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Measurement of the Effects of Food Preparation Activities on the Microclimate of the Snowball Dining Room Area of Mammoth Cave

Kelly Kaletsky

Measurement of the Effects of Food Preparation Activities on the Microclimate of the Snowball Dining Room Area of Mammoth Cave

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by

Kelly Kaletsky

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Measurements of the Effects of Food Preparation
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Snowball Dining Room Area of
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Director of Thesis

L. Michael Trapasso

Conrad T. Moore

Stuart A. Foster

Date Approved July 30, 1992

Elmer Gray

Dean of the Graduate College

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Kelly Kaletsky June 20, 1992

Directed by: Dr. L. Michael Trapasso, Dr. Stuart Foster, Dr. Eugenie Rovai, Conrad Moore

Department of Geography and Geology Western Kentucky University

The stability of Mammoth Cave's microclimate has never undergone extensive investigation. The Snowball Dining Room area was chosen to measure the microclimate of the cave and to determine if food preparation, human presence and surface temperature variations alter this microclimate. Three portable weather stations containing a temperature/humidity probe, datalogger and microbarograph were placed in various locations along three passageways leading away from the dining room. Readings were taken 24 hours per day for four months. Plotting temperature readings in graph form show a correlation between temperature of the passageway and distance from the dining room.

Chapter One

Introduction

For nearly 175 years, millions of visitors have toured Mammoth Cave National Park. For as many years, these guests have been told the interesting, but confusing details of the cave's microclimate. It has been said by many a cave guide that both temperature and humidity within Mammoth Cave remain at a constant level throughout the day as well as throughout the year. The possible variation due to natural and human factors represent different motivations for research.

Publications concerning the constant microclimate and airflow patterns of Mammoth Cave date back over a century. An old guide's manual from the late 1800s tells of the difference in summer and winter airflow patterns, which depend upon the surface air temperature (Guide Manual of Mammoth Cave, c.1875). These well-documented patterns will be presented in a later chapter. This early document states that the whole of Mammoth Cave (which contained fewer discovered passageways then than now) experienced a uniform, year-round temperature of 59 degrees fahrenheit (15 degrees celsius). However, the document failed to explain how this temperature was derived. Most texts concerning karst features and speleology state that caves have a constant temperature and humidity, but fail to go into detail. It is as if this information has been passed down from person to person and writers have accepted this information without question. For example, Palmer (1981) states that the temperature in Mammoth Cave is "cool, about 55 - 57 degrees fahrenheit (12.7 - 13.8 degrees celsius) year-round." In addition, the above-mentioned Guides' manual quotes 59 degrees fahrenheit (15 degrees celsius), but describes no fluctuation in this temperature. This publication also provides no documentation on how these data were derived.

Through the years, these original assumptions derived from writings concerning Mammoth Cave's microclimate have never undergone an in-depth investigation. Over time, the number of visitors to the cave has dramatically increased and many new miles of passageways have been opened to the public. With this increased tourism, physical changes have taken place within the cave. Tourist trails have been paved, restrooms built, stairways constructed, an elevator installed, and even an underground dining area constructed; the latter is the major focus of this research.

This research coincides with a revival of official National Park Service policy, both nationwide and at Mammoth Cave National Park, which is to "...conserve the scenery and the natural and historic objects and the wildlife therein..." (Albright, Dickenson and Mott, 1987, p.6). For example on the local level, the tradition of torch throwing as an alternative lighting method within the cave was abolished in Mammoth Cave as of January 1, 1991, in order to better protect the cave. It was determined that torch throwing has a detrimental effect upon the cave by releasing smoke and heavy metals into the cave atmosphere (Mihalic, 1990).

The variability of the microclimate of Mammoth Cave is investigated in this thesis. The study area is the Snowball Dining Room, 267 feet (81.3 meters) below the earth's surface. This site was chosen to examine the possible temperature and humidity changes due to unventilated cooking activities. The Snowball area was also chosen because it is insulated from outside meteorological phenomena, situated over one mile from the nearest entrance. Snowball received it's name because of the pure, white gypsum formations that covered the walls. At one time, the ceiling of this area was pure white. However, years of tours using smokey lanterns and lint from the clothes of visitors have resulted in a black coating on the walls of the cave in this area (Chaney, 1988). It is hypothesized that heat and steam produced by food preparation activities in this dining area also contribute to this problem as well as effect the cave's microclimate. A major objective of this paper is to monitor the temperature and humidity of the Snowball dining room area and adjacent areas to determine the influences which effect the microclimate in this section of the cave. Questions regarding the microclimate of Mammoth Cave, it's stability and the effects of increased human presence on this microclimate have not yet been addressed and provide the impetus for this research. It is hypothesized that unventilated food preparation activities in the Snowball Dining Room of Mammoth Cave National Park is affecting the delicate microclimate of the surrounding cave.

Problem Statement and Objective

It was decided in the summer of 1990 to study the microclimate of the Snowball Dining Room area of Mammoth Cave National Park. This area was chosen to determine if food preparation activities alter the presumed stable microclimate of this section of cave passageways. The dining room accommodates up to 500 visitors per day every day of the week during the summer and approximately 15 visitors per day during winter weekdays and 75-100 on winter weekends. Hot meals are prepared in the dining room on a daily basis without ventilation. The issue of food preparation (e.g. heat from steam tables) and the presence of visitors altering the stable climate of the cave, has brought about questions regarding the microclimate of this section of cave passageways. It is hypothesized that these food preparation activities alter the microclimate of this area of the cave.

Plan Of Development

This paper will be divided into chapters covering various aspects of the project. Chapter one will introduce why the investigation of Snowball Dining Room is taking place. This will include a historical sketch of the dining room area and a description of the study area. Chapter two is a literature review of pertinent materials. Articles relevant to the study will be introduced, both research performed at Mammoth Cave and other caves world-wide. Prior research cited in this chapter will be compared to the Snowball project for similarities and how previous research could benefit this project. Chapter three will explain methods used in data collection. Instruments used in data collection will be described and techniques of data extraction and manipulation will be defined. Any problems encountered in data collection will also be discussed. In chapter four, methods of data analysis will be introduced. This will include statistical methods performed on the data as well as charts and graphs generated as a result of analysis. The final chapter is an interpretation the results of data analysis in relation to the hypothesis of this research. Finally, recommendations for the preservation of the dining area microclimate will be made. These recommendations, if followed, will help protect the microclimate of the Snowball area and preserve the original beauty of this section of Mammoth Cave.

Chapter Two

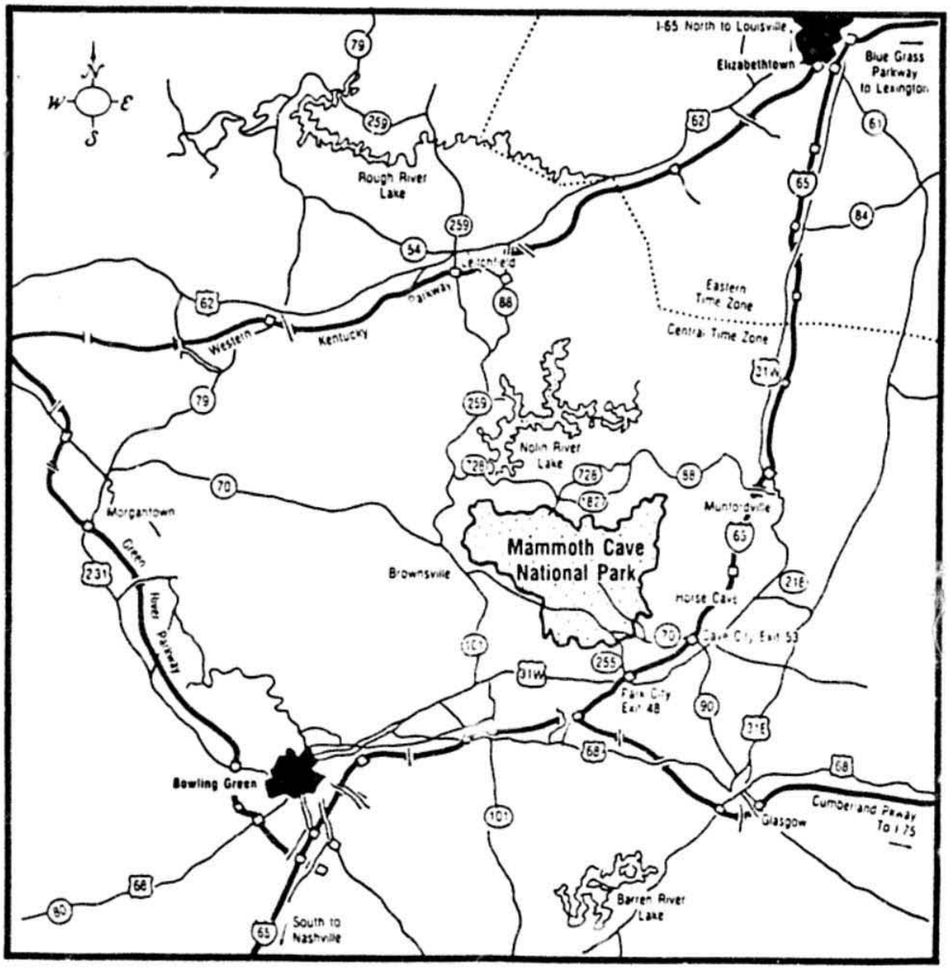
Study Area

Mammoth Cave National Park contains over 52,000 surface acres (210.4 square kilometers) and over 330 miles (528 kilometers) of mapped and surveyed cave passageways. The park is located in south-central Kentucky in Edmonson, Barren and Hart Counties, approximately 90 miles (144 kilometers) from both Nashville and Louisville via Interstate 65 (See Figure 1). Most major points within the park appear on the Mammoth Cave and Rhoda, 7 1\2 minute series, topographic quadrangles published by the United States Geological Survey.

