for LAWRENCE

# The Climate of Gypsy Cave:
# Some Notes on Preliminary Measurements

GGY 609

Spring 1979

Jerry Davis
Kathy Hallisey

Geography Department
University of Georgia
Athens, Georgia

June 2, 1979

# INTRODUCTION

The climate of caves has often been considered as exhibiting great stability and uniformity. Temperature is assumed to be constant with a short distance from the entrance. The presence of moist wall conditions has suggested a high humidity.

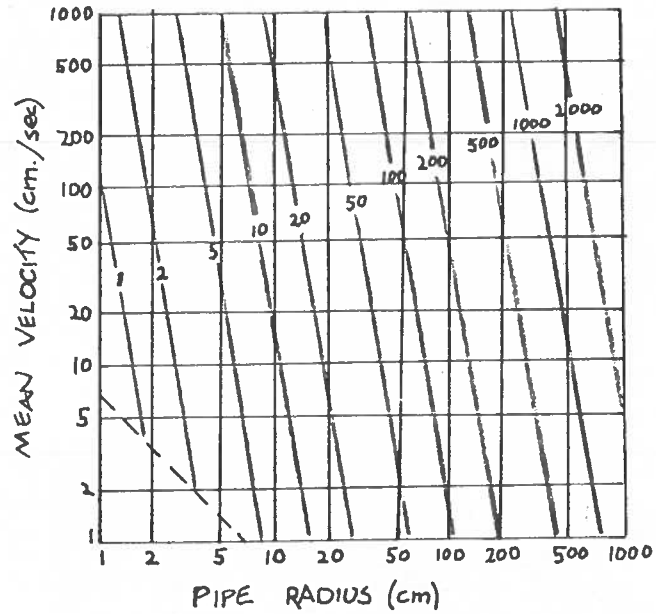
While, to a large degree, the above statements prove true, there is a need for substantiation. Caves can be fairly unique in their environments, it seems, due to various processes at work. Through the study of individual caves, these processes might be able to be identified and interpreted.

# PREVIOUS RESEARCH

## Temperature Profiles

Wigley and Brown (1971) apply theories of heat and mass transfer through pipes to cave conditions. Adjusting these theories to consider moist wall conditions, they propose characteristic temperature profiles for various cave situations. Seasonal differences are distinguished by characteristic shapes, the scale of which is dependent upon the passage size and wind speed (see figs. 1 and 2). The primary control on temperature profiles shapes is latent heat exchange. Thus the summer profile shows a near entrance warm zone where water vapor in air entering the cave condenses upon the cool walls, releasing latent heat. The winter example, however, would exhibit a cold zone, as cold, dry air inflow evaporates water from cave walls. Periods of transition would also exhibit evaporative cooling, but as in the example shown, this would serve primarily to advance attainment of equilibrium, with only a minor cold zone produced.

FIG. 1

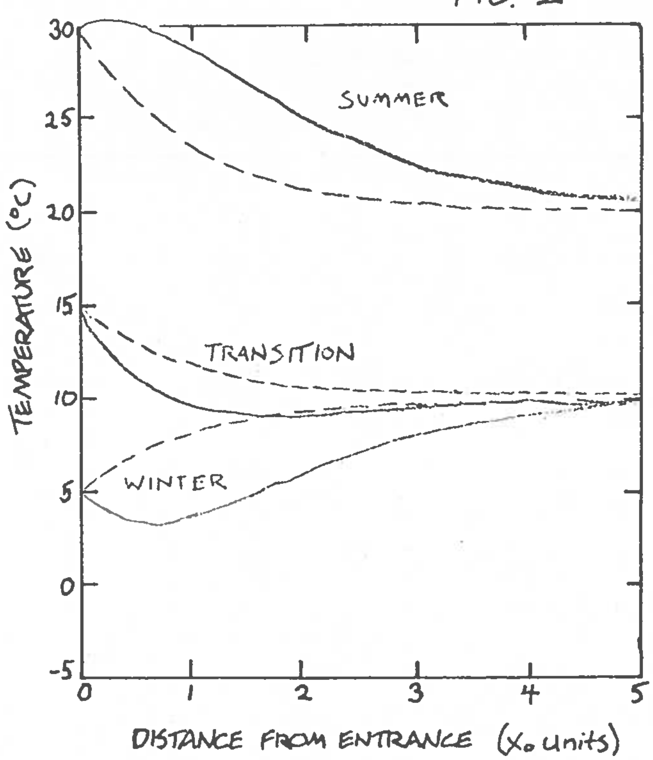



RELAXATION LENGTH

$X_o$ in meters

(AFTER WIGLEY & BROWN)

FIG. 2




TEMPERATURE PROFILES

LATENT HEAT

—— CONSIDERED

- - - - NOT CONSIDERED

(AFTER WIGLEY & BROWN)

Moore and Sullivan (1978) review some theories of cave climate in their compilation of research in speleology. One of these relates cave temperatures to past climatic changes. Analogous to wave theories of daily and annual temperature fluctuations, cave temperatures at depths too great for such fluctuations to be felt are explained. A temperature change of $1^{o}C$ at depth x, in meters, is thus related to T, the length of time in years for a temperature change to be completed, and the surface temperature fluctation N in $^{o}C$, according to the formula:

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

Also cited in Moore and Sullivan is a study of a Nevada cave, in which temperatures measured at various depths are related to past climatic changes. (see figure 3). The basis for the assignments to climatic events rests primarily in the rate of temperature change. This in turn is a function of the temperature differences between levels.

It is evident from an analysis of the various theories of temperature change that easy interpretation is not possible. Formulas assume different rates for different cycle periods and magnitudes. Superimposed cycles predicted by these formulas quickly become quite messy. Adding to this the effects of air and water flow, the prediction of cave air temperatures approaches insanity.

Humidity

The importance of humidity in determining temperature profiles has been mentioned above, in Wigley and Brown (1971).

