

OZARK UNDERGROUND LABORATORY

Rt. 1 Box 62 • Protem, Missouri 65733 • (417) 785-4289

REVIEW DRAFT

FINAL REPORT

**SNOWBALL DINING ROOM RESTORATION STUDIES
MAMMOTH CAVE, MAMMOTH CAVE NATIONAL PARK
KENTUCKY. PHASE II INVESTIGATIONS.**

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**Thomas Aley and Catherine Aley
Ozark Underground Laboratory**

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EXECUTIVE SUMMARY

The ceiling and many of the walls in the Snowball Dining Room in Mammoth Cave were covered with beautiful light colored "snowballs" of gypsum crystals as late as the early 1960's. By the mid 1970's the ceiling had begun to turn grey, and in some areas black. By the mid 1980's wags at Mammoth Cave had begun to refer to the area as the "Sootball" Dining Room.

This is the Final Report on Phase 2 of the restoration studies of the Snowball Dining Room in Mammoth Cave. Phase 1 studies (Aley and Aley (1986) found that a 5.25% sodium hypochlorite solution would oxidize (and thus destroy) most of the unnatural black coatings when lightly sprayed on the cave surfaces.

The present study has demonstrated that much of the black coatings in the Snowball Dining Room are fungus. Incorporated in the fungal growth is algae, lint, sediment particles, and carbon particles. The carbon particles are of particular interest since data developed in this study demonstrate that at least some of these particles are derived from the throwing of kerosine-soaked torches by NPS guides elsewhere in Mammoth Cave.

Carbon particles can readily be captured in filters placed in air quality sampling equipment. As a part of this investigation we developed two independent methods of quantitatively assessing the magnitude of carbon particulate matter in the air filters; the results of both methods were similar. There is a strong seasonal pattern of particulate matter concentrations in the Snowball Dining Room. Particulate matter is four to six times more abundant in the cave air in the winter than it is in the summer. Data demonstrate that this seasonal variation is due to airflow patterns. The airflow patterns seasonally change the source areas for air moving through the Snowball Dining Room area.

We have used both laboratory and field tests to develop a detailed methodology for restoring cave surfaces in the Snowball Dining Room to near-natural conditions. We estimate that at least 95% of the unnatural coatings can be removed with negligible adverse impacts on cave resources.

Other unnatural deposits are found on cave surfaces throughout the toured portions of Mammoth Cave. These have been identified and discussed; restoration approaches for dealing with these deposits have been identified.

Mammoth Cave is urgently in need of extensive resource cleaning and resource restoration work throughout essentially all of the toured passages. The magnitude of the resource degradation which has occurred is enormous. As a result, the magnitude of the necessary restoration work is also enormous. What Mammoth Cave needs, and what it should receive, is a restoration of almost all surfaces within the toured passages of Mammoth Cave. This work should begin in the Snowball Dining Room and along the Historic Tour.

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INTRODUCTION

This is the Final Report on Phase 2 of the restoration studies of the Snowball Dining Room in Mammoth Cave, Mammoth Cave National Park. Phase 1 studies were reported upon in Aley and Aley (1986). We suggest that the reader of the present report also consult the previous document.

Phase 1 studies found that a 5.25% sodium hypochlorite solution would oxidize (and thus destroy) much of the unnatural coatings when lightly sprayed on the cave surfaces. It was concluded that subsequently rinsing treated surfaces with water was an important part of the treatment approach.

The organization of this report follows the organization of tasks identified in the Purchase Order under which these investigations were conducted. This report summarizes the results of analytical work and field testing. This report will enable the National Park Service to plan the actual restoration work in the Snowball Dining Room area and to formulate management actions for preventing the reoccurrence of the unnatural black coatings.

NATURE OF THE UNNATURAL COATINGS

Determining the nature of the unnatural coatings is important in preventing the future re-development of the coatings. Phase 1 work noted that the black coatings found in the Snowball Dining Room appeared to be associated with the cooking and heating of foods. Phase 1 work also noted that fungal mycelium could be seen in some of the black coating samples from the Snowball Dining Room.

Gas Chromatograph Analysis

Samples of the black coating from the Snowball Dining Room were submitted to Consulting Analytical Services International (CASI), Springfield, Missouri for gas chromatography analysis. We were specifically interested in whether or not kerosine or animal fats were identifiable as major constituents of the black coatings. CASI was selected because they were experienced in the analysis of arson samples, so analysis for kerosine or kerosine residues in samples was common in their work.