Within the park, the Snowball Dining Room can be easily accessed by an elevator located approximately 2 miles (3.2 kilometers) from the Visitors Center. The dining room, almost directly under Highway 255, is located 268 feet (81.6 meters) below the surface. It can also be reached by walking approximately 1.5 kilometers down Cleaveland Avenue from the Cleaveland Entrance (White, 1989, p.311) (See Figure 2). The dining room is used by visitors on the Half-Day and Wild Cave tours, as well as the Cleaveland Avenue Tour for the disabled. Both the Wild Cave and Half Day

Figure 1

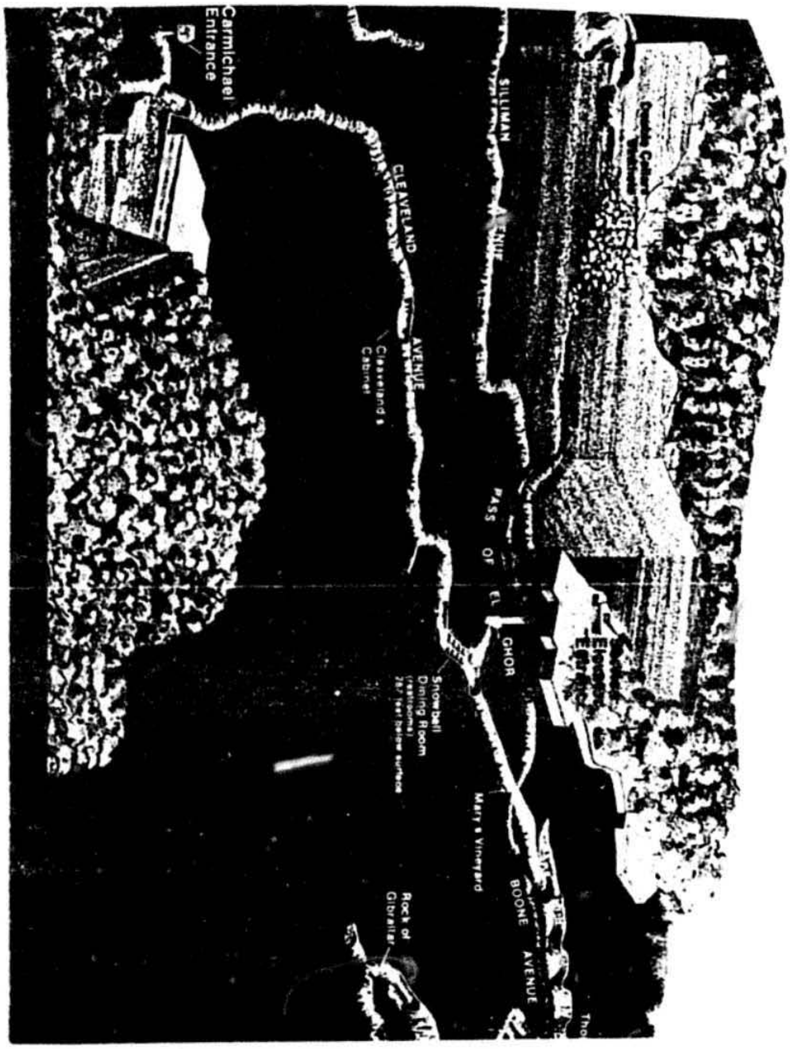
Mammoth Cave Area Map



Courtesy: National Park Service. U.S. Department of the Interior.

Figure 2

Snowball Dining Room Area



Courtesy: Richard Schlecht (1984). National Geographic Society.

tours reach Snowball area from Cleaveland and proceed down Boone Avenue. The tour for the disabled enters from the elevator located down Marion Avenue, pass through the dining room, proceed down Cleaveland Avenue and double back to the elevator (see Figure 1).

History

When compared to the historic section of Mammoth Cave, the Snowball area has been recently explored. The Snowball area was discovered in the early 1800s by Stephen Bishop. This area was named by the man who discovered it and has been described as looking "...exactly as if snowballs had been tossed up there and became frozen to the roof" (Thompson, 1909, p.31).

However, the Snowball area was not used as a dining facility until the turn of the century. The first visitors traveled through the Snowball area beginning in the 1840s and bypassed the Snowball area in order to eat at a location named Jenny Lind's Table. After 1900, Jenny Lind's Table was abandoned as a dining area and tours began to stop at the Snowball Room. This was due to the spaciousness of the Snowball area which provided more room for the increasing number of visitors (Handly, 1991). At this time, the Snowball area was officially designated as the Snowball Dining Room. Until 1931, the only way to reach the Snowball section was to travel several miles from the Historic

Entrance. In 1931 the Carmichael Entrance was blasted open and shortened the journey to the Snowball Room to less than one mile (1.6 kilometers).

It is interesting to note that Snowball area attracted the attention of the nation as well as the world when it was the site of the world's first subterranean radio broadcast on July 8, 1935 (The Times Journal, 1935).

In the early days of Snowball, meals were not prepared in the dining area. They were carried in packs on the backs of cave guides down 183 steps and over a mile from the Carmichael Entrance until an elevator was installed in 1957. After the installation of the elevator, better accessibility and improvements were made in the Snowball area. Restrooms, new lighting systems, concrete flooring and cooking facilities were installed for the convenience of the visitors (Park City Daily News, 1957).

Chapter Three

Literature Review

A number of articles were found that relate to this research. However, prior research indicates a lack of long-term, continuous data collection. Other studies have not utilized equipment capable of gathering digital data on a 24-hour basis with the ability to discern minute changes in temperature and humidity. Many articles concerning cave microclimates were found in speleological journals. The literature review will examine new storage methods adopted by business and industry to take advantage of the apparently constant temperature and humidity of caves. Articles of a general nature (i.e. general investigations) and the manner in which they apply to the Mammoth Cave study will be included. The chapter will also involve specific climatic research that has been conducted at Mammoth Cave National Park and in various caves world-wide.

Caves As Food Storage Facilities

The first section of this chapter concerns the use of caves as food storage facilities. Although these articles do not deal specifically with microclimate, they do attest to the fact that most people believe the majority of caves experience a stable, cool atmosphere that allows for the economical storage of foods and goods.

According to Cox (1981), Beatrice Foods Co. stores almost 10% of all the frozen foods consumed in the U.S. in a cave near Kansas City, Kansas. This revival in underground storage is a result of increased costs associated with refrigeration and warehouse storage. Cox also explains that underground storage allows surface lands to be used for urban purposes. Food from this one 18 million square foot facility is shipped daily to locations throughout the United States. The article also states that many other cities and countries throughout the world are using caves and underground structures for storage, business and entertainment.

With 55.4 degrees fahrenheit (13 degrees celsius) being the most desirable storage temperature for rice; Mitsuda, Kawai and Yamamoto (1972) conducted research into the storage of large quantities of rice in caves and underground facilities. Beginning in August 1969, a study was undertaken placing brown rice into storage at an abandoned mine. The rice was placed where the temperature was 48.2 - 52.7 degrees fahrenheit (9 - 11.5 degrees celsius) and the relative humidity was greater than 94%. The researchers found that the rice was well preserved while stored inside the cave. Research into the formulation of adequate protective packaging to guard against spoilage and ingestion by rodents was also included. In conclusion, they called for additional research to be carried out on a national basis in order to preserve rice and other cereals for future consumption.

Cave Studies of a General Nature

On file in Mammoth Cave National Park are two brief studies of the microclimate of the cave system, which appear to be of little scientific significance. From 1935 to 1937, temperature and humidity readings were taken in the historic section of the cave. The study is simply a list of temperature and humidity readings taken at various locations on various dates throughout the study period (Vertical File, 1937). No supporting information is included in the report such as the names of the researcher(s), what instruments were used, or the methodology utilized in the research. It should be noted that this study area is far removed from the Snowball dining area by several kilometers. Unlike the Snowball area, the Historic section of the cave is subject to fluctuations in temperature due to the large natural opening in the cave system. This opening allows air from the surface to enter the cave, thus altering the microclimate. The nearest cave entrance to the Snowball area is located approximately 1.6 kilometers away and remains sealed to prohibit the free exchange of surface air.

Supporting the theory that cave temperatures are constant is an article by Sloan (1985). In this research, he reported the temperature of Huautla Cave in Mexico as being a constant 70 degrees fahrenheit (21.1 degrees celsius). It is obvious that this temperature reading was either taken only a few times or with analog equipment, both of which would result in a lack of accuracy.

Lewis and Hale (1982) also conducted a temperature and humidity profile in the Historic section of Mammoth Cave. The validity of their findings are questionable because temperatures were only taken on two occasions. Using a Cole Parmer Psychro-dyne battery operated fan psychrometer the pair recorded varying temperatures ranging from 46 to 58 degrees fahrenheit (7.7 - 14.4 degrees celsius), depending on the distance from the Historic Entrance. However, since readings were only taken on two occasions, it is impossible to conclude that these are representative of the temperatures of this section of Mammoth Cave.

Ashton (1967) attempted to explain the heating and warmth of certain caves. In a vague article which lacked a clear experimental design, the climates of Swansea Cave and Worthy Park I Cave were investigated. This study was found to be lacking in several ways. The location of either of these caves is not known from the research presented. After a series of empirical formulas and mention of Newton's Law of Cooling, (Ashton, 1967) the researcher indicated that cave readings were taken by sling psychrometer, but no explanation regarding times, frequencies and locations of measurements were given. Several graphs accompanying the article indicate that there was an approximate 2.7 degree celsius variation of temperature within the cave, but the findings are questionable due to the lack of background information explaining the data collection process.

Despite the lack of documentation and description of his methods, Ashton presents an interesting theory. He feels that the rise of temperature within Swansea Cave was due to the large number of bats located along the ceiling. It was hypothesized that the cave was heated not only by the body heat of the bats, but also by the decomposition of guano. However, there were no other citations included in the research that would support this theory.

Wefer (1989) provided the only "how-to" article concerning an appropriate method of measuring the relative humidity inside caves. This article gave basic definitions of cave meteorology, temperature and humidity. He also explained how to calculate relative humidity of a cave using a psychrometer and established mathematical formulas. Wefer also discusses appropriate field recording and documentation in order to use the gathered information.

In Lawrence's (1972) article concerning the advances in speleo-meteorology, he questions why more research has not been conducted in this field. Lawrence noted that over the past years interest in cave climates has increased due to military and industrial interests, including mining. Lawrence suggests that information regarding past cave climates may be revealed by studying stalactite and stalagmite rings and cave ice. Lawrence, in his short article, discusses briefly a 1968 symposium, explaining the basic principles of cave circulation. He also describes dynamic caves, like Mammoth Cave, as a cave with one or more openings which experience convection currents that equalize temperatures. Though no new theories are presented in this article, Lawrence does mention an interesting avenue of research regarding the investigation of past cave climates.

Denbo (1979) also called for more research into cave climates. In his article, Denbo discussed the characteristics of temperature, humidity and air circulation within cave systems, but added that more research is needed in order for information to be compared with theories.

Research Involving Specific Cave Climates

A common theme among the following research projects is that they have been undertaken within small caves with several openings which are subject to strong air drafts which pull in outside air. Researchers agree, as presented in this review, that cave microclimates are variable within a short distance from the cave entrance as a result of these air currents. Therefore, the results of this previous cave microclimate research may not be indicative of Mammoth Cave's microclimate because of the vast size and numerous openings to the surface contained in the Mammoth Cave system may result in a more insulating effect upon cave temperatures.

Although research has taken place world-wide, West Virginia was a common site for many research projects included in this chapter. Atkinson, Smart and Wigley (1983), as part of their research into cave radon levels, performed a limited investigation into the microclimate of Castlegard Cave in the Columbia Icefields of Alberta. In 1979 and 1980, the researchers obtained temperature readings as far as 4200 and 8100 meters from the cave's entrance. Readings were taken with sling-mounted mercury thermometers with wet and dry bulbs and no digital or automatic readings were taken. It is interesting to note that the researchers also measured the temperature of the surrounding rock by inserting a thermometer between cracks in the rocks. This method of measuring cave temperatures is original, being found in no other research. The authors conclude that the warming and cooling of air inside the cave is due to the warming and cooling of the surrounding rock walls.

As in other research, the findings support the theory that near the entrance of the cave temperatures vary greatly, and stabilize further down the passageways. Central sections of the cave appear to have a very stable temperature (Atkinson, Smart and Wigley, 1983, p.495). The cave has a central core which is warm and it is hypothesized, but not proven, that this is due to a geothermal heat flow (Atkinson, Smart and Wigley, 1983, p.501).

Davies (1960), in his meteorological study of Martens Cave in West Virginia, states that temperature in the study cave vary with location. The study took place during an discontinuous 11-year period therefore limiting the accuracy and credibility of his study. Lack of time and finances did not allow continuous data collection and resulted in discontinuous daily readings. Furthermore, the reliability of the findings were questionable because the self-recording instruments used were not properly rewound. Appropriate charts were not changed and errors in recording collected data also contributed to the problem (Davies, 1960, p.92). Davies discovered that there was a wide variation in temperature just inside of each of Martens two natural entrances, but further into the cave and in smaller passageways, temperatures stabilize. He further explained that the main passageways were heated and cooled by outside winds passing through the small cave and that the temperature was also controlled by several streams flowing throughout the cave.