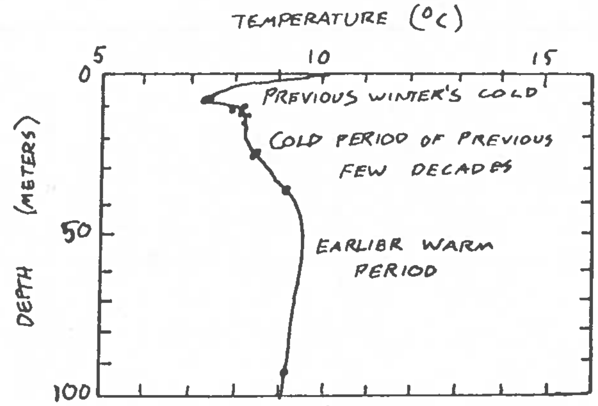



FIG. 3

(AFTER ARTHUR L. LANGE IN MOORE & SULLIVAN)

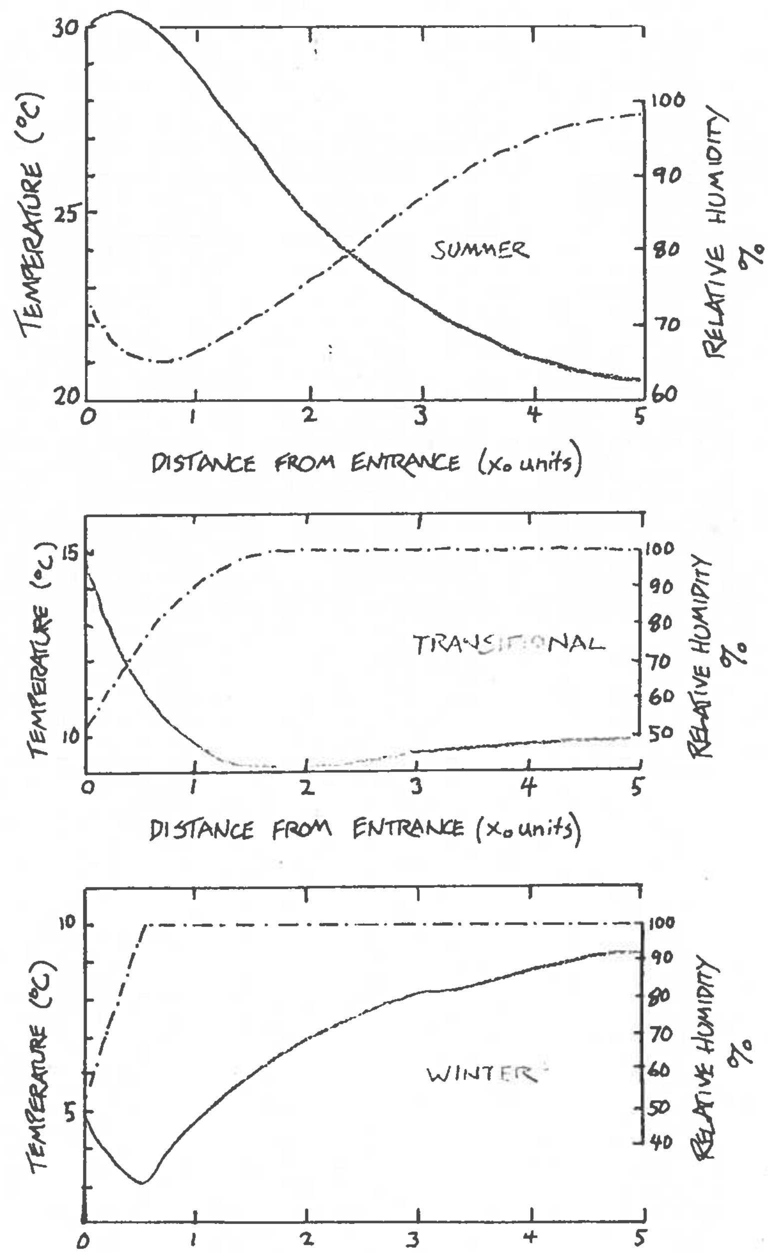
FIG. 4

HUMIDITY / TEMPERATURE PROFILES

— · — · — HUMIDITY

———— TEMPERATURE

(AFTER WIGLEY & BROWN)



In their research, the differing seasonal amounts of specific humidity of incoming air will greatly influence air temperatures just inside entrances. Relative humidity is seen to approach 100% with distance in the cave, except in the summer. In the summer case, condensation on the colder walls prevents the air from ever becoming saturated (see figure 4). In winter and transitional periods, however, saturation is reached within a short distance. This seems also to change the temperature curves.

Moore and Sullivan, using simple temperature/relative humidity relationships, predict quite different humidity profiles. In summer, the fall in temperature within caves produces rapid saturation. In winter, they predict a fall for a distance, followed by a gradual rise to saturation at depth.

Cave Winds

Air movement remains one of the more confusing aspects of cave climatology. Passage sizes, shapes, and lengths vary and combine to produce complex results. Pressure differences on the surface seem to produce unique winds in some caves while others seem unaffected.

Geiger (1966) divides caves into those with a single entrance and those with more. Multiple-entrance caves might experience a chimney effect of thermally-induced air movement. His interpretation of single-entrance caves as static environments seems dubious, however. For one thing, even single-entrance caves should experience changes with the seasons as well as with surface pressure differences.

In a study of two Black Hills caves, Conn(1966) tests theories of single-entrance caves. Winds at entrances of both caves were measured with a recording device, and surface barometric pressure measured. Good correlation is exhibited between air direction/velocity measurements and theoretical values. As a result, estimates of actual cave volume are made. Thus, the Conns have projected the actual length of Jewel Cave to be much greater than presently known.

Wigley and Brown (1976) review theories of air movement in caves. Processes claimed to induce such include gravitational drainage, entrainment by streams, and resonance. Cold air could feasibly drain into single-entrance caves. Entrainment by streams would be caused by friction at the water surface. Given ideal passage configurations and relationships, caves have also been known to resonate, the famous "breathing" phenomena.

Biologic Environments

There has been a good deal written on the needs of cave fauna for unique environments. Adaptation studies have shown that while many cave animals can exist in either cave or surface environments, some have adapted to a degree that they require quite specific environments to survive. While usually the most important aspect of this environment is the availability of food, constant temperatures and humidity is often required.