Kerosine or kerosine residues were not found in the samples analyzed by CASI. Similarly, this laboratory failed to find a match between the gas chromatographic profiles of the black coatings and the profiles obtained from a sample of canned chili. Similar analytical

work was done on portions of air pump filters collected in the Snowball Dining Room. Kerosine and animal fats were not detectable in extracts made from these filters.

The failure to detect kerosine or animal fats means one of two things. The first possibility is that these constituents are not implicated in any of the unnatural cave deposits. Logic dictates that this is unlikely to be the case. The second possibility is that kerosine or animal fats may be implicated in the black coatings, but that they have been changed so as to no longer be identifiable as the initial material. Such changing of the initial material could occur through chemical, physical, and/or biological activity. This is the probable explanation. The presence of fungal growth in the unnatural black coatings is a demonstration of biological activity. The reader must recognize that the gas chromatograph data do not demonstrate or indicate that kerosine and animal fats are not implicated in the black coatings.

Microscopic Examination

Microscopic examinations were conducted of various samples of the unnatural black coatings found in the Snowball Dining Room. The examination clearly demonstrated that the black material consists largely of fungus with some algae and undoubtedly some bacteria associated with it. The mixture could be called a biofilm, but because of the predominance of fungus, we believe the better characterization is "fungus with associated materials".

For comparison purposes we collected samples of the black coatings from Salts Cave, Mammoth Cave National Park. These coatings are largely the result of pre-Columbian soot from the extensive mining conducted in that cave by Indians. Under microscopic examination there is little or no fungus associated with the black coatings from Salts Cave; there is a small amount of algae. Algae can grow in total darkness in caves; when this occurs, the algal growth is typically black colored rather than green (Aley and Aley, 1985).

Scanning Spectrofluorophotometer Analysis

Fifty samples of various materials were collected for analysis on a Shimadzu Spectrofluorophotometer, Model RF-540. We will refer to this instrument as the RF-540. Many materials exhibit some fluorescence; the fluorescence will peak at particular wavelengths. Our sampling was conducted in an effort to "fingerprint" materials coating cave surfaces in Mammoth Cave.

We collected a wide range of samples. Some samples were rock chips with coatings on them, other samples were cave sediments, and still others were cotton wipes of various surfaces within Mammoth Cave. While the majority of the samples were solids, a few were liquids. All samples were subjected to RF-540 analysis, and an analytical chart was developed for each sample.

Table 1 identifies the samples collected. For convenience, the samples are placed in groups in the table. The groups are as follows:

Group 1 consists of samples of various exotic materials present in Mammoth Cave which may produce unnatural coatings on cave surfaces. This group includes cave sediments.

Group 2 consists of samples of exotic plant growth in Mammoth Cave (much of the growth is algae). Group 2 is similar to Group 1 in that it represents materials exotic to Mammoth Cave.

Group 3 consists of unnatural coating samples collected in and around the Snowball Dining Room.

Group 4 consists of samples collected elsewhere in Mammoth Cave.

Group 5 consists of unnatural coatings collected in Salts Cave (these represent pre-Columbian Indian activity).

Each sample was given a reference number. In addition, each sample was assigned a laboratory analysis number developed for our internal reference purposes.

A number of samples were taken on 100% cotton wipes. The cotton used was Swiss Beauty Pads; they were selected because of their relatively uniform fluorescence characteristics and the absence of dyes such as optical brighteners.

Table 1

Description of Samples Collected for RF-540 Analysis

Group 1. Various exotic materials present in Mammoth Cave which may produce unnatural coatings.

Ref. Number	Lab Number	Description of Sample
1	1211	Soup served in the Snowball Dining Room; in water
2	1530	Cotton wiping of restroom walls with residual cleansing agents
3	1546	Burned remains of recently burned NPS torch; cotton soaked in kerosine. From Methodist Church.
4	1547	New unburned torch as used in Methodist Church. Cotton soaked in kerosine.
5	1549	Soot from NPS kerosine torches. Star Chamber, slope deposits on Whale Rock. Smear on cotton sampler.
6	1553	Soot from NPS kerosine torches. Methodist church. Powder.
7	1556	Piece of Indian cane torch--burned.
8	1560	Black cobweb hanging from ceiling in Snowball Dining Room.
9	1634	Lint from near the first light after the Wooden Bowl Room, Historic Tour.
10	1635	"Clay worms" (vermiculations). Smear on cotton sampler. After the Wooden Bowl Room, Historic Tour.
11	1638	"Clay worms". Smear on cotton sampler. Sampler turned black by smear. Above trail, just before sign stating that dome is 31 feet high.