Due to its vastness in size, it would be difficult to apply these principles to Mammoth Cave. Like Martens Cave, Mammoth Cave's temperature is variable in close vicinity of its natural openings, but the vast expanse of cave passageways away from entrances tend to be insulated by the surrounding limestone. In addition, the variation of temperature due to streams inside Mammoth Cave would not likely effect the entire cave system as it does in Martens Cave. Although there are several rivers flowing through Mammoth Cave, they are located in the lowest level, approximately 360 feet (109.7 meters) below the surface. It is probable that these rivers do influence the climate of the cave in the surrounding areas; however, their influence would most likely be minimal in relation to other areas of the cave due to the small area of the waterways.

Ives (1964) described an approximate one month delay between the time significant changes in surface temperatures occur and the resulting change in cave temperature. Ives plotted annual temperature and humidity changes in Delaps Cave, Tennessee. The main focus of this study, however, was the migration of certain insects within the cave system. Therefore, the main interest of this research was biological, not meteorological.

Nicholas and Moore (1964) also conducted research which theorized the time delay between surface temperature changes and the resulting change within the cave. This research was conducted in Cathedral Cave in Kentucky at a depth of 10 meters. Contradictory to the previous study, Nicholas and

Moore stated that there was a three month delay between surface temperature changes and the change of temperature within the cave. The researchers confirmed this delay because the temperature changes within this section of the cave were out of phase with the seasonal surface temperature.

Several studies were carried out in caves that receive a high number of visitors. The climate of the Sterkfontein cave in South Africa is one of those studies (Niven and Hood, 1978). As in most studies, the researchers explain that temperature around the cave entrance zone experiences the greatest variations in climate and these variations become more subtle as one proceeds into the cave.

The study in this tourist cave was not as extensive as this present research project and involved a cave much smaller in size than Mammoth Cave. According to the researchers, the cave measured 250 meters from east to west and 130 meters from north to south. The study took place between May 1974 and September 1975 in which recordings were taken only on five different occasions at twelve sites. Readings were taken for one-half hour every two hours over a 24-hour period. The researchers did not indicate the season of the year the readings were taken or if the instruments used were analog or digital.

Bamberg (1973) presented a seven-month study of the climate of Lehman Caves in Nevada. In this study, Bamberg described measurements of carbon dioxide present in cave air in addition to periodic temperature readings and descriptions of air circulation. Unlike the Mammoth Cave study, Bamberg conducted his research during the summer months.

Niven and Hood (1978) also discovered that there was a variation in the Sterkfontein cave climate near the natural entrances of the cave, but found "negligible temporal variations in the deep cave areas." The authors also admitted that the variations throughout the majority of the tourist cave were due to the number of entrances. It is likely that the small size of a cave in relation to the number of openings would also play a major role in the stability of the cave's microclimate, a point Niven and Hood failed to mention.

Another study involving a tourist cave was undertaken during 1979-1980 in Glowworm Cave, New Zealand (De Freitas, et al., 1982). Due to heavy visitor use and delicate fauna which live within, the researchers elected to investigate the microclimate of this cave. Like Mammoth Cave, tourism began in Glowworm in the 1800s and the cave is managed by a government organization, thus it is subject to certain governmental standards. The Glowworm study however, describes the rate and direction of air circulation within the cave. The researchers theorize higher winds that enter the cave from the surface and increased circulation offsets the equilibrium of the cave microclimate.

Like the other studies, the Glowworm Cave is small (1300 meters of passageways) therefore the circulation of outside air within the cave will play a larger role in the results of the research. The researchers chose 23 sites within the cave and measured the temperature twice weekly. The results showed a temperature variation within the cave, especially in the winter when cold air is drawn into the cave (De Freitas, et al. 1982, p.386). The smallest temperature variations within the cave are in small, isolated passageways located furthest away from the entrances.

The Baker Creek cave system was the topic of research performed by Bridgemon (1965). Although his studies concentrated on Pictograph Cave, Bridgemon's meteorological observations included ten different caves in the Baker Creek cave system. The results from the research on Pictograph Cave are difficult to compare with the Mammoth Cave study because Pictograph is a shallow, small cave system and cannot compare in size or depth with Mammoth Cave. Like Mammoth, however, Bridgemon did describe a temperature gradient that was related to distance from the cave entrance.

Aley (1989) discussed the effects of commercial cave development in relation to temperature, humidity and air flow readings within a cave. This article addresses problems similar to those being experienced in the Mammoth Cave system. In conclusion, Aley also provides several rules which help prevent the deteriorating effects of commercial development of a tourist cave.

Research Directly Addressing the Consistency of Cave Climates

Research which directly addresses when cave temperatures are consistent was undertaken in Cropley (1965). His findings indicate that cave temperatures are not nearly as stable as people are led to believe and that cave climates can be effected by outside weather conditions for thousands of feet inside a cave system. The study took place between February and November 1963, in two large cave systems located in Greenbrier County, West Virginia. The data collection consisted of 86 temperature recordings at distances varying from 0 to 6000 feet (0 to 1528.8 meters) from the cave entrances.

Cropley found that one had to travel over 5000 feet (1524 meters) before a state of temperature equilibrium was reached. He expressed surprise, as he hypothesized that the distance where outside influences could effect the cave would be much less. He also discovered that temperature changes on the surface effect the temperature within a block of limestone after a considerable time lag. He calculated this time lag between a maximum temperature on the surface and a maximum temperature within the limestone as seven days for every foot (.30 meter) of distance traveled into the rock. According to Cropley, this was due to the dense limestone which insulates well and is resistant to temperature extremes.

The cave was also divided into three zones, depending on the distance from the opening. Zone 1, closest to the opening, showed the widest variation in temperature; Zone 2, smaller variations than in the previous zone; and Zone 3, in which very little or no temperature variations occurred due to the insulation properties of the limestone. Cropley explained that cave air temperatures could be estimated by determining the surface air temperature and factoring in these temperatures to the characteristics of the established zones within the cave. Cropley concluded that the change of temperature inside a cave from the surface temperature to a constant temperature was not as abrupt as once thought. A gradual change can occur up to thousands of meters inside the cave. He also suggested that these gradual alterations might indicate changes for various forms of cave life.

Human influence in cave microsystems was the topic of research performed by Stark (1969). The study, conducted at Lehman Cave in eastern Nevada, studied the effect of lights upon plant and animal life inside the cave. Stark reported that although the cave environment was quite stable, the use of lights could result in extremes of temperature, humidity, air movement and thus change the drying effects of air.

According to this research, the strength and positioning of lights inside Lehman Cave strongly influenced what lives inside the cave. He continued that the strongest change took place around a light that was boxed in on four sides. The resulting change of temperature 0.1 meter from the light after 10 minutes was 11.3 degrees celsius, accompanied by a 89.9% loss of surface moisture in four hours. The extremes in temperature and humidity prevented any growth in this area. He added that less extreme changes occurred on lights which are boxed on three sides. The resulting temperature change after the light had been on ten minutes was 8.2 degrees celsius. This research is significant because the concentrated heat from boxed lights can build and the combined effects from several lights placed in close vicinity could alter the microclimate for a small section of cave passageway.

Research by Nepstad and Pisarowicz (1989) analyzed temperature and humidity variations at Wind Cave National Park in Hot Springs, South Dakota. This work was another that openly challenged the theory that caves are subject to characteristically constant temperature and humidity. The study took place between November 1984 and March 1988. During this time, temperature and humidity readings were recorded on the surface and along the tour routes inside the cave. One drawback of this research was that the readings were not continuous, they were taken with a sling psychrometer as the researchers walked through the cave on 109 different days through the study period. The findings of the study showed that there were varying temperatures within Wind Cave depending on the location. Mean temperatures within the cave ranged from 48.4 to 52.2 degrees fahrenheit (9.14 degrees to 11.27 degrees celsius). Humidity also varied, ranging from 86.61 percent to 94.07 percent.

The results of this research should not be compared too closely to the Mammoth Cave project since winds inside Wind Cave can be extreme. Unlike Mammoth Cave, wind speeds in excess of 120 kilometers per hour have been recorded at the cave's entrance. These strong winds, in addition to several artificial openings, including elevator shafts, in an area smaller than Mammoth Cave can further increase the air flow within the cave system, thus pulling in cold winter air from the surface and altering the climate of the cave.

The Wind Cave study also examined the effects of changing cave climate on the park's cave fauna. The researchers expressed concern over the building of unnatural entrances which alter the wind flow, thus altering the temperature and humidity within the cave system. Unfortunately, like Mammoth Cave, there have been no data collected in the past to serve as a comparison.

Mammoth Cave Studies

Aley (1988) attempted to determine the cause of the black coating forming along the cave walls and ceilings in the Snowball Dining Room. Since this was the emphasis of the study, the microclimate of the area was not subject to extensive analysis. He also suggested a means of eliminating this coating by the application of chemicals to the cave walls. Aley writes that in the summer (as in winter) there are daily increases in temperature and humidity in the dining room. He did not describe how his meteorological data were gathered or analyzed. Nor did he mention what instruments were used or the time frame involved in his research. He described the increase as beginning at approximately 10 a.m., reaching a peak at 4 p.m., then decreasing until approximately 7:30 p.m. According to Aley, daily increases in temperature ranged from 0.9 to 1.5 degrees fahrenheit (.3 to .8 degrees celsius). Relative humidity also underwent a daily cycle, rising throughout the morning and early afternoon, then subsiding. Aley hypothesized that this heating was caused by electric lights, cooking, and human presence within the cave.

The research also described the analysis of the black coating removed from the dining area. Analysis determined that the black material was a combination of fungus and algae. Although food preparation activities were not found to be directly responsible for the discoloration, Aley warned that this does not eliminate the possibility that food preparation plays an important part in the spread of the material. He explained that compounds released by food preparation most likely provide a growth medium for the material. He called for the elimination of heating and cooking materials within the cave, suggesting that food be heated at the surface. The recommendations, however, are made to eliminate the reoccurrence of the coating once it is removed, not to reestablish the cave's original microclimate.

In an article which dealt with mainly the biology present within the New Discovery section of Mammoth Cave, Dearolf (1942) briefly described the temperature of this section of the cave as being 56 degrees fahrenheit (13.3 degrees celsius) and a humidity reading of 100 percent. This readings are questionable because of the brief mention of these readings. Although the New Discovery section is not open to the public, there are doors that link this section with the surface, therefore providing a pathway for surface air to seep into the cave system and influence both temperature and humidity readings.

Summary

Cave circulation and microclimate are dependent on many variables including size, natural and blasted openings, elevation of the openings and the presence of water running within the cave system. Because these variables differ widely from cave to cave, it would be difficult to draw conclusions from one study and apply them to another, therefore the microclimate of caves should be investigated separately.

The main dissimilarities between the research discussed and the Mammoth Cave project are the amount of time involved in the data collection process and the size of the study caves. The study undertaken at Mammoth Cave involves a continuous 24-hour-per-day monitoring of the cave microclimate for a five month period. Other investigations have included far fewer days of data collection using equipment not as accurate as equipment used in this study.