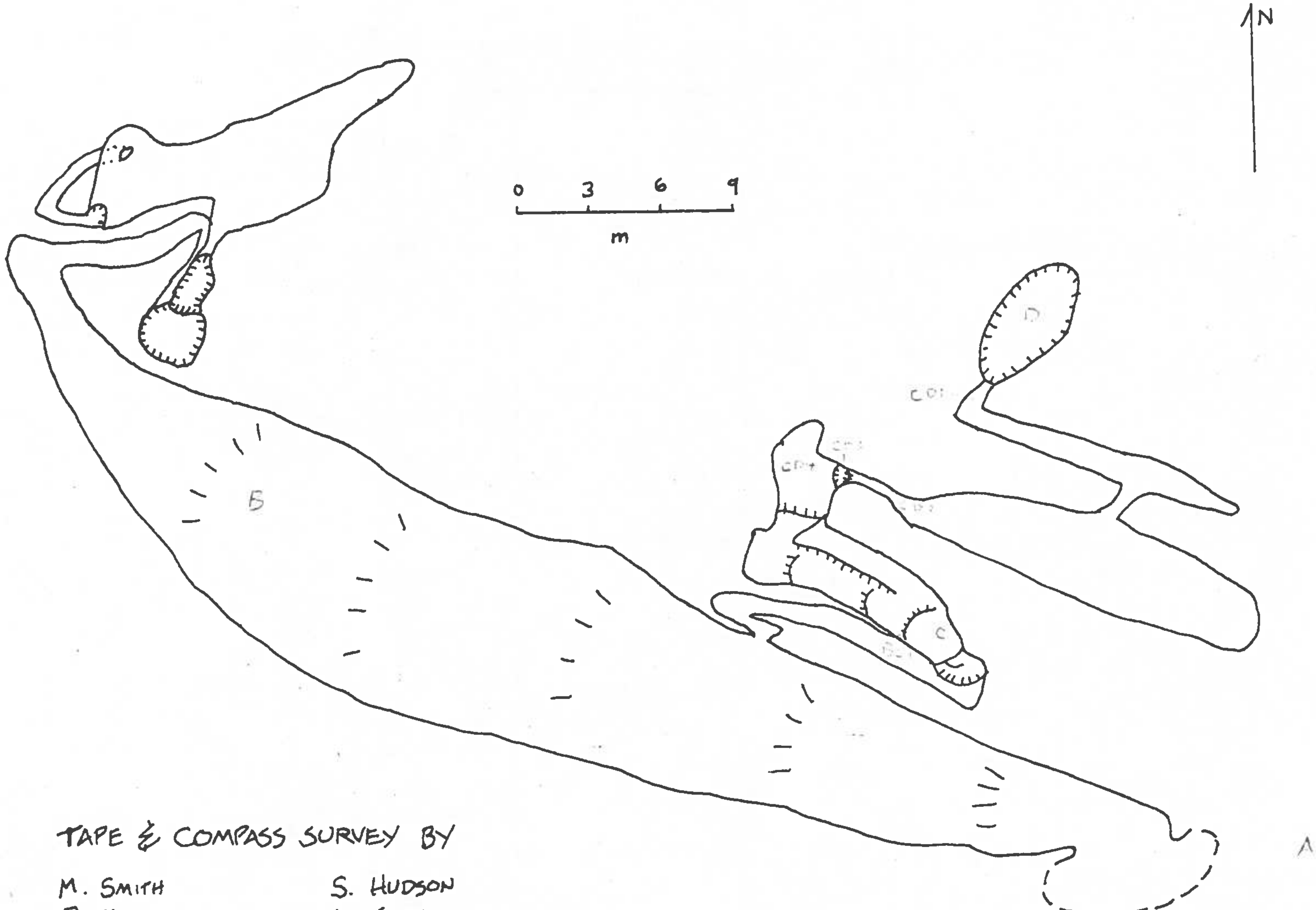
The choice of roosts by bats for winter hibernation is observed by Hooper (1976). It seems that bats not only have specific requirements, but also tend to return to favored places year after year. Bats are highly sensitive to temperature changes and tend to choose stable environments for winter months. However, as spring approaches, some are known to migrate to more variable localities. Since summer roosting occurs on a daily basis, bats might be found in many areas, as well as in man-made structures.

## GYPSY CAVE

The entrance to Gypsy Cave can be found at an elevation of 460 meters in Johnson's Crook of Lookout Mountain in north-east Georgia. While not great in length ( 167.6 meters), the cave has a depth of over 72 meters (see figures 5 and 6 ) making it the fifth deepest in Georgia (Georgia Speleological Survey, 1978). The single entrance is quite large (3 meters high by 5 wide), within which a collapse breakdown pile leads into a vast chamber. Probably over 30 meters tall at its greatest extent, this forms the largest room in the cave. It is possible that other passages (and possibly entrances) lead off at the top of this dome, however, it has proved inaccessible to date.

As might be expected, movement through this cave is made difficult and dangerous by its vertical drops. Two pitches require rope work, one belay and one rappell. In order to reach the bottom of the cave, a standing rope must by rigged for rappelling/prussiking (20-25 meters).

The cave, like most in the area, is formed in the Bangor limestone. Base level for the area is much below the deepest point in Gypsy. No streams flow through the cave, the only water input resulting from slow percolation through fractures