Table 1 (continued)
Description of Samples Collected for RF-540 Analysis
Group 2. Exotic plant growth

Ref. Number	Lab Number	Description of Sample
12	1623	Mildew on Snowball Dining Rm. weather station; smear on cotton sampler.
13	1650	Moonmilk, Indian Ave.
14	1655	Algae. Blacksnake Pass. First room past the Wooden Bowl Rm.
15	1629	Algae wipe on cotton. Second light on right inside Historic Entrance, near first aid box.
16	1630	Algae wipe on cotton. Historic Tour; about 10th light into the cave.
17	1631	Algae wipe on cotton. Historic Tour; passage below Wooden Bowl Rm.
18	1632	Algae wipe on cotton. Historic Tour; apparently blue-green algae. First light after Wooden Bowl Rm.
19	1633	Algae wipe on cotton. Historic Tour; very green algae. First light after Wooden Bowl Rm.
20	1636	Algae wipe on cotton. Historic Tour; name F. Peters on ceiling.
21	1637	Algae wipe on cotton. Thick golden growth, green at edges. Historic Tour, just before dome 31 ft. high.
22	1639	Clay worms and algae wipe on cotton. Above trail just before dome 31 ft. high. Historic Tour.
23	1640	Pink algae wipe on cotton. Above trail just before dome 31 ft. high. Historic Tour.
24	1644	Algae on cotton wipe; green. Top of Mammoth Dome, Historic Tour.

Table 1 (continued)
Description of Samples Collected for RF-540 Analysis
Group 3. Samples from Snowball Dining Room area.

Ref. Number	Lab Number	Description of Sample
25	1209	Water ~~from~~ washing Snowball Dining Room wall--no bleach treatment.
26	1210	Water ~~from~~ washing Snowball Dining Room wall--after bleach treatment.
27	1522	Dust on cotton sampler, 30 ft. up elevator shaft.
28	1524	Top of high lights above steam table--on cotton sampler.
29	1525	Cotton wipe of lights at tables closest to cooking area.
30	1526	Cotton wipe of electric control box at bottom of elevator
31	1527	Cotton wipe of lights in Snowball Dining Room furthest from cook area.
32	1529	Cotton wipe of lights in Boone Ave. near Mary's Vineyard.
33	1531	Cotton wipe of light near restroom, Snowball.
34	1532	Cotton wipe of light between Snowball and elevator.
35	1533	Cotton wipe of high lights over water fountain.
36	1536	Snowball; fresh ceiling spall (rock chips)
37	1558	Red cave sediments near freezers, Snowball.
38	1559	Cleveland Ave. just before Snowball. Gypsum coating

Table 1 (continued)
Description of Samples Collected for RF-540 Analysis
Group 4. Samples from elsewhere in Mammoth Cave

Ref. Number	Lab Number	Description of Sample
39	1528	Specimen Ave. Cotton wipe of light fixture nr. R54. Black deposits of 20 years or more.
40	1534	Cleveland Ave. Cotton wipe of light; last transformer before Snowball.
41	1535	Cleveland Ave. Cotton wipe of light with 1.5 years of accumulated "dust".
42	1548	"Humic acids". Kentucky River Cliffs, past Rotunda. Torch soot also present.
43	1551	Cotton wipe of 2nd light past Wooden Bowl Rm.
44	1552	Red "beady" material; powder sample.
45	1554	Rotunda wall; chips of rock and soot.
46	1557	Historic Entrance; black material on wall. Powder sample.
47	1645	Chips of rock with black coating. Near light at top of Mammoth Dome.

Group 5. Samples from Salts Cave; associated with Indian use

48	1626	Black "dirt" from cave floor.
49	1627	Rocks with black coatings; from ceiling.
50	1628	Brown cave sediment from which gypsum crystals grow.

Discussion of the RF-540 Data

One or more significant fluorescence peaks was found in 47 of the 60 samples subjected to RF-540 analysis. A total of 263 fluorescence peaks were identified. We have arranged the data based both on station number and on the wavelength of the observed fluorescence peaks (see Appendix A). This organization of the data facilitates comparisons of fluorescence peaks in different samples.