Windflow patterns described in smaller caves result in conclusions that would differ from the Mammoth Cave study. The strong windflow inside smaller caves would result in a more severe change in the microclimate. The larger size of Mammoth Cave would make it much more difficult for climate changing factors from the surface to penetrate to all sections of the cave; therefore, there are sections of

Mammoth Cave that would experience a more stable microclimate than smaller caves.

Chapter Four

Experimental Design

This chapter will detail the methods used in the data collection process. An appropriate design of the collection method is vital to obtaining valid and useful data. The data collection process of this study was designed to monitor the microclimate of all three passageways leading away from Snowball Dining Room and to determine the rate of change of temperature in relation to distance from the dining room. This was accomplished by placing three portable weather stations at various locations throughout each passageway.

There is a large variability between the number of visitors who pass through the Snowball Dining Room during the week and during the weekend. Under ideal conditions, the cave microclimate would be monitored simultaneously at numerous locations within each passageway. In practice only three monitors, one for each passageway, were available. Therefore, external conditions did not remain constant while readings were taken at differing distances, locations and times, raising the possibility that the effects of distance might be confounded with possible meteorological and climatological influences.

It was decided that distances down passageways each station was placed would be determined by a spatially stratified, random sampling technique. The passageways were broken into 50-foot (15.2 meter) sections. Then a section was randomly selected and a position within that section was randomly selected. A 450-foot (137.1 meter) limit was chosen for each passageway because of the presence of both an elevator shaft and junctions in differing passageways. The proximity of both of these structures could alter the airflow patterns in the immediate area, thus not allowing the heat plume to travel to these instruments.

A reference point for measurement was established for each passageway. For Carmichael Passageway, distance was measured from the light switch at the beginning of the passageway. For Marion and Boone, measurement was started at a water fountain located at the entrance to both passageways.

Instrumentation

After randomly-selected distances were measured, equipment was placed in each passageway. Each station consisted of a datalogger, temperature and humidity probe and a microbarograph.

The temperature and relative humidity probe was Model 207, manufactured by Campbell Scientific, Inc. The probe contained a Phys-Chemical Research Corporation PCRC-11 RH sensor and a Fenwal Electronics UUT51J1 thermistor. The accuracy of the temperature probe under a worse case example is +-0.4 degrees celsius. The accuracy of the relative humidity sensor is +-5%. Both sensors were capable of recording changes down to one-hundredth of a degree or one-hundredth of one percent.

The probe was connected to a 21X Micrologger manufactured by Campbell Scientific, Inc. The datalogger was used to convert the sensor signal into a digital value, to process the measurements over a given time period and to store the data until retrieved. The battery-operated computer can be programmed to obtain sensor readings over a variety of time periods.

A microbarograph was also at each station. The microbarograph chosen for this study was a Model B211 manufactured by Weather Measure Corporation. The spring-wound, analog instrument accommodated a seven-day stripchart and was changed weekly.

The final piece of equipment used inside the cave was a wind direction indicator. The indicator was manufactured by Campbell Scientific, Inc. This stationary instrument was located in the entrance of the Snowball Dining Room for the duration of the data collection period. This instrument remained stationary because of the difficulty in reorienting to a correct compass reading after each movement.

Data was extracted from the datalogger through the use of an RC-35 cassette tape recorder. The datalogger and tape recorder contained jacks which allowed a patch cord to be connected, thus extracting data from the datalogger and placing it on tape.

The wind direction indicator and the temperature and humidity probes were connected to the datalogger. Before installation in the cave, it was decided that the dataloggers be programmed to take readings at two minute intervals. When it became evident that the intervals were too closely spaced, the datalogger was reprogrammed to record an hourly reading, unless a significant change of temperature or wind direction occurred. It this case, the change was recorded at the exact time at which it occurred.

The locations of stations were moved once during the week and once during the weekend. The days of movement varied, but usually fell on Thursdays and Saturdays. The instruments were placed in each passageway beginning 09 November 1990 and allowed to sit for several days in order to become adjusted to the cave environment. The first readings began on 11 November 1990. Tours were conducted every day the instrumentation was in place, with the exception of Christmas Day, the only day of the year in which the park is closed. This one day of inactivity allowed control data to be collected.

The Mammoth Cave system is subject to air flow patterns that change from winter to summer. Whenever the surface temperature rises above or falls below 54 degrees fahrenheit (12.2 degrees celsius), the circulation inside the cave changes direction. The catalyst for cave circulation is dependent upon the number of entrances in the cave system.

Circulation within the Mammoth Cave system is influenced by the fact that there are several entrances to the cave at varying elevations. In wintertime, cold, dense air flows downward, flowing in the lower entrance and out the upper entrances. In the summer, this process is reversed with warm air flowing upward, out the lower entrances and in the upper entrances (Hanna, 1977).

Due to the fact that a change in circulation could alter the validity of the readings, it was decided that readings would be taken during the period of winter circulation throughout the cave and would cease when summertime air circulation resumed during the first weeks of March.

Data Extraction

Data were extracted from the data loggers twice weekly. After arriving at the station, time on site was noted in the event that human contact caused an increase in temperature. Voltage readings were then taken to assure that the dataloggers retained enough power to record readings and to transfer data onto the tape recorder. Patch cords were then connected to both the datalogger and the tape recorder. The datalogger was then programmed to dump the data onto the cassette tape. Afterwards, the station was moved to the next location designated on the randomization chart. Before leaving the site, the time the station was abandoned was noted. After being brought to the surface, the data on the cassette tape were transferred onto computer disks. Data were then transformed onto a LOTUS 123 program where the information was compacted.

Problems In Data Extraction

Several minor problems were encountered in the data collection process, especially in the beginning weeks of collecting data. In the initial weeks, the datalogger was programmed to take readings every two minutes. The datalogger is capable of holding a limited amount of data; therefore the frequency of the readings caused the datalogger to record over itself before the data could be extracted. As a result, the datalogger automatically erased several days' worth of data. This massive amount of data also proved to be too much data for the LOTUS 123 program to accommodate; therefore the datalogger was reprogrammed to take readings on the hour, unless a significant change occurred within the hour.

In addition, poor quality cassettes were used for data extraction at the beginning of the data collection period. The poor quality of these cassettes resulted in garbled data that the computer was unable to read. This resulted in the loss of data. Switching to higher quality cassettes solved the problem. The total amount of data lost due to the overrun of the datalogger and the cassette tapes was approximately seven days.

The final difficulty in data collection involved the malfunction of the temperature probe located in Boone Avenue. The probes are very sensitive and will malfunction if in direct contact with skin. It is believed that a visitor on the half day tour touched the probe, causing the probe to permanently display temperatures above normal. Fortunately, these erroneous readings were discovered shortly after the incident. The datalogger was programmed to read the temperature inside the datalogger and the sensor and interior temperatures were compared. It was discovered that the sensor was reading temperatures approximately 8.0 degrees celsius higher than the actual cave temperature (determined by the temperature inside the datalogger). Therefore, the temperature error could be subtracted from the sensor reading to obtain an accurate reading. The humidity sensor was not effected and continued to record accurate values. It should be noted that the temperature probe in Boone was not repaired because the instrument would have to be shipped to the originating factory. It was anticipated that this process would have taken approximately six weeks and the project would have to be restarted at a later date. Since the correction factor was accurately formulated, the instrument was left in service.

Chapter Five

Data Analysis

Graphical Analysis

Graphical analyses of selected temperature and humidity readings for a 24-hour period served as a preliminary evaluation of the data collected.

Figure 3 represents temperature readings taken in Marion Avenue on November 15, shortly after data collection began. The collector probe was placed in the vicinity of the elevator shaft. Although small, this graph shows that there is definitely a temperature variation within the Snowball Dining Room area. It is assumed that the strong temperature spike that occurs at approximately 1500 hours is a result of the cooking and heating activities of the dining room. Although the increase takes place several hours after the dining room is used, it should be noted that the temperature probe was located several hundred feet from the heat source and the time delay could be a result of the time it takes the warmed air to travel down the corridor.

Figure 4 is a graphical representation of the temperature readings taken in Marion Avenue on Christmas Day, a day in which there is no cooking activity. The analysis resulted in a constant, flat temperature graph.

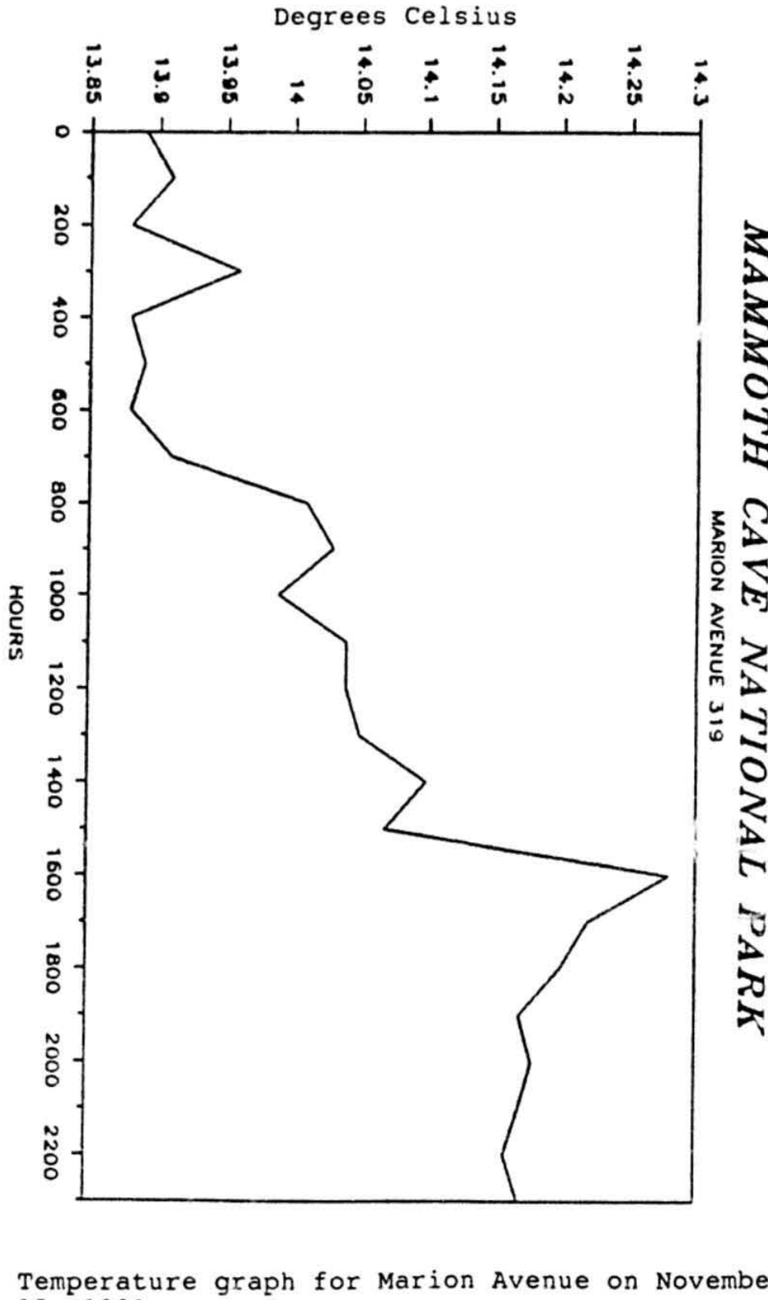


Figure 3. Temperature graph for Marion Avenue on November 15, 1991.

