ENVIRONMENTAL MONITORING IN CAVES: PART 1

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Abstract

A summary is given of the considerations that influenced the design of a cave monitoring program.

Environmental monitoring is the systematic measurement of the environmental factors concerned with the well-being of a natural resource.

In caves the natural resources to be protected are many and varied. An incomplete list might include: fungi, bacteria, algae, plants, insects, spiders, worms, amphibians, fishes, mammals, birds, minerals, sediments, fossils, archaeological artifacts and the ever-popular speleothems. If a new cave is discovered, careful research is needed to determine what is of value in the cave, and then more research is needed to find out what conditions are important to conserve these features.

This paper is about the measurement of the physical cave environment, temperature, humidity, airflow and energy flows. Although many descriptions of the cave environment have been published over the last 70 years, it seems to me that the caves we have measured are far more complicated and varied than the simple models described (Ford & Cullingford, 1976; Gèze, 1965; Martel, 1908; Moore & Sullivan, 1978; Trombe, 1952). So here is a short description of the relevant processes that seem to control the physical cave environment. The supporting physical evidence is not complete, but at least it is based on about eight years work, involving the development of instruments and techniques to be able to measure some effects in a limited number of caves.

Caves are formed in the earth's crust which has a temperature gradient with depth called the geothermal gradient. The intensity of this gradient is about 1°C per 30 m depth but it can vary from place to place. The gradient is caused by a heat flow called the geothermal flux which ranges from about 40 milliWatts per square metre ($mW\ m^{-2}$) to 100 $mW\ m^{-2}$. Any cave formed in this temperature gradient will tend to have this increase of temperature with depth, but a volume of air with this gradient will be unstable, in the meteorological sense, and convective circulation will start to transport heat to reduce the temperature gradient in the cave. As caves are often damp, evaporation and condensation of water will often be involved in this convection of heat from the lower parts of a cave to the higher levels.

If we consider caves with just this one process occurring we will find that the temperature at any place will be constant. As convection is a very efficient process, the temperatures from place to place will be close to each other. This does not mean that the cave is meteorologically static. What it means is that the active process in the cave is steady.

The magnitude of the effects caused by the geothermal flux should not be underestimated. Although the heat that would have flowed through the floor

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of a cave is only say 60 mW m^{-2} before the cave was formed, with the heat flow in the cave there is a change in the uniformity of the thermal field and heat flows 100 times larger are probable. A simple, calculable case is a horizontal cave of indefinite length (Michie, 1977). If this cave is at surface temperature then Fig. 1 shows the distribution of temperature in the rock around the cave. Fig. 2 shows the amount of heat captured by such caves with diameters of 0.2 m, 2 m and 20 m. It can be seen from this graph that water flowing in a tube 200 mm in diameter at a depth of 200 m could collect heat at the rate of 10 000 Watts per kilometre.

To investigate the heat flows in a cave it is helpful to have an accurate vertical section map of the cave. This map should include all passageways and cracks, even if they are too small to enter. Measurements of air temperature and humidity will now reveal the vertical temperature gradient and areas of evaporation and condensation.

If the temperature decreases more than 1°C per 100 m of increased altitude, which is the adiabatic lapse rate of dry air, then the air in the cave is unstable and heat is being transferred. If the temperature decreases between 0.5 and 1°C per 100 m, the lapse rates for moist and dry air, then stability is conditional, and heat may or may not be transferred, and if the gradient is less than 0.5°C per 100 m, or if the gradient is inverted, then the air in the cave is stable and very little heat can be conducted by the air.

If an inversion is found in a cave, that is, if the bottom of the cave is full of cold air, then either there is a heat sink at the bottom of the cave, a heat source at the top of the cave or the inversion is a temporary situation.

A large number of caves are not isolated from the surface conditions but may freely convect heat to the surface. When temperatures outside the cave are low there will be convection of heat to the surface. When outside temperatures rise the cave becomes stable and no heat is transferred.

Extreme cases of this phenomenon are the freezing caves, found in many parts of the world, which fill with snow and ice in winter and which stay stable all the rest of the year while maintaining very low temperatures.

If a cave has more than one connection to the surface it may behave as a chimney cave. Fig. 3 is a diagram showing a simple chimney cave (Gèze, 1965). Included are some important features that other authors neglect: the geothermal gradient and the stored heat in the walls of the cave.

The caves that we have studied have included aspects of caves which are stable in hot weather and caves which act as chimneys. Much of the work has been monitoring the reversal conditions of multi-entrance caves, that is, the conditions for which airflow will cease. Each cave has proved as unique in its behaviour as it is unique in shape.