TAPE & COMPASS SURVEY BY

M. SMITH　　S. HUDSON
D. HUNTER　　L. GUY
G. McCLUSKEY　　J. YOUNG

# GYPSY CAVE

- PLAN -

GSS 32

FIG. 5

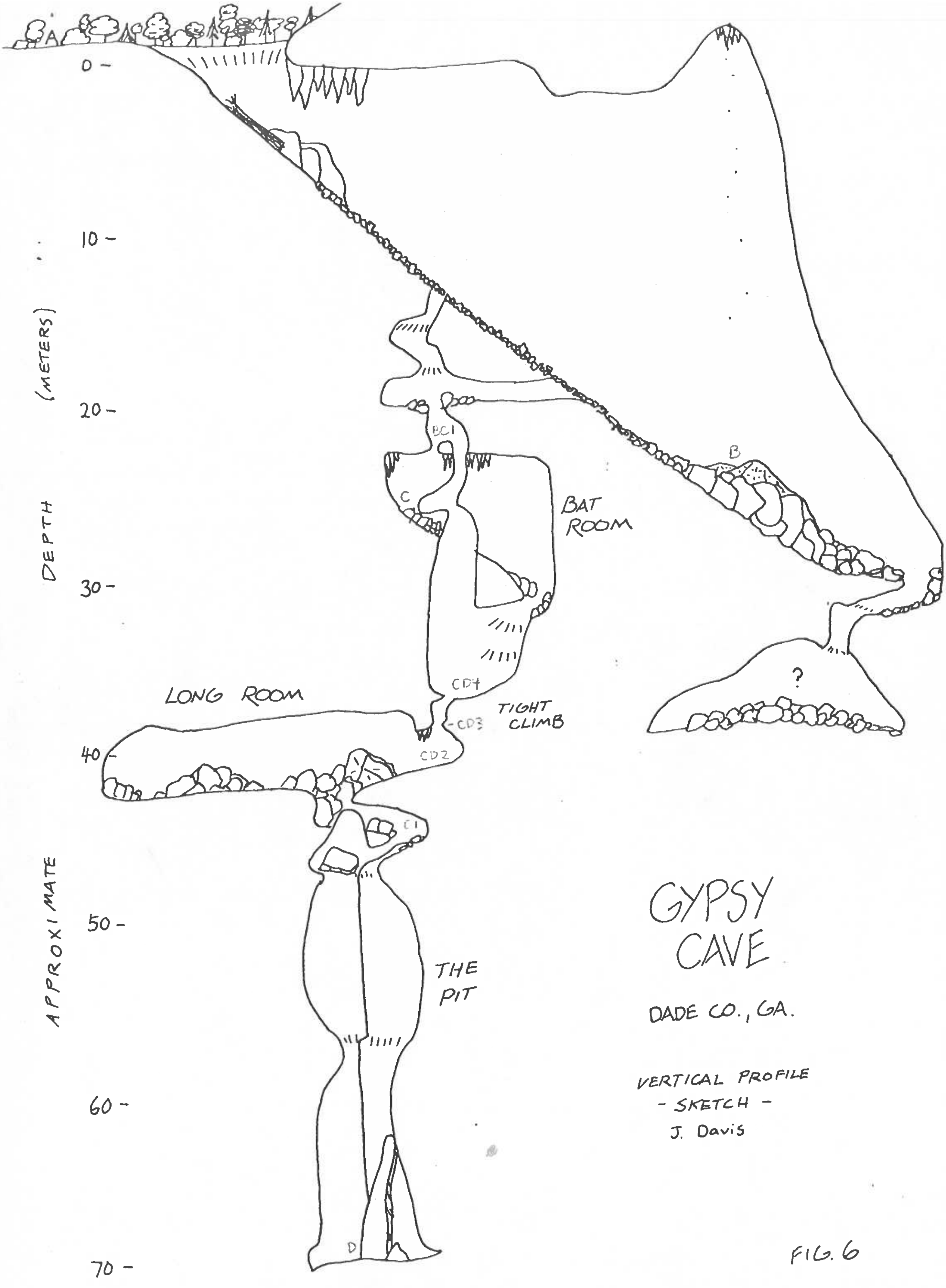

A
B
C
D
0 -
10 -
20 -
30 -
40
50 -
60 -
70 -
APPROXIMATE DEPTH (METERS)
BC1
BAT ROOM
CD4
TIGHT CLIMB
CD3
CD2
LONG ROOM
C1
?
THE PIT
GYPSY CAVE
DADE CO., GA.
VERTICAL PROFILE
- SKETCH -
J. Davis

FIG. 6

in the bedrock. Several areas in the cave have fairly consistent drips, one of which includes two small rimstone pools.

Preliminary Visit

A trip was made to the cave during the first week of December 1978. Most of the cave was seen at that time; the pit, however, was not descended. Several features indicating a unique cave environment were observed. The large entrance room has characteristics of both twilight and deep cave zones. Upon descending the initial talus into the room, it was noticed that diffused light illuminated most of the walls to some degree. The sky could still be seen at the bottom of the slope. However, at this point, the vaulted ceiling dripped water, below which large stalagmites had formed. Even with the light of day, the environment was essentially cave-like.

Deeper into the cave, in the Bat Room, bats were seen hibernating. These bats were determined to be Pipistrelles, a non-social genus. This room was unique in the cave for having such.

Still deeper, the Tight Climb was made into the Long Room. Air movement through this constriction was noted. While the direction of flow was constant from upper to lower levels, the magnitude varied. The flow would often seem to make a total halt. Elsewhere in the Long Room air currents could be followed, though at no point did they seem to lead out of the room. No explanation could be decided for the observed patterns.

Research Outline

While the most unusual pattern was that of air flow in the Long Room, it was decided that it would not be possible to thoroughly study such due to the scale of the current project. An excessive number of measurements would be needed in order to begin such a task.

In terms of temperature and humidity characteristics, however, the cave might give itself to natural zones. If we were to use the terminology of cave biologists, three zones would be distinguished: entrance, twilight, and dark zones. However, as mentioned above, the large entrance room might be difficult to classify. The Bat Room, as noted, might be unique in providing a favorable environment for bat hibernation. The Tight Climb, a narrow wet aperture might not only have a unique environment of its own, but might also divide two major areas of the cave.

It was decided that four sites would be used for week-long continuous records. A Friez-Bendix recording hygro-thermograph would be placed at the entrance, in order to have a base against which to compare cave results. The first significant cave station would be in the large entrance room, at the farthest extent to which the sky could be seen. It was felt that daily variations should still be perceptible here. The next hygrothermograph would be in the Bat Room, in the bat hibernation area. It was hoped that a unique environment could be perceived here to explain such. Finally a Casella-London thermograph would be placed at the deepest point in the cave, at the bottom of the pit (-72.5 meters).

These stations would be supplemented by other measurements at significant points, using a Bendix psychrometer to measure temperature and humidity. Above the Bat Room, at the end of a crawlway from the entrance room, the first "dark zone" measurements would be taken. Measurements would also be taken on either side of the Tight Climb. It was thought that here might be measured a thermal/mass gradient. In order to determine any difference between opposite ends of a vertical shaft, measurements would be made at the top of the pit. Measurements would also be made at all recording stations, for calibration.

## Field Work

### 4 May 1979

Before the cave was entered, station A was established on the surface. A rock overhang remote from the entrance was used. While preferable would be a standard weather box, it was felt that the location chosen had adequate airflow and shade to approximate standard conditions.

The cave was entered around noon, after station A was calibrated. Stations B and C were established and calibrated. The instruments used proved difficult to calibrate in this environment. The prime difficulty lay in the hair hygrometer component, which required coarse adjustments. The pit was rigged with standard caving rappell rope, and descended. Station D proved easier to calibrate, there being no hygrometer to deal with.

Measurements with the Bendix psychrometer were made at the above mentioned points on the way out of the cave. This instrument proved fairly useful for cave use. Not only was it of adequately rugged construction, but it required no slinging ( a certain disaster in confined spaces).

A Taylor hand-held anemometer was used to measure air flow through the Tight Climb. A cyclic nature was again observed here, also, with no reversals but calms at intervals. The greatest flow was recorded as 3.75 feet/second (1.14 meters/second). Significant eddies were also noted.

The cave was exited at approximately 21:00.

12 May 1979

Returning to the cave the following weekend brought bad news. Most of the recording instruments had ceased operation after two days. The one instrument that had been pre-tested lasted five days. There were also problems with ink traces.

Similar measurements to those of 4 May were made. No anemometer readings were made; however, a cyclic nature was again observed in the Tight Climb.

## RESULTS

Traces of temperature and humidity are displayed as figures 7 through 10. While the accuracy of these records is questionable the constant traces of B, C, and D are worthy of note. The environment at B was expected to be more affected by surface conditions.