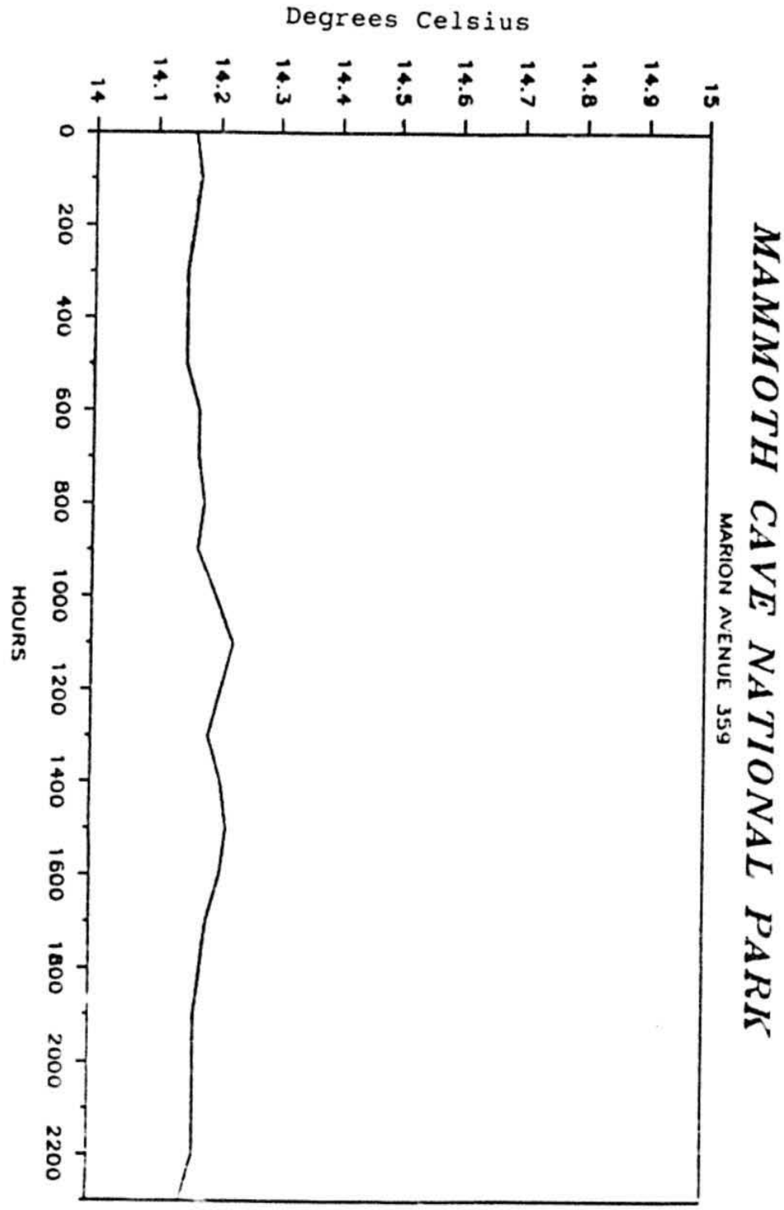


Figure 4. Temperature graph for Marion Avenue on December 25, 1991.

This lends further proof that cooking activities alter the microclimate of the Snowball area.

The two Carmichael graphs, located upwind of Snowball Dining Room, represent more gradual temperature changes, due to the general heating and cooling trends as a result of changes of temperature on the surface.

Figure 5 represents the temperature profile of Charmichael passageway on Christmas Day. Although there is a constant change in temperature, there is no temperature spike, which is representative of cooking and visitor activity.

Figure 6 is the temperature pattern of Carmichael on December 29. Two separate variations are evident. There is a general warming trend during the 24-hour period and a pronounced spike at approximately 1000 and 1300 hours, the time visitors travel through the passageway. During wintertime air flow conditions, heat and humidity produced by cooking activities would not travel upwind towards Carmichael. However, the data collection equipment is easily noticed and is often used as an interpretative stop along the tour route. The sensitivity of the equipment was able to read the temperature change due to a large group standing nearby and was represented on the graph.

Statistical Analysis

Correlation and regression analyses were used to

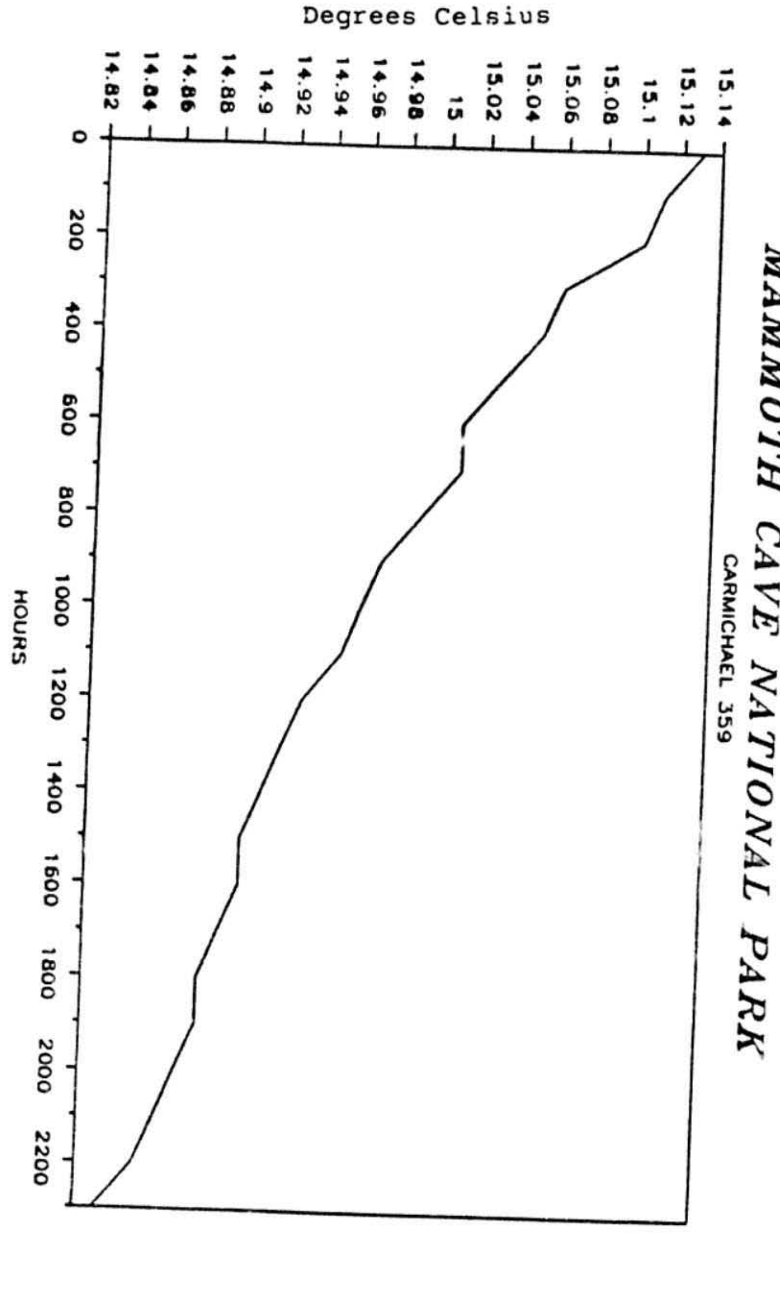


Figure 5. Temperature graph for Carmichael Passageway on December 25, 1991.

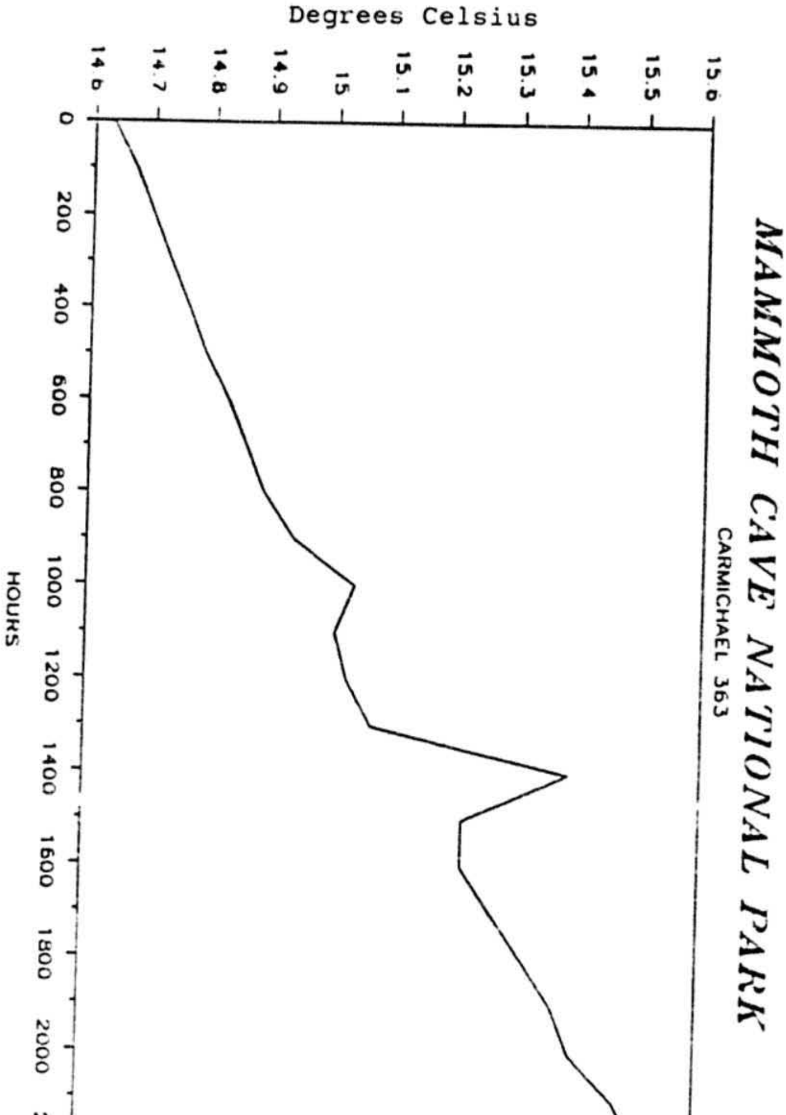


Figure 6. Temperature graph for Carmichael Passageway on December 29, 1991.

determine if there was a systematic relationship between the distance from Snowball Dining Room and the meteorological variables of temperature and relative humidity and to objectively report the nature of that relationship.

Separate analyses were performed for each passageway and for readings taken at different hours of the day. For example, a 1200 Carmichael Passageway scatterplot and correlation would consist of all the readings taken in Carmichael Passageway at the 1200 hour.

The analyses were carried out as follows. Scatterplots were generated for visual examination of the relationships of distance with the variables of temperature and humidity. Each scatterplot was accompanied by a corresponding correlation coefficient and regression equation. The correlation and regression analyses provided an objective representation of the data, while the scatterplot provided visual information regarding the general behavior of the relationship.

Chapter 6

Results

One hundred forty-four scatterplots were generated, each broken down by hour and passageway. In addition, correlation coefficients and regression equations were generated by using an SPSS/PC program. As it would be difficult to manually analyze this number of scatterplots, 15 scatterplots were selected for a detailed visual analysis. It would not be necessary to examine each hourly scatterplot because one would not expect to find significant change between each hour during certain times.