The peak wavelength at which a fluorescent material will fluoresce will typically vary by several nanometers. For example, fluorescein dye in a mixture of 5% aqua ammonia and isopropyl alcohol has a mean fluorescence peak at 518.6 nm, yet may create fluorescence peaks under various conditions ranging from about 514.1 nm to 520.4 nm. Fluorescein dye is used in this example because it is a highly fluorescent material for which we have extensive data.

Fluorescence peaks found in Appendix A cluster into groups. For purposes of our data analysis we have presumed that each group of peaks probably represents a single fluorescent material. We believe this is generally a valid assumption for the materials with which we are working in this study.

The following sections of the report identify fluorescence peaks associated with various materials unnatural materials which are now found in Mammoth Cave. For each of the identified materials we have identified cave samples which produced similar fluorescence peaks.

Fluorescence peaks associated with soup.

Sample 1 was a water suspension of the soup served in the Snowball Dining Room. It was considered possible that steam from heated soup might be a component of unnatural coatings found in the Snowball Dining Room area.

Fluorescence peaks in Sample 1 (the soup in a distilled water suspension) were found at 405.0 and 609.4 nm. Similar peaks were not found in any other samples collected. Therefore, using the RF-540 we cannot detect any fluorescence associated with soup on cave surfaces. It should be noted that the steam rising from the soup is primarily water, and thus might not leave a detectable fluorescent "fingerprint" on the tested surfaces.

Fluorescence peaks associated with cleansing agents.

Various cleansing agents are used in the restrooms and elsewhere in the Snowball Dining Room. Sample 2 was a cotton wiping of restroom walls which had been subjected to cleansing agents. Fluorescence peaks in Sample 2 were found at 356.5 nm and 554.2 nm.

Six other samples which we collected had fluorescence peaks in the range of 354.0 to 357.5 nm. In addition to Sample 2 they included three algal samples from the Historic Tour area (samples 20, 21, and 23), and two wipings of lights in the Snowball Dining Room (samples 28 and 34). It would be illogical to find the same fluorescent compound present in both algae and in a cleansing agent which would probably have germicidal ingredients. Furthermore, other fluorescence peaks found in samples from the lights in the Snowball Dining Room area are generally different from fluorescence peaks found in Samples 20, 21, and 23; there is a great deal of similarity in the fluorescence peaks found in the latter three samples. The conclusion is that cleansing agents similar to those found on restroom walls are also found on some light fixtures in the Snowball Dining Room; they have either been applied to the fixtures during a cleaning operation, or else they have been deposited as airborne contaminants. The latter possibility is unlikely since they have not been detected elsewhere in the Snowball Dining Room. Fluorescence peaks common to algae are generally absent from the two lights represented in Samples 28 and 34.

The fluorescence peak found in Sample 2 at 554.2 nm was found in no other sample collected during the study. The nearest fluorescence peaks occurred at 551.1 and 551.4 nm; these were samples 21 and 16 respectively. Both of these samples were algae wipes; the discussion in the previous paragraph is again relevant.

In summary, using the RF-540 we cannot detect the presence of any cleansing agents on the natural cave surfaces sampled.

Fluorescence peaks associated with kerosine.

Kerosine lanterns have been used in the past in Mammoth Cave. Kerosine "torches", which are made of tightly rolled pieces of cotton cloth soaked in kerosine, have been ignited and thrown about the cave for many years. The torches are thrown by guides to illuminate portions of the cave or to demonstrate how the cave was formerly illuminated for tours.

Sample 4 (see Table 1) was a new, unburned torch as used in Methodist Church; it consisted of cotton soaked in kerosine. Sample 5 was soot from National Park Service kerosine torches. The sample was from slope deposits on Whale Rock in the Star Chamber. The sample was a smear on a cotton samplers. Both samples 4 and 5 showed a unique fluorescence peak at 616.0 nm.; neither of these samples had any other distinctive fluorescence peaks. The unique fluorescence peak at 616.0 appears to be a kerosine component; this peak was not found in any other samples collected in Mammoth Cave. This finding is compatible with our inability to detect kerosine in gas chromatograph analysis. Neither sample 4 nor 5 had any additional fluorescence peaks.

Samples 3 and 6 are also associated with National Park Service torches thrown in Mammoth Cave. Sample 3 was the burned remains of a torch from the Methodist Church section of the Cave; it consisted of cotton soaked in kerosine. Sample 6 was soot from kerosine torches; it was collected as a powder.