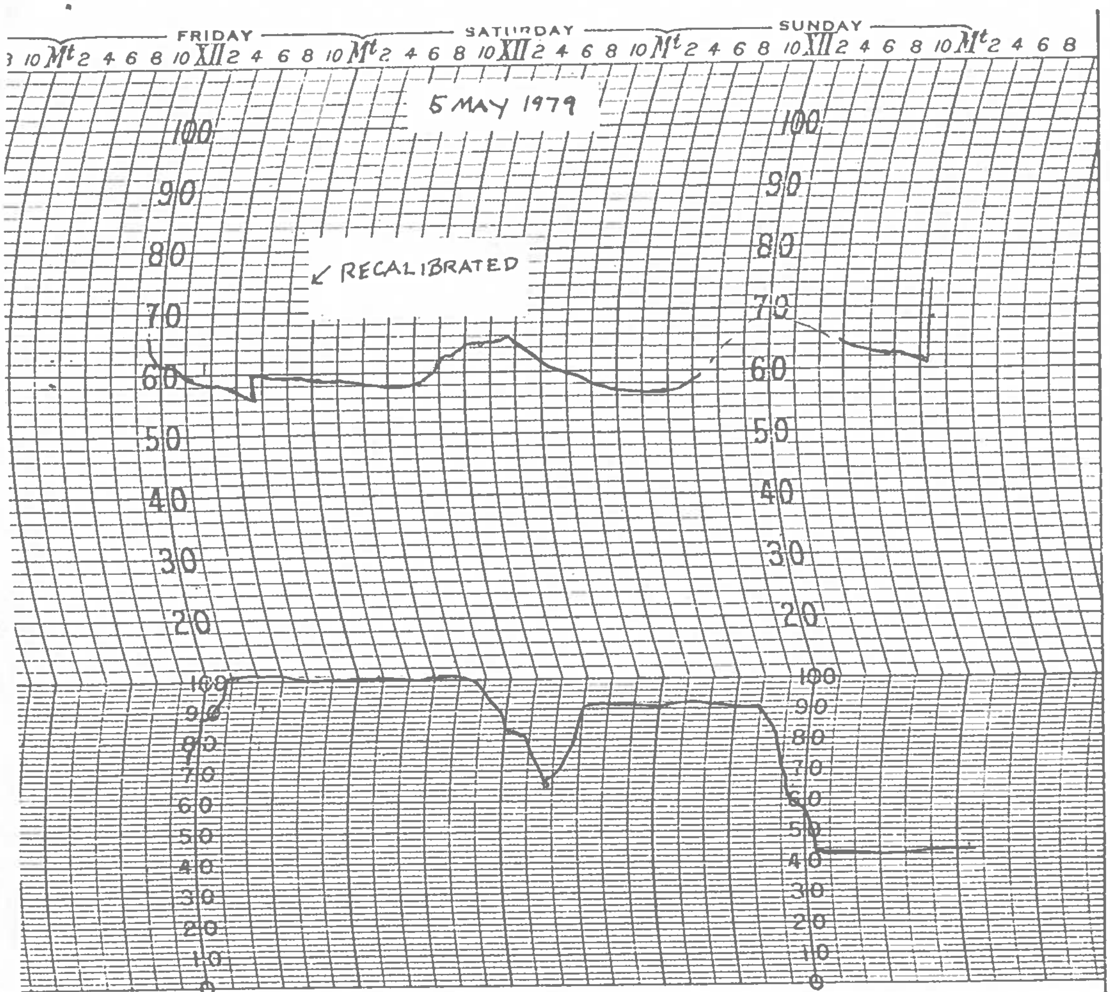
Other measurements are given in Table 1. Temperature and humidity measurements are related to depths below the surface in figure 11. Humidity measurements are derived from wet and dry bulb psychrometer readings. Since survey notes were not available, estimates of relative depths in the cave were made. Added to these figures were amounts estimated from the effect of surface slope.

## ANALYSIS

### Temperature

A look at the temperature profile in figure 11 (also see figure 6) suggests the possibility of temperature zones within

FIG. 7



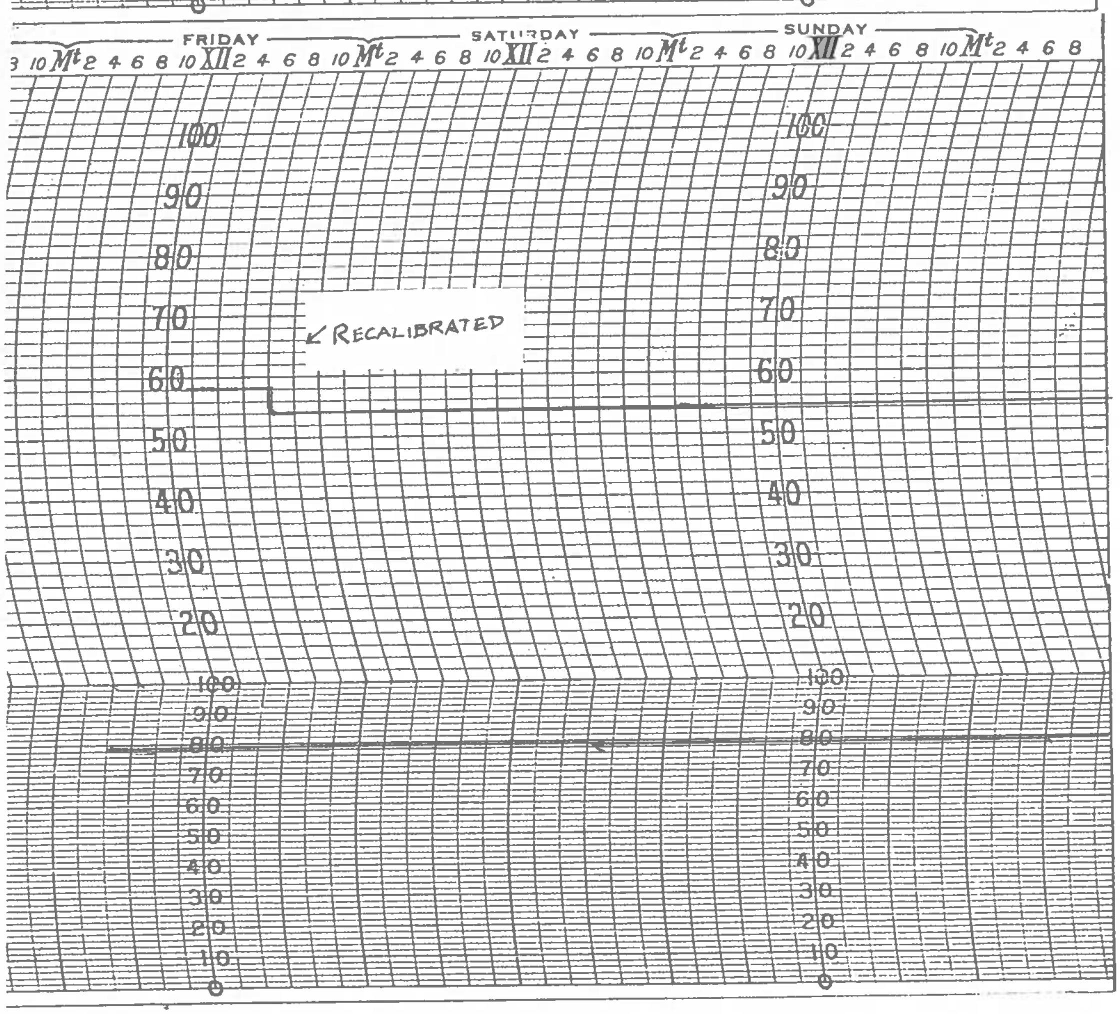

HYGROTHERMOGRAPH RECORD

STATION A

TEMPERATURE (°F)