So the first step in monitoring a cave is to make sufficient measurements of the shape of the cave and the conditions found in the cave over the whole range of external conditions until self-consistent data have been acquired. By this stage the effect of digging new entrances or blocking old ones should be predictable.

The only guide to the quantity of data that will be required for a cave is that based on past experience. I am building an eight-channel recording system to continuously monitor a cave at Jenolan for a period which may be as long as two years to acquire a data base.

Figure 1. Calculated temperature field around a very long cave.

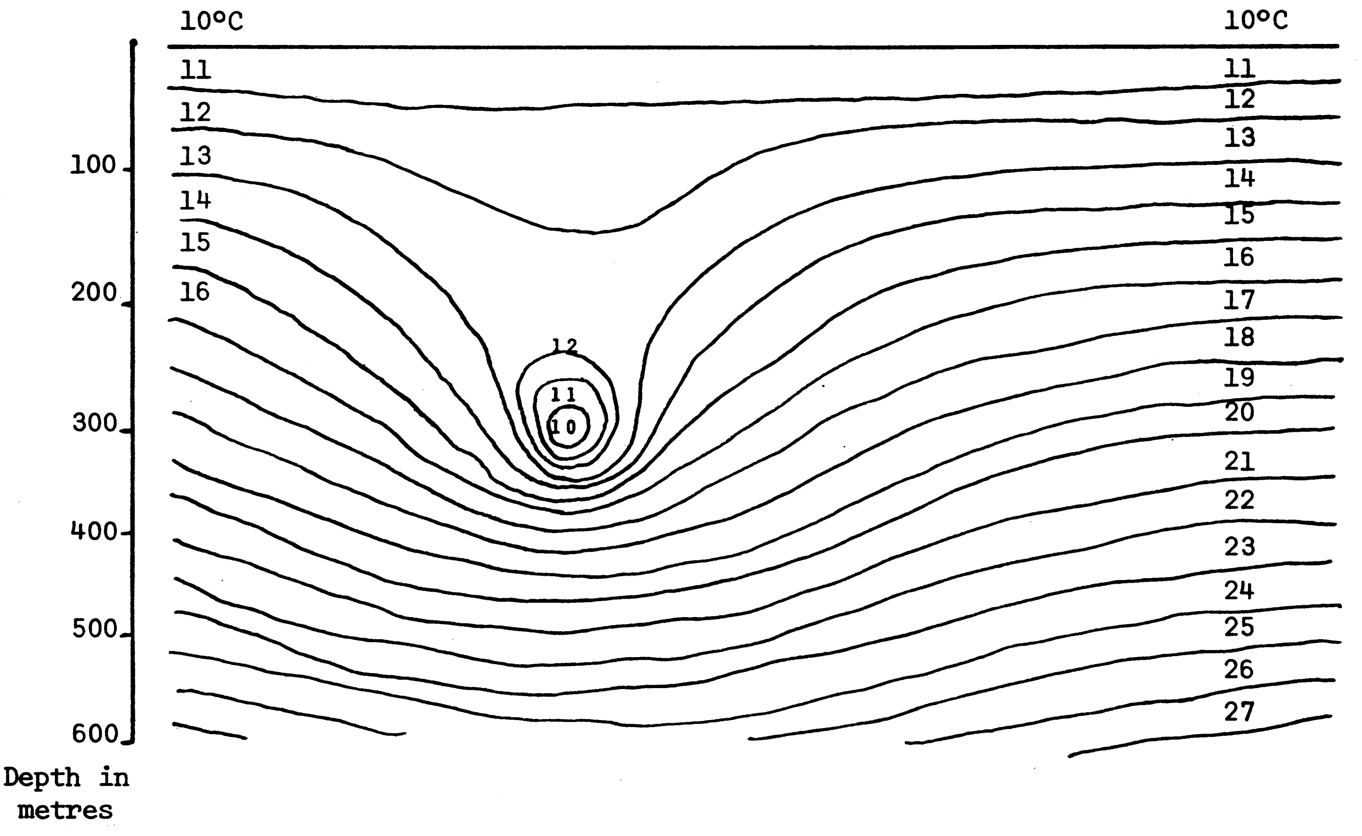


Figure 2. Heat gathered by a long horizontal cave at surface temperature.