Sample 3 contained only one reasonably distinct fluorescent peak; this peak was at 593.0 nm. This peak was within a cluster of measured fluorescence peaks which ranged from 590.0 to 602.3 nm; there were 10 samples in this group. The samples in this group are identified in Table 2. The data in this table demonstrate that the fluorescence peak associated with Sample 3 is also found in a number of samples from cotton wipings of lights in the Snowball Dining Room and elsewhere. These data indicate that some of the dark-colored "dust" which coats features in the Snowball Dining Room and elsewhere is associated with the burning of kerosine-soaked torches in the cave. It should be noted that none of the fluorescence peaks in the range between 590.0 and 602.3 nm were from samples associated with Indian torches or Indian activity. These were samples 7, 48, 49, and 50.

Table 2.

Mammoth Cave samples with fluorescence peaks in the 590.0 nm to 602.3 nm range. Results from Sample 3 are highlighted.

Fluorescence peak (nm)	Sample Number	Sample Description
590.0	32	Cotton wipe of lights in Boone Ave. nr. Mary's Vineyard.
591.7	28	Top of high lights on steam table in Snowball Dining Room; on cotton sampler.
592.1	9	Lint from nr. first light after the Wooden Bowl Room, Historic Tour.
593.0	3	Burned remains of an NPS torch; cotton soaked in kerosine. From Methodist Church.
595.0	40	Cleveland Ave. Cotton wipe of light; last transformer before Snowball.
597.7	41	Cleveland Ave. Cotton wipe of light with 1.5 years of accumulated "dust".
599.2	31	Cotton wipe of lights in Snowball Dining Rm furthest from cooking area.
599.8	33	Cotton wipe of light between Snowball and elevator.
600.1	43	Cotton wipe of 2nd light past Wooden Bowl Rm.
602.3	29	Cotton wipe of lights at tables closest to cooking area, Snowball.

Salts Cave, located within Mammoth Cave National Park, is an important archeological site where pre-Columbian Indians mined cave minerals. The walls and ceilings of the cave are coated with soot from Indian fires and cane torches. The torches used by the National Park Service are cotton soaked in kerosine.

We collected three samples from Salts Cave for RF-540 analysis. These were as follows:

Sample 48. Black "dirt" from cave floor

Sample 49. Rocks with black coatings; taken from ceiling.

Sample 50. Brown cave sediment from which gypsum crystals grow.

Table 3 identifies the 12 groups of fluorescence peaks found in one or more of these three samples. Seven of the 12 groups had fluorescence peaks at the identified wavelength found in only one of the three samples. Three of the 12 groups had fluorescence peaks at the identified wavelength found in two of the three samples. Two of the 12 groups had fluorescence peaks at the identified wavelength found in all three of the samples.

Table 3
Fluorescence peaks found in samples from Salts Cave

Fluorescence Group Number	Sample 48. Black dirt from cave floor	Sample 49. Rocks with black coatings	Sample 50. Brown cave sediment
1		341.4	
2		353.0	
3	409.0		
4	424.6		
5	454.7		454.7
6	471.9	471.3	471.6
7	498.5	498.5	499.5
8		502.0	
9	510.1		512.5
10	531.0		536.0
11	756.6		
12			776.6

A total of 14 samples (Samples 25 through 38) were collected from the Snowball Dining Room area. There were 20 different fluorescent peaks or groups of peaks in the 14 samples. Eight groups of peaks were found in three or more of the samples; these were selected for comparison with fluorescence peaks found in Samples 3 and 6 (kerosine torch remains) and three samples from Salts Cave.

Table 4 compares the eight groups of fluorescence peaks found in 3 or more samples from the Snowball Dining Room area with fluorescence peaks found in Park Service torch remains and in deposits found in Salts Cave. Based upon this comparison we can make several observations.

First, there is an obvious correspondence between fluorescence peaks found in the Snowball Dining Room area and those associated with the burning of both pre-Columbian and modern torches. However, it should be remembered that the unnatural black coatings in the Snowball Dining Room are relatively recent developments (and certainly post-date Indian activity).