HUMIDITY %

FIG. 8




STATION B

TEMPERATURE (°F)

HUMIDITY %

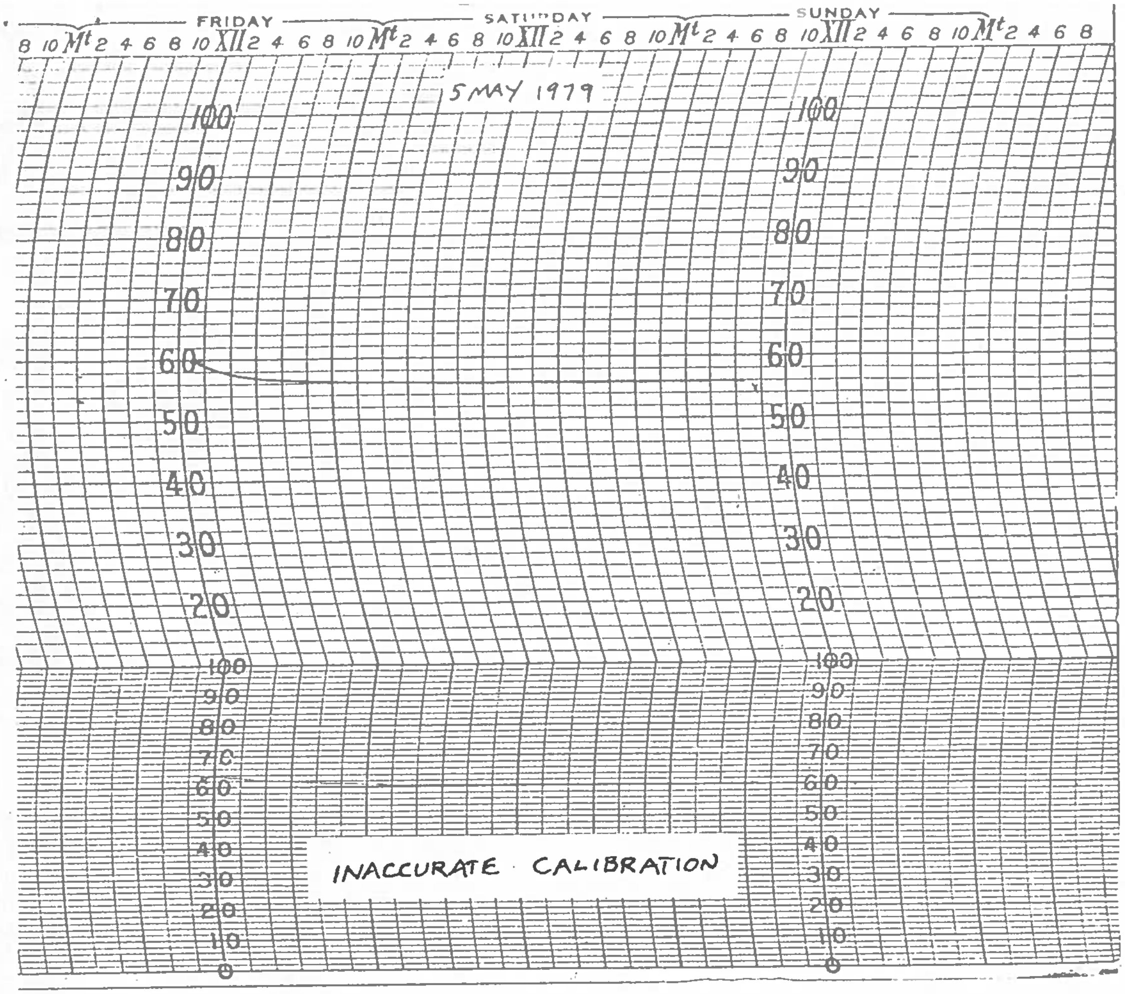



FIG. 9.

HYGROTHERMOGRAPH RECORD

STATION C

TEMPERATURE (°F)

HUMIDITY %

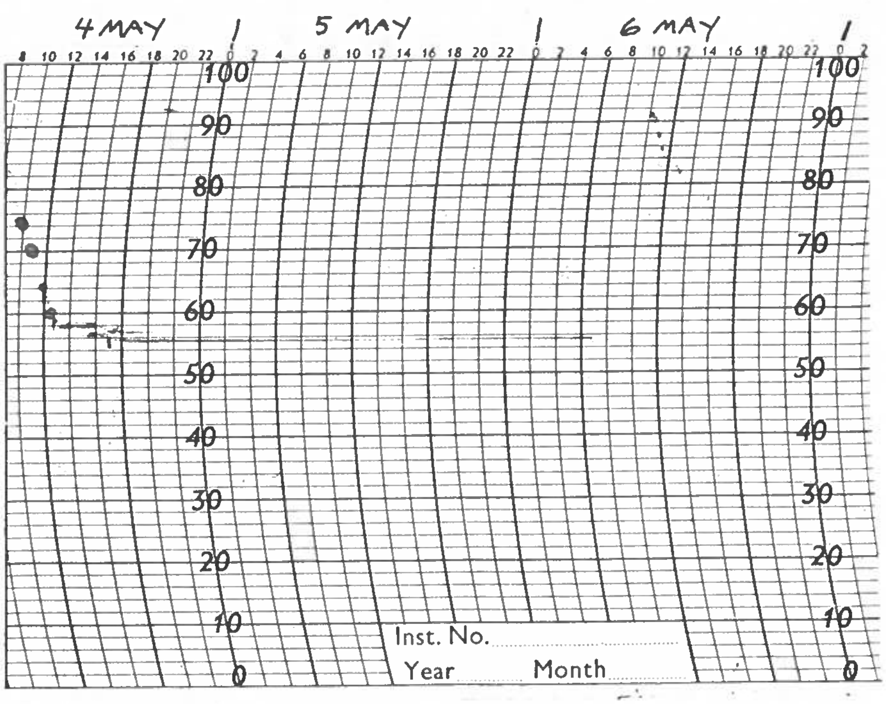



FIG. 10

THERMOGRAPH RECORD

STATION D

°F

the cave. Table 2 lists some of these. Perhaps the area from B through the Bat Room and into the Tight Climb could be considered as a colder zone. This would include B, BC1, C, CD4, and CD3. A warmer zone would then include CD2, CD1, and D, in the area of the Long Room and the Pit. The statistical significance of this division was thus tested through analysis of variance, using a 0.05 significance level (see Table 2). Thus, for 4 May observations this zoning pattern is significant, but not so for 12 May. Significance is again achieved in the combined set.