The correlation coefficients for temperature and humidity with distance were recorded in chart form for each passageway and hour, resulting in 24 sets of data for each corridor (see Figure 7). In addition, regression charts were generated including the regression constant, slope and R-squared (see Figure 8 A-F).

After charting the coefficients (see Figure 9 A-B), several scatterplots were chosen on the basis of the strength or weakness of the correlation. Several weak, moderate and strong correlations were chosen from each passageway.

Figure 7
Chart of Correlation Coefficients

	Carmichael		Boone		Marion	
	Humidity	Temp.	Humidity	Temp.	Humidity	Temp.
0100	.23	.34**	.19	.43	-.71	.75
0200	-.26	-.31	.22	.47	-.72	.74
0300	-.25	-.32	.22	.47	** -.70	.69
0400	-.24	-.29	.26	.44	-.72	.70
0500	-.24	-.34	.25	.42	-.72	.70
0600	** -.24	-.35	**.26	.41	** -.72	.71
0700	-.25	-.31	.25	.42	-.71	.70
0800	-.26	-.36	.20	.41	-.71	.71
0900	-.31	-.35	.16	.42	-.69	.70
1000	-.31	-.35	.18	.39	-.69	.71
1100	-.31	-.35	.15	.40	-.70	.72
1200	** -.29	-.25	**.05	.44	** -.68	.69
1300	-.31	-.33	**.05	.51	-.72	.69
1400	-.32	-.33	** -.32	-.33	** -.68	.74
1500	-.30	-.31	.12	.48	-.70	.69
1600	-.30	-.35	.14	.51	-.70	.72
1700	** -.32	-.38	.17	.51	-.71	.71
1800	-.32	-.33	**.17	.53	-.72	.72
1900	-.32	-.35	.18	.50	-.73	.71
2000	-.32	-.34	.19	.50	-.73	.71
2100	** -.34	-.32	.18	.48	** -.73	.71
2200	-.32	-.34	.23	.41	-.72	.70
2300	-.32	-.32	.20 -	.39	-.71	.71
2400	-.24	-.31	.20 -	.45	-.71	.71

** Indicates correlations used for visual analysis

Figure 8 - A
Regression Chart for Temperature - Carmichael

	Constant	Slope	R Squared
0100	15.19 (.2063)#	-.00153 (.0007)*	.05468
0200	15.26 (.2033)	-.00174 (.0007)*	.06939
0300	15.24 (.2047)	-.00169 (.0007)*	.06521
0400	15.24 (.2072)	-.00164 (.0007)*	.05972
0500	15.24 (.2082)	-.00166 (.0007)*	.06061
0600	15.23 (.2056)	-.00163 (.0007)*	.05872
0700	15.20 (.2044)	-.00165 (.0007)*	.06269
0800	15.22 (.2003)	-.00171 (.0007)*	.06807
0900	15.38 (.1991)	-.00218 (.0007)**	.10014
1000	15.36 (.1989)	-.00215 (.0007)**	.09976
1100	15.38 (.1972)	-.00214 (.0007)**	.09613
1200	15.34 (.2016)	-.00210 (.0007)**	.08926
1300	15.38 (.2006)	-.00218 (.0007)**	.09939
1400	15.43 (.2022)	-.00224 (.0007)**	.10316
1500	15.34 (.1974)	-.00205 (.0007)**	.09212
1600	15.39 (.2014)	-.00211 (.0007)**	.09070
1700	15.43 (.2008)	-.00224 (.0007)**	.10375
1800	15.43 (.1994)	-.00224 (.0007)**	.10483
1900	15.43 (.1992)	-.00226 (.0007)**	.10681
2000	15.41 (.2010)	-.00223 (.0007)**	.10422
2100	15.44 (.1966)	-.00238 (.0007)**	.10279
2200	15.37 (.1971)	-.00216 (.0007)**	.10469
2300	15.37 (.1959)	-.00217 (.0006)**	.10618
2400	15.22 (.2069)	-.00163 (.0007)*	.05904

Numbers in parentheses indicate the standard errors for values.

*Indicates significance at the level of .05

**Indicates significance at the level of .01

Figure 8 - B
Regression Chart for Humidity - Carmichael Passageway

	Constant	Slope	R Squared
0100	93.29 (.0625)#	-.00071 (.0002)**	.11831
0200	93.26 (.0607)	-.00062 (.0002)**	.09747
0300	93.26 (.0611)	-.00065 (.0002)**	.10341
0400	93.25 (.0599)	-.00058 (.0002)**	.08627
0500	93.26 (.0576)	-.00067 (.0002)**	.11998
0600	93.29 (.0614)	-.00074 (.0002)**	.12533
0700	93.26 (.0622)	-.00065 (.0002)**	.09994
0800	93.29 (.0604)	-.00076 (.0002)**	.13669
0900	93.29 (.0603)	-.00074 (.0002)**	.12357
1000	93.28 (.0598)	-.00074 (.0002)**	.12767
1100	93.29 (.0607)	-.00077 (.0002)**	.12625
1200	93.28 (.0804)	-.00071 (.0002)*	.06598
1300	93.31 (.0646)	-.00076 (.0002)**	.11317
1400	93.30 (.0637)	-.00075 (.0002)**	.11519
1500	93.30 (.0633)	-.00068 (.0002)**	.09743
1600	93.32 (.0593)	-.00075 (.0002)**	.12731
1700	93.32 (.0571)	-.00077 (.0002)**	.14465
1800	93.30 (.0586)	-.00068 (.0002)**	.10937
1900	93.29 (.0567)	-.00070 (.0002)**	.12340
2000	93.28 (.0564)	-.00067 (.0002)**	.11812
2100	93.27 (.0569)	-.00064 (.0002)**	.10624
2200	93.29 (.0599)	-.00070 (.0002)**	.11767
2300	93.27 (.0598)	-.00067 (.0002)**	.10811
2400	93.27 (.0618)	-.00065 (.0002)**	.09962

Numbers in parentheses indicate the standard error for values.

* Indicates significance at the level of .05

** Indicates significance at the level of .01

Table 8 - C
Regression Chart for Temperature - Boone Avenue

	Constant	Slope	R Squared
0100	19.18 (.5039)#	.00366 (.0020)	.03924
0200	18.99 (.5053)	.00425 (.0020)*	.05108
0300	18.98 (.5090)	.00430 (.0020)*	.05250
0400	18.77 (.5152)	.00510 (.0021)**	.06877
0500	18.76 (.5200)	.00508 (.0021)*	.06662
0600	18.76 (.5138)	.00512 (.0021)**	.06809
0700	18.75 (.5135)	.00501 (.0021)*	.06586
0800	18.87 (.5337)	.00403 (.0021)	.04094
0900	18.93 (.5432)	.00339 (.0022)	.02748
1000	18.79 (.5487)	.00380 (.0022)	.03459
1100	18.98 (.5415)	.00327 (.0022)	.02538
1200	19.45 (.5503)	.00121 (.0022)	.00359
1300	19.52 (.5545)	.00306 (.0022)	.00112
1400	15.43 (.2022)	-.00224 (.0007)**	.10316
1500	19.24 (.5535)	.00247 (.0022)	.01482
1600	19.23 (.5410)	.00287 (.0021)	.02145
1700	19.06 (.5375)	.00342 (.0021)	.02983
1800	19.07 (.5372)	.00351 (.0021)	.03190
1900	19.01 (.5343)	.00368 (.0021)	.03478
2000	18.98 (.5383)	.00381 (.0021)	.03727
2100	18.87 (.5587)	.00381 (.0022)	.03419
2200	18.64 (.5486)	.00497 (.0022)*	.05712
2300	18.90 (.5452)	.00414 (.0022)	.04085
2400	19.02 (.5143)	.00402 (.0021)	.04392

Numbers in parentheses indicate the standard errors for values.

* Indicates significance at the level of .05

** Indicates significance at the level of .01

Table 8 - D
Regression Chart for Humidity - Boone Avenue

	Constant	Slope	R Squared
0100	92.34 (.1264)#	.00222 (.0005)**	.19353
0200	92.31 (.1210)	.00235 (.0004)**	.22396
0300	92.31 (.1210)	.00235 (.0004)**	.22577
0400	92.34 (.1233)	.00224 (.0005)**	.20098
0500	92.36 (.1231)	.00211 (.0005)**	.18063
0600	92.38 (.1233)	.00205 (.0005)**	.16960
0700	92.37 (.1220)	.00212 (.0005)**	.18220
0800	92.38 (.1187)	.00198 (.0004)**	.17158
0900	92.39 (.1184)	.00206 (.0004)**	.18009
1000	92.41 (.1274)	.00202 (.0005)**	.15894
1100	92.39 (.1284)	.00213 (.0005)**	.16386
1200	92.33 (.1330)	.00241 (.0005)**	.19756
1300	92.20 (.1349)	.00293 (.0005)**	.26145
1400	93.30 (.0637)	-.00075 (.0002)**	.11519
1500	92.25 (.1530)	.00306 (.0006)**	.23190
1600	92.25 (.1474)	.00316 (.0005)**	.26257
1700	92.26 (.1444)	.00316 (.0005)**	.26577
1800	92.26 (.1351)	.00305 (.0005)**	.28239
1900	92.28 (.1393)	.00296 (.0005)**	.25473
2000	92.28 (.1330)	.00280 (.0005)**	.25520
2100	92.32 (.1331)	.00266 (.0005)**	.23310
2200	92.40 (.1388)	.00231 (.0005)**	.16986
2300	92.42 (.1357)	.00213 (.0005)**	.15371
2400	92.33 (.1259)	.00235 (.0005)**	.20749

Numbers in parentheses indicate the standard errors for values.

* Indicates significance at the level of .05

** Indicates significance at the level of .01

Table 8 - E
Regression Chart for Temperature - Marion Avenue

	Constant	Slope	R Squared
0100	14.39 (.0426)#	-.00165 (.0001)**	.51825
0200	14.40 (.0425)	-.00169 (.0001)**	.52814
0300	14.39 (.0441)	-.00165 (.0001)**	.50015
0400	14.40 (.0432)	-.00169 (.0001)**	.52136
0500	14.39 (.0431)	-.00168 (.0001)**	.51925
0600	14.39 (.0418)	-.00168 (.0001)**	.53207
0700	14.38 (.0425)	-.00165 (.0001)**	.51142
0800	14.38 (.0430)	-.00165 (.0001)**	.50660
0900	14.39 (.0435)	-.00164 (.0001)**	.48975
1000	14.41 (.0448)	-.00167 (.0001)**	.48734
1100	14.43 (.0438)	-.00169 (.0001)**	.50033
1200	14.47 (.0465)	-.00171 (.0001)**	.46446
1300	14.63 (.0535)	-.00224 (.0002)**	.51851
1400	14.78 (.0708)	-.00264 (.0002)**	.47098
1500	14.59 (.0551)	-.00212 (.0002)**	.50085
1600	14.53 (.0520)	-.00199 (.0002)**	.49990
1700	14.48 (.0472)	-.00182 (.0001)**	.50516
1800	14.45 (.0445)	-.00176 (.0001)**	.52019
1900	14.43 (.0434)	-.00177 (.0001)**	.53427
2000	14.41 (.0423)	-.00173 (.0001)**	.53599
2100	14.41 (.0429)	-.00177 (.0001)**	.53758
2200	14.40 (.0436)	-.00174 (.0001)**	.52336
2300	14.41 (.0439)	-.00173 (.0001)**	.51345
2400	14.41 (.0445)	-.00174 (.0001)**	.51390

Numbers in parentheses indicate the standard errors for values.

