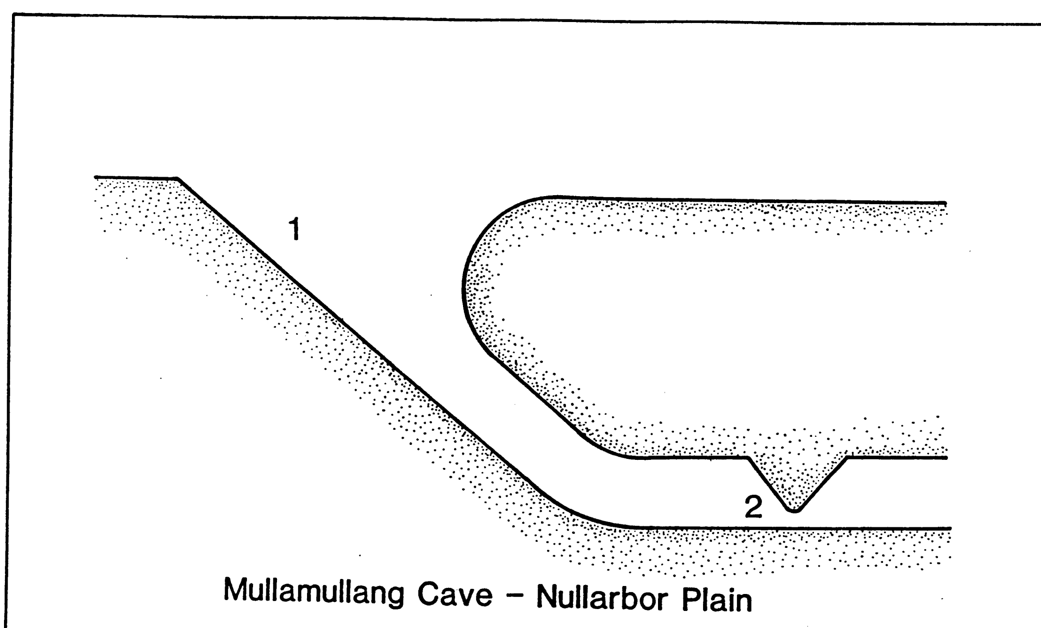


Figure 8. Schematic diagram of Mullamullang showing 1 the entrance doline and 2 the Southerly Buster constriction.

pressure. Thus it follows that the total out flow should be proportional to the barometric pressure as can be seen in Figures 9 and 10. The time delay between these graphs is the subject of great interest because it may reveal details of the structure of the cave. However to observe it needs records that extend over many days. Analysis of the flow in Mullamullang has shown a complex time response with time constants extending beyond two days. From this one may infer that the structure is very long, thin, has very big bits and is complex.

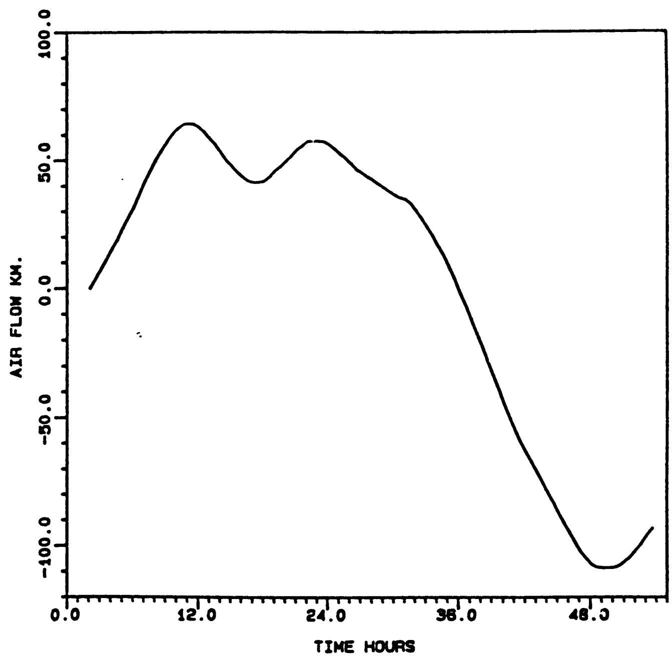
Discussion

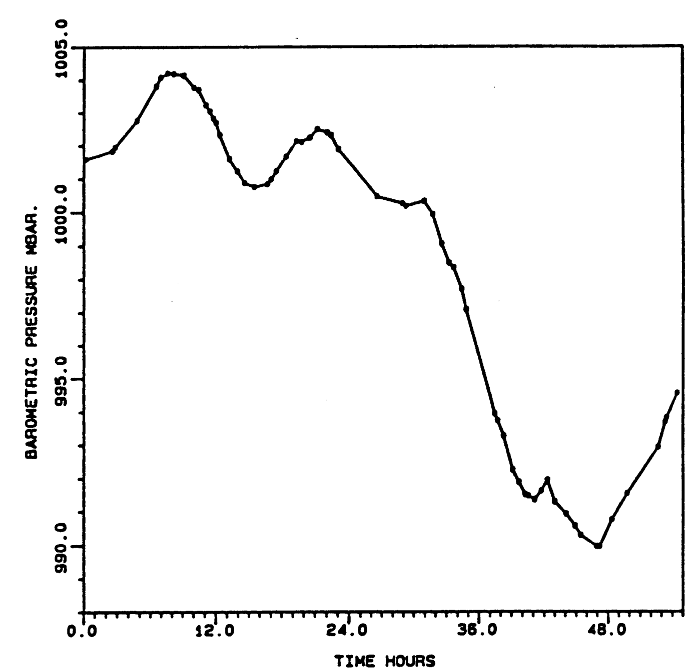
There is a long list of caves with chimney air flows, a lower entrance, but no sign of an upper entrance. It brings up the question of airflow in soils. Water can flow through soils and air is less viscous than water, so what is the place of airflow in soil as a component of cave air circulation? Only more observation and more physical experimentation will tell.

Conclusion

Caves have climates that are determined by the shape of the cave, the outside climate and the presence and distribution of water in the cave. As no two caves have the same shape, it follows that no two caves will have identical climates. Cave climates are important to cave fauna and the formation of speleothems. From climatic observations in caves we can deduce the existence of unknown caves, so that cave climatology can assist cave exploration. We can learn valuable lessons in energy conservation by observing the naturally occurring mechanisms that store heat, modify humidity and circulate air.

The tracing of air currents is still the single greatest physical phenomenon for detecting new caves.





Figures 9 and 10. Plots of the measurements of air flow and barometric pressure at the Southerly Buster in Mullamullang Cave.

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