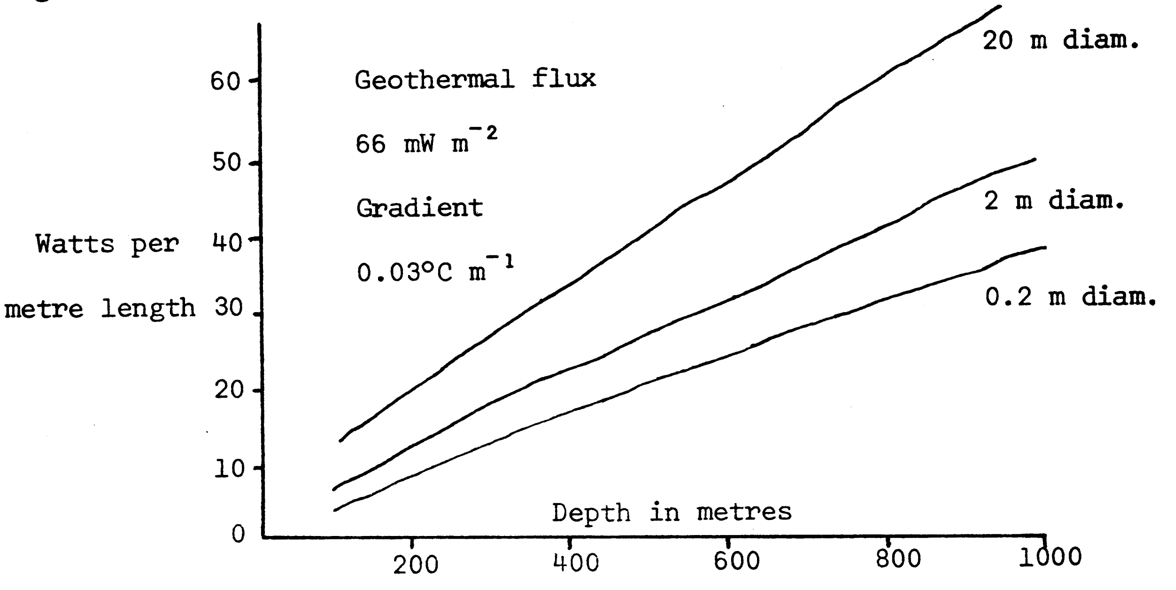
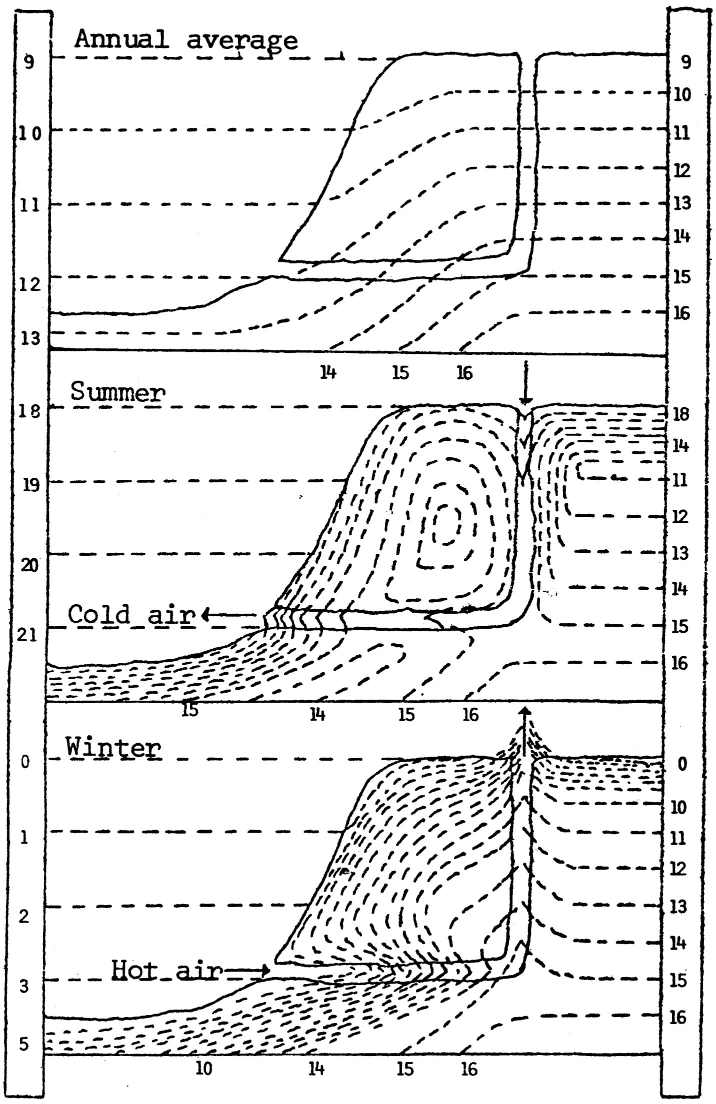


Figure 3. Simple chimney cave showing isotherms.
(After Gèze 1965.)



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