* Indicates significance at the level of .05

** Indicates significance at the level of .01

Table 8 - F
Regression Chart for Humidity - Marion Avenue

	Constant	Slope	R Squared
0100	95.91 (.1090)#	.00466 (.0004)**	.56810
0200	95.91 (.1083)	.00458 (.0004)**	.55842
0300	95.91 (.1204)	.00437 (.0004)**	.48548
0400	95.91 (.1177)	.00443 (.0004)**	.50218
0500	95.90 (.1177)	.00444 (.0004)**	.50200
0600	95.91 (.1165)	.00443 (.0004)**	.50430
0700	95.93 (.1167)	.00438 (.0004)**	.49629
0800	95.89 (.1165)	.00452 (.0004)**	.51191
0900	95.88 (.1169)	.00448 (.0004)**	.49991
1000	95.82 (.1168)	.00462 (.0004)**	.51746
1100	95.79 (.1133)	.00461 (.0004)**	.52675
1200	95.79 (.1157)	.00437 (.0004)**	.47740
1300	95.56 (.1286)	.00496 (.0005)**	.47856
1400	95.36 (.1296)	.00567 (.0005)**	.55132
1500	95.65 (.1254)	.00465 (.0005)**	.48200
1600	95.73 (.1153)	.00464 (.0004)**	.52571
1700	95.81 (.1136)	.00446 (.0004)**	.51631
1800	95.85 (.1129)	.00446 (.0004)**	.51879
1900	95.88 (.1142)	.00449 (.0004)**	.51638
2000	95.90 (.1141)	.00448 (.0004)**	.51557
2100	95.90 (.1152)	.00453 (.0004)**	.51517
2200	95.91 (.1173)	.00447 (.0004)**	.50103
2300	95.90 (.1164)	.00448 (.0004)**	.50631
2400	95.90 (.1160)	.00453 (.0004)**	.51494

Numbers in parentheses indicate the standard errors for values.

* Indicates significance at the level of .05

** Indicates significance at the level of .01

Figure 9A

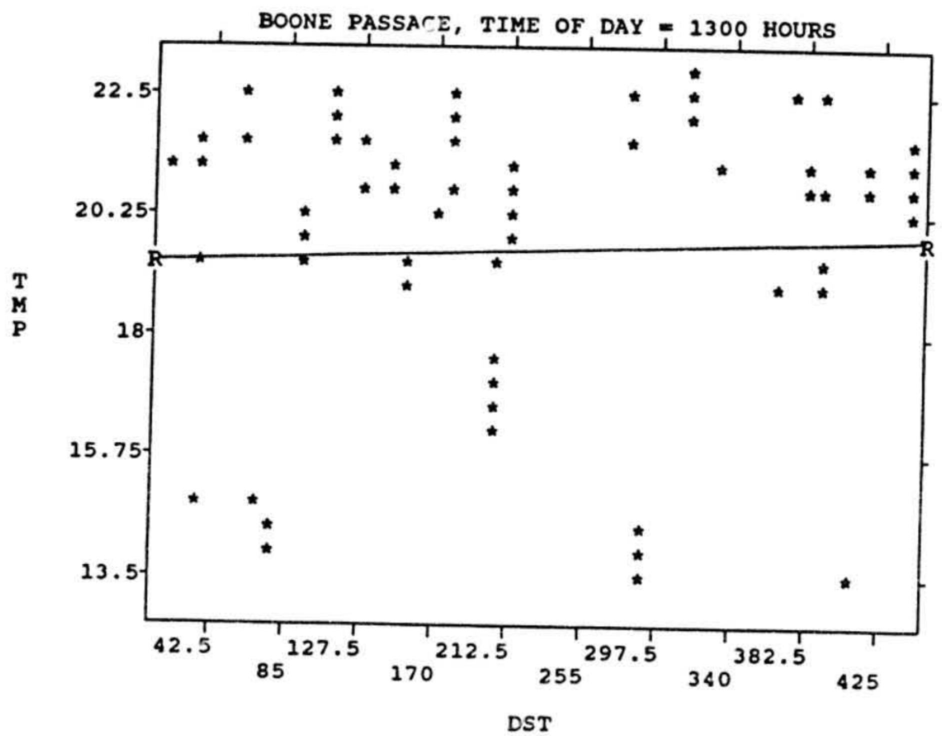
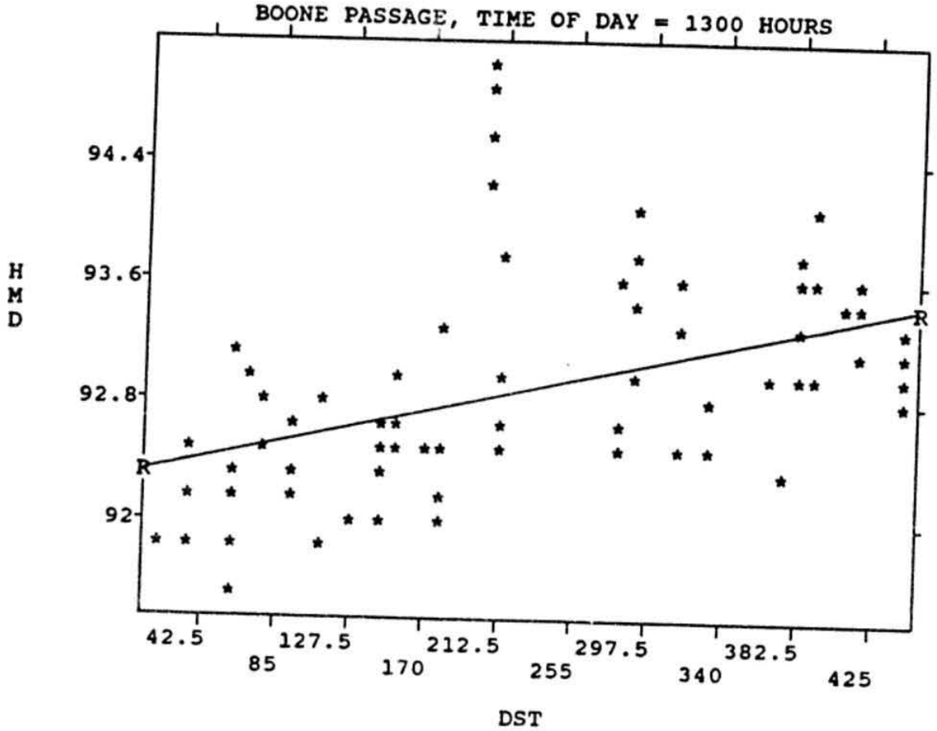

BOONE PASSAGE, TIME OF DAY = 1300 HOURS
22.5
20.25
18
15.75
13.5
TMP
R
R
42.5
85
127.5
170
212.5
255
297.5
340
382.5
425
DST

Figure 9B



BOONE PASSAGE, TIME OF DAY = 1300 HOURS
H
M
D
94.4
93.6
92.8
92
R
R
42.5
85
127.5
170
212.5
255
297.5
340
382.5
425
DST

On the basis of chart analysis of the correlation coefficients, it was evident that Marion Avenue had the strongest relationship between all variables, while Boone Avenue showed stronger humidity/distance correlations and weaker temperature/distance correlations. Carmichael passageway had slightly weaker correlations between humidity/distance and stronger correlations between temperature/distance.

Marion Avenue, which lies closest to the dining room food preparation equipment, experienced significant correlation coefficients in both temperature and humidity for every 24-hour period (see Figure 7). Analysis of the scatterplots confirmed a linear relationship for each of the charts. Therefore, given the close proximity of the corridor to the dining room equipment, it can be assumed that dining room activity does affect the microclimate in this section of the cave.

However, a definite cause-effect relationship would result in the correlations becoming stronger and the regressions becoming more clearly defined in a time period ranging from a few minutes to a few hours after the dining room equipment is activated. This does not seem to be the case as the correlations and regressions remain at a constant level throughout the day. The only period of increased correlation occurred at 1800-2100 hours and this change is slight, only one to two hundredths of a point.

Regression slopes for Boone and Carmichael passageways confirm the less clearly defined relationship (see Figures 9 A-B and 10 A-B). The slopes for Boone Avenue were positive, but nearly zero, while the slopes for Carmichael were negative, but nearly zero. The regression slopes for Marion Avenue were the strongest, with a mixture of positive slopes for humidity and negative slopes for temperature (see Figure 11 A-B).

A possible cause for the continuously high correlations and regressions in Marion Avenue could be due to the constant operation of certain equipment in the dining room area, some of which extends down Marion Avenue. Refrigeration units and beverage equipment run continuously throughout the day and night giving off heat which can be detected by the sensors.

The difference in correlations and regressions in Carmichael and Boone passageways could be explained by the wintertime wind flow patterns. Both variables of temperature and humidity, although low in winter, remain at a constant level in Carmichael because wind flow patterns blow from the passageway to the dining room, preventing any possible increases in temperature and humidity from entering the area.

Any effects from the dining room would be blown in the direction of Boone Avenue. Although the temperature correlations and regression slopes in Boone are lower than