The lack of significance on 12 May requires closer inspection. It would seem that the value which might most likely be the difficulty is the reading for BC1 on that date. Perhaps BC1 might best be excluded from this zone. To do so, however, would also require the exclusion of B (see figure 6), leaving only the sites associated with the Bat Room and the Tight Climb. An F-test was thus applied distinguishing zones C-CD4-CD3 from CD2-CD1-D. Significance was achieved in all tests (Note: due to a reduction in sample size, 4 May results were lessened in significance, yet still within the confines of the current test).

Humidity

Similar tests (with similar groupings) were used with humidity derivations (mixing ratio). While both arrangements prove significant as combined data sets, specific day measurements are generally unsuccessful. The importance of sample size is brought forth here, however, in the superiority of the large group 1 over the exclusive group 1 in attaining significance on 4 May.

Table I-Measurements and Derivations

| | Station | Dry Bulb Temp(°C) | Wet Bulb Temp(°C) | Dew Point(°C) | Relative Humidity% | Vapor Pressure (mb) | Mixing Ratio $(g/g) \times 10^{-3}$ |
|---|---|---|---|---|---|---|---|
| | A | 15.6 | 15.6 | 15.6 | 100.0 | 17.75 | 10.90 |
| | B | 12.2 | 11.4 | 10.8 | 91.3 | 12.98 | 7.97 |
| | BC1 | 12.2 | 11.7 | 11.3 | 94.4 | 13.42 | 8.24 |
| | C | 12.8 | | | | | |
| 4 May | CD4 | 12.8 | 11.9 | 11.2 | 90.1 | 13.33 | 8.19 |
| | CD3 | 12.2 | 11.4 | 10.8 | 91.3 | 12.98 | 7.97 |
| | CD2 | 13.6 | 12.5 | 11.6 | 87.7 | 13.69 | 8.40 |
| | CD1 | 13.6 | 12.5 | 11.6 | 87.7 | 13.69 | 8.40 |
| | D | 13.6 | 12.8 | 17.2 | 91.1 | 14.22 | 8.73 |
| | A | 18.8 | 18.8 | 18.8 | 100.0 | 18.58 | 11.40 |
| | B | 12.1 | 11.4 | 10.8 | 91.8 | 12.98 | 7.97 |
| | BC1 | 13.3 | 12.5 | 11.9 | 91.2 | 13.95 | 8.57 |
| | C | 12.5 | 11.7 | 11.1 | 91.4 | 13.25 | 8.13 |
| 12 May | CD4 | 12.2 | 11.7 | 11.3 | 94.4 | 13.42 | 8.24 |
| | CD3 | 12.5 | 11.7 | 11.1 | 91.4 | 13.25 | 8.13 |
| | CD2 | 13.1 | 12.2 | 11.5 | 90.1 | 13.60 | 8.35 |
| | CD1 | 12.8 | 12.2 | 11.7 | 93.1 | 13.78 | 8.46 |
| | D | 13.3 | 12.8 | 12.4 | 94.1 | 14.40 | 8.84 |