Figure 10A

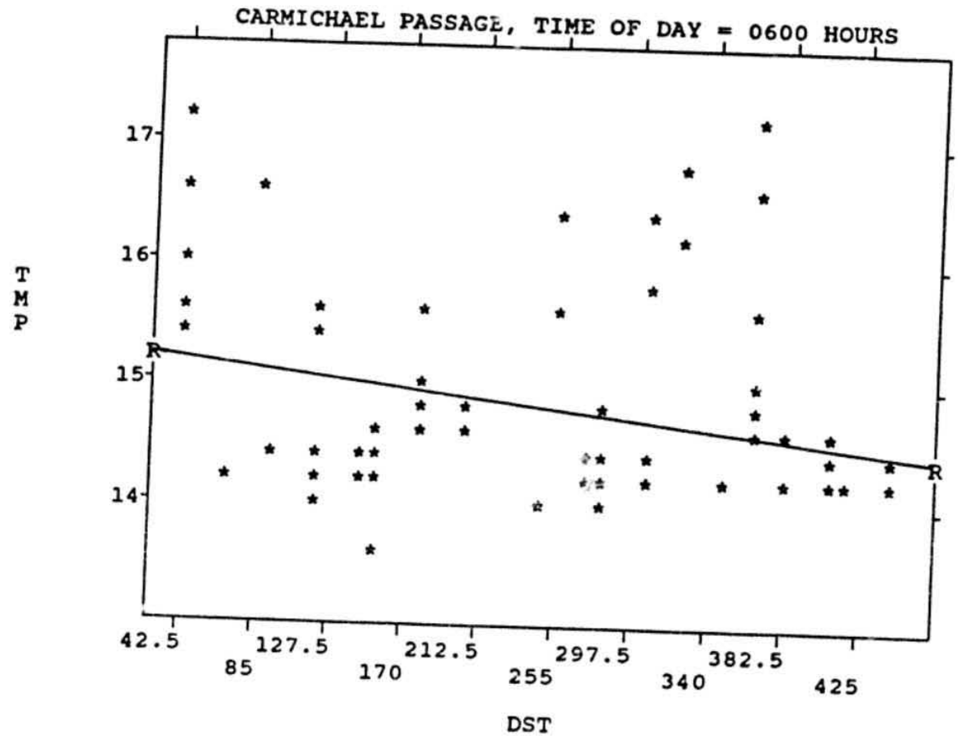

CARMICHAEL PASSAGE, TIME OF DAY = 0600 HOURS
17
16
15
14
T
M
P
R
R
42.5
85
127.5
170
212.5
255
297.5
340
382.5
425
DST

Figure 10B

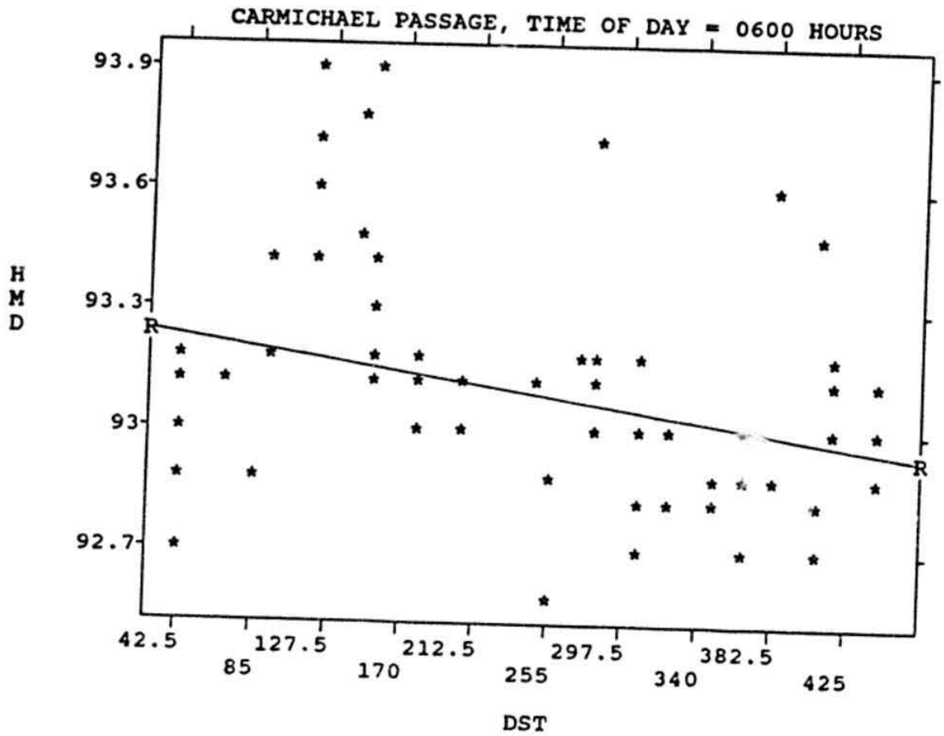

CARMICHAEL PASSAGE, TIME OF DAY = 0600 HOURS
93.9
93.6
93.3
93
92.7
H
M
D
R
R
42.5
85
127.5
170
212.5
255
297.5
340
382.5
425
DST

Figure 11A

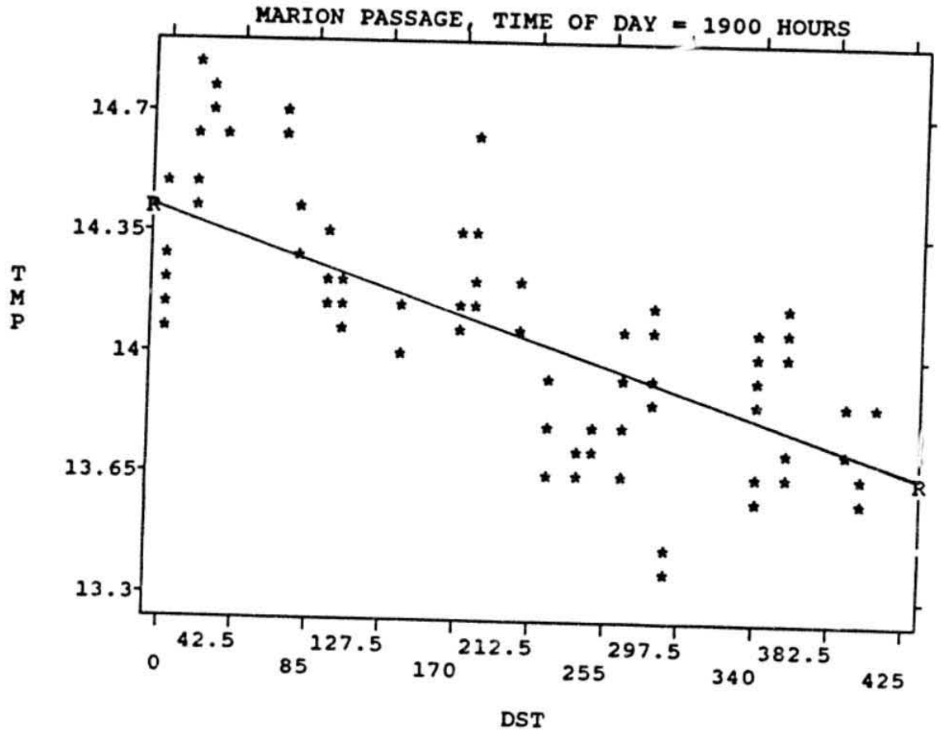
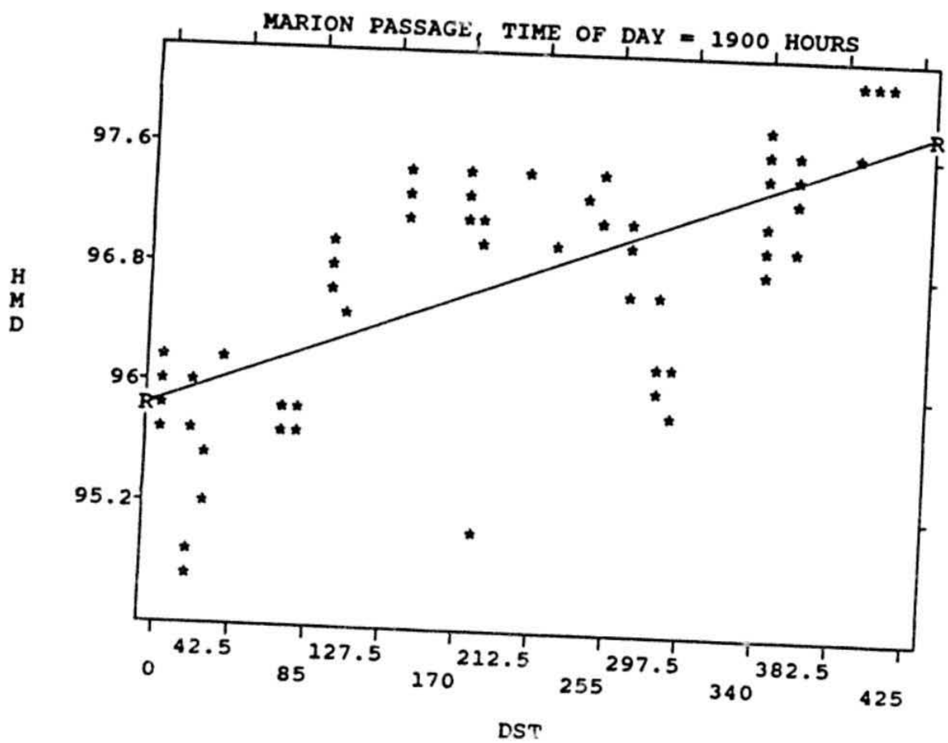

MARION PASSAGE, TIME OF DAY = 1900 HOURS
14.7
14.35
14
13.65
13.3
T
M
P
0
42.5
85
127.5
170
212.5
255
297.5
340
382.5
425
DST

Figure 11B


MARION PASSAGE, TIME OF DAY = 1900 HOURS
97.6
96.8
96
95.2
H
M
D
0
42.5
85
127.5
170
212.5
255
297.5
340
382.5
425
DST

the other passageways, they are more variable. Temperature correlations increase during the nighttime hours, reaching a peak correlation of .26 at 0400 hours. There is, however, a pronounced correlation "spike" to .32 at 1400 hours, the time cooking equipment is active and tours pass through the area (see Figure 7). This "spike" marks an increased correlation of .05 from the previous two hours. After this hour, the correlations return to a lower level.

The humidity correlations and regressions are much stronger than temperature, with a peak correlation of .53. There are six hourly correlations which reached a significant level, ranging from 1300 hours to 2000 hours. Although the temperature correlations may not remain high because of the dilution from the cool cave air, it is possible that the humidity correlations are not reduced because the cave air is very humid and allows the increased humidity from the steam tables to travel down Boone Avenue. Since the air is already laden with water vapor, the cave air will not dissipate the steam and allow the air to "dry out."

A visual observation of the selected 15 scatterplots confirmed the correlation analysis (see Figures 9 and 10). Increases and decreases in the correlation coefficients were evident in the slope and linear relationship of the plots. The Marion scatterplots exhibited a more clearly defined linear relationship than the other passageways. Most of the scatterplots in Carmichael passageway showed little, if any, linear relationship between the variables. The selected Boone Avenue scatterplots also showed little linear relationship except for the instances mentioned above. The scatterplot taken for temperature at the 1400 hour revealed an increased linear relationship than the hours preceding. The stronger humidity correlations for the same passageway were also evident in the scatterplots.

Chapter Seven

Conclusion

As a result of the visual and statistical analyses performed on the data, it becomes apparent that the microclimate of the Snowball Dining Room is not static and is subject to change.

Because of the strength of the Marion Avenue statistical data and the weaker data for Boone and Carmichael Avenues, it can be concluded that human presence does indirectly alter the microclimate of the area. Visitors alone do not appear to have a significant effect upon the microclimate, evidenced by the fact that the data from Carmichael passageway does not show a statistical significance in temperature change.

However, the indirect presence of visitors can be evidenced. The heat and steam released by food preparation activities, along with the heat generated by the constant operation of certain equipment is evident in the visual and statistical analysis of the Marion and Boone Avenue data. The presence of an increased correlation that appeared at the time a tour passed through Boone Avenue and the consistently significant readings in Marion Avenue support this fact. The most pronounced effect was in Marion Avenue, where the majority of food preparation equipment extends.

This information could prove valuable to the preservation of the Snowball Dining Room area. As stated earlier, the park service personnel have expressed a renewed interest in preserving and protecting the cave and surface region of Mammoth Cave National Park. These findings could aid in protecting the delicate microclimate of the Snowball region by suggesting a return to the original microclimate.

This return could take place though the reduction of food preparation activities in the dining room. Several programs could be implemented to bring about this change, including, but not limited to, the cessation of meals in the dining room, serving only foods that do not require heating, or heating food on the surface and transporting it to the dining room. The reduction in heat and steam discharge may also halt the discoloration of the walls and ceiling of the dining room.

Although this research attempts to answer fundamental questions concerning the microclimate of the dining room, several questions and topics for future research remain. This study was conducted during wintertime conditions within the cave. Research conducted utilizing a longer study period could include both summer and winter air flow patterns and visitor loads. This additional long-term data could perhaps further pinpoint the causes of unnatural temperature and humidity variations.

This research could also be utilized from a biological standpoint by further examining the fungus present on the walls and ceiling and determining if cooking and heating activities do indeed promote this growth. It may also be possible that these changes in temperature and humidity, however small, change the geological structure and strength of the area.

There are increasingly fewer areas on the earth that are unchanged by humans. Society, in its attempts to explore, conquer and control are constantly altering what nature has provided for us. It is hoped that this research will provide information needed to encourage the return of the Snowball Dining Room area to a more natural environment -- one less disturbed by human presence.

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