FIG. 11 MEASUREMENT GRAPHS: TEMPERATURE & HUMIDITY

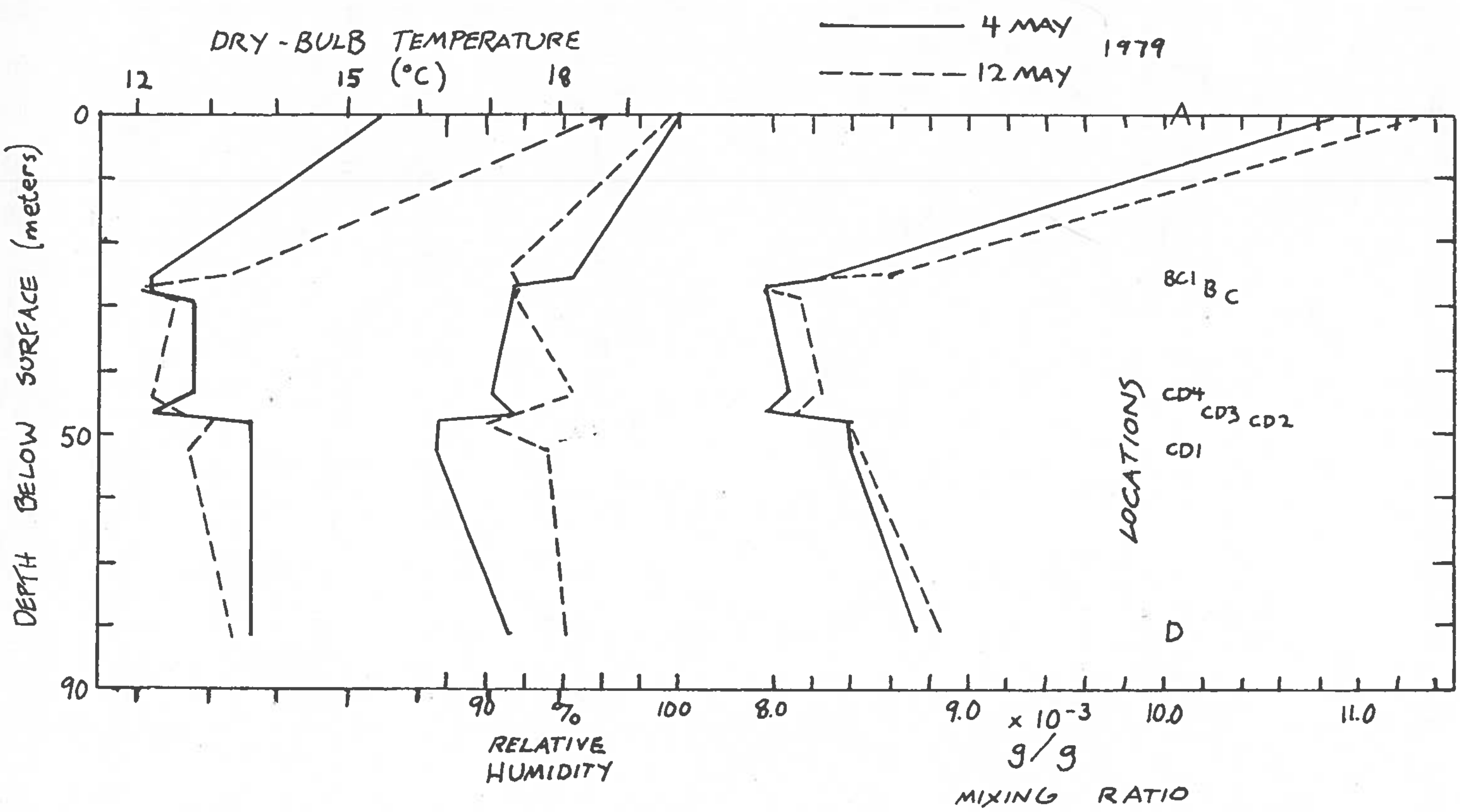


Table 2- Analysis of Variance

| Temperature | | | | Mean °C | F | df | Significance .05 | .01 | .001 |
|---|---|---|---|---|---|---|---|---|---|
| 1. ICooler | IIWarmer | 4 May | I | 12.4 | 41.35 | | * | * | * |
| B | CD2 | | II | 13.6 | | | | | |
| BC1 | CD1 | 12 May | I | 12.5 | 2.86 | | | | |
| C | D | | II | 13.1 | | | | | |
| CD4 | | combined | I | 12.5 | 19.36 | | * | * | * |
| CD3 | | | II | 13.3 | | | | | |
| 2. ICooler | IIWarmer | 4 May | I | 12.6 | 16.43 | | * | | |
| C | CD2 | | II | 13.6 | | | | | |
| CD4 | CD1 | 12 May | I | 12.4 | 14.29 | | * | | |
| CD3 | D | | II | 13.1 | | | | | |
| | | combined | I | 12.5 | 22.82 | | * | * | * |
| | | | II | 13.3 | | | | | |

| Humidity-Mixing Ratio | | | | Mean $g/g\ 10^{-3}$ | F | df | Significance .05 | .01 | .001 |
|---|---|---|---|---|---|---|---|---|---|
| 1. IDrier | IIMoister | 4 May | I | 8.09 | 11:14 | 1 & 5 | * | | |
| B | CD2 | | II | 8.51 | | | | | |
| BC1 | CD1 | 12 May | I | 8.21 | 3.95 | 1 & 6 | | | |
| C | D | | II | 8.55 | | | | | |
| CD4 | | combined | I | 8.16 | 13.07 | 1 & 13 | * | * | |
| CD3 | | | II | 8.53 | | | | | |
| 2. IDrier | IIMoister | 4 May | I | 8.08 | 6.87 | 1 & 3 | | | |
| C | CD2 | | II | 8.51 | | | | | |
| CD4 | CD1 | 12 May | I | 8.17 | 6.28 | 1 & 4 | | | |
| CD3 | D | | II | 8.55 | | | | | |
| | | combined | I | 8.13 | 15.66 | 1 & 9 | * | * | |
| | | | II | 8.53 | | | | | |

It is instructive to compare the humidity curves with that of temperature (figure 11), given the above analyses. The temperature curve, while demonstrating the suggested zoning, shows a fair amount of variation between measurement dates. The relative humidity curve shows even greater variation, with no easily discernible depth-related pattern. The mixing ratio curve, on the other hand, shows not only little variation between dates, but also a noteworthy pattern.

Indeed the pattern exhibited might explain the low degree of significance indicated above. After the humidity reaches a low point in the vicinity of B and C, it exhibits a gradual rise with depth, interrupted only by the low mark in the Tight Climb. The humidity climb through CD2-CD1-D tends to reduce homogeneity in that zone.

## CONCLUSIONS

The two theories suggested above as explanation for temperature profiles need consideration.

### Climatic Change

In order to establish a climatic change as cause for a temperature anomaly in a cave, there is need for three pieces of information: period of the cyclic change, magnitude of the change and magnitude of the anomaly. Since two of these are unknown, and the other (magnitude of the anomaly) subject to dubious assumptions (i.e. absence of any effect on air temperature other than bedrock temperature), this theory proves difficult to substantiate.

### Microclimate Causes

Local effects of air movement, humidity and surface conditions might be seen to cause a given temperature profile.

"Cold zones" and "warm zones" might be produced near entrances as a result of the processes reviewed above, from Wigley and Brown (1971). Important should be passage configuration and its effect on air movement and humidity. Thermal and mass gradients would of necessity differ dependent upon passage size, thus constrictions would be important.

The zones established in the temperature profile analyzed above are reflected in the mixing ratio profile. Yet mixing ratio is a convenient measure in that it is independent of temperature. The established zonation then has an effect on both elements taken separately. Thus there is support for a conclusion that these zones are microclimatically caused rather than an effect of climatic change. Humidity changes have never been established to flow through soil and bedrock analogous to temperature waves.

How then might these results be explained, in terms of microclimatic causes? The key might be in the passage constriction at the Tight Climb. This might provide the dividing point between zones in both cases. Perhaps a cold zone (zone 1) is produced by evaporation of wall moisture. In the Tight Climb, wall moisture is at its greatest in the cave. The nearly constant fresh air flow passes rapidly through here, with the result of wall moisture evaporation and continued cool conditions. Moisture is gained to the point that need for exchange is reduced. Air temperatures then approach the wall temperature (which should approximate the annual surface temperature), and humidity increases only slowly thereafter.

It is possible that BC1 represents a site more affected by surface conditions than at B. The greater values for temperature and humidity on the day with greater surface values (12 May) might support this. The closer proximity of this station to the surface would be reasoned to overcome its remoteness from such due to passage constrictions, relative to the open air situation for station B.

There certainly are other interpretations for the above results. However, for any concrete statements to be made, more measurements would be required. The cave needs to be studied at other times during the year and the results compared. Only then might the processes involved be accurately isolated.

Notes on Bats

While patterns of hibernation were observed during winter months, no measurements were taken at that time. During the measurement period, however, bats were fairly ubiquitous. Thus no conclusions could be suggested. As with the other aspects of the study, a year round study would be needed.

ACKNOWLEDGMENTS

Our appreciation is extended to the helpful individuals who assisted in the field work: Lawrence Camp, Don and Karen Hunter, and Dan Marshall. Needed information was supplied by various members of the Georgia Speleological Survey.

## BIBLIOGRAPHY


Barr, T.C. (1961). Caves of Tennessee. (Nashville: State of Tennessee).

Cropley, J.B. (1965). Influence of surface conditions on temperatures in large cave systems. N.S.S. Bulletin 27:1-10.

Hooper, J.H.D. (1976). Bats in caves. In T.D. Ford and C.H.D. Cullingford. The Science of Speleology (London: Academic Press): 453-494.

Moore, G.W., and G.N. Sullivan (1978). Speleology-The Study of Caves. (Teanack: Zephyrus Press).

Renault, P. (1961). Premiere etude meteorologique de la grotte de Moulis (Ariege). Annales de Speleologique 16: 39-45.

Rosenberg, N.J. (1974). Microclimate: The Biological Environment. (New York: John Wiley and Sons)

Went, F.W. (1970). Measuring cave air movements with condensation nuclei. N.S.S. Bulletin 32: 1-9.

Wigley, T.M.L. (1967). Non-steady flow through a porous medium and cave breathing. J. Geophysical Research: 72: 3199-3205.

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

—(1976). The physics of caves. In T.D. Ford and C.H.D. Cullingford. The Science of Speleology (London: Academic Press); 329-344.