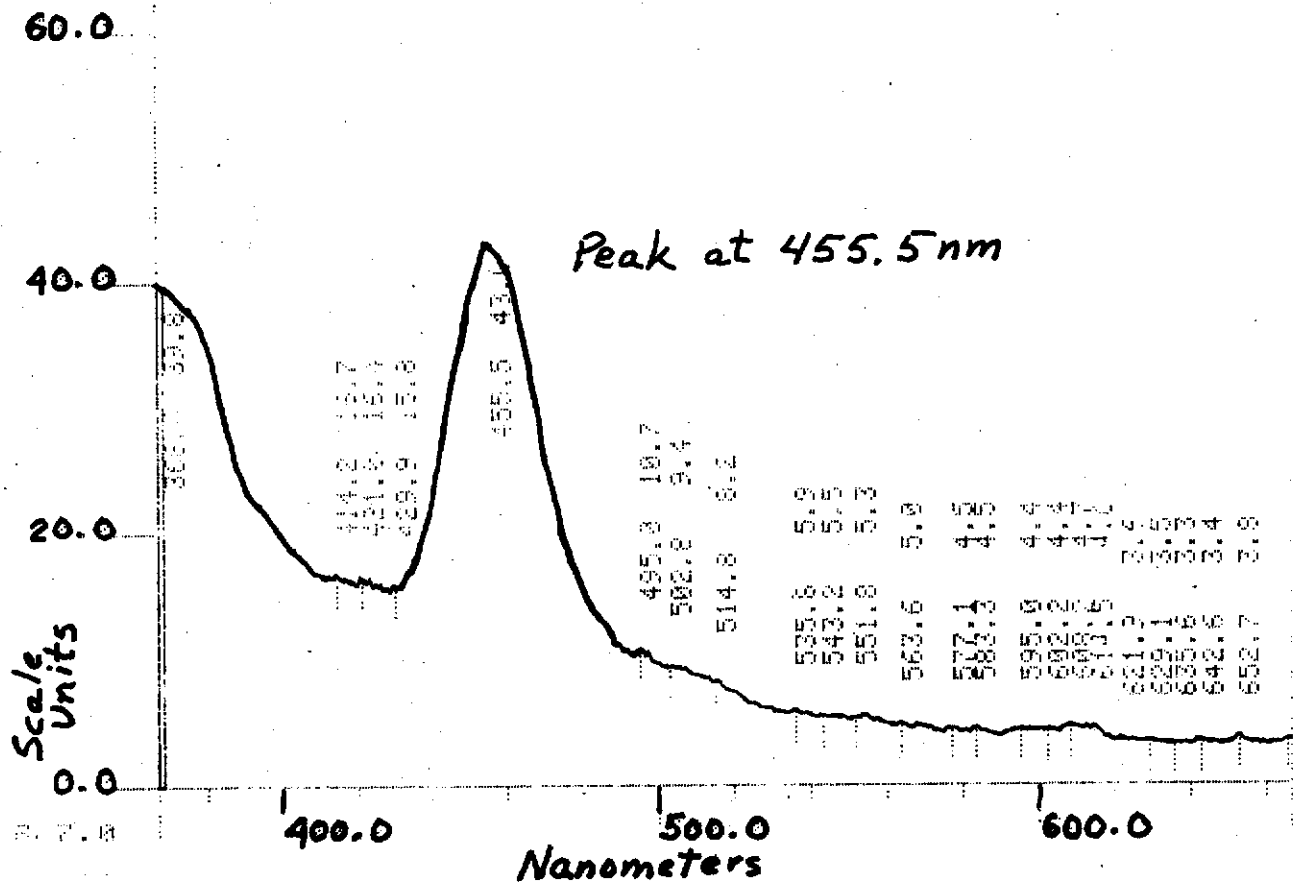
Second, Figure 1 is a photocopy of the analysis chart of Sample 26, which was water which dripped from a wall in the Snowball Dining Room after it was lightly sprayed with unchlorinated water; note the dominant fluorescence peak at 471.6 nm. Fluorescence peaks at or near this wavelength were found in a total of 4 samples from the Snowball Dining Room, in Sample 6 (remains of a burned torch), and in all samples from Salts Cave. This clearly shows that deposits from torches are appreciable within the Snowball Dining Room area.

Table 4

Fluorescence peaks found in three or more samples from the Snowball Dining Room area.

Range of fluorescence peak (nm)	Number of Snowball Samples with a peak in this group	Is peak associated with burned torches (samples 3 and 6)?	Is peak associated with soot from Salts Cave?
352.7 to 361.8	3	No	No. 0 of 3 samples
453.9 to 456.3	5	Yes. Sample 6	Yes. 2 of 3 samples
471.0 to 471.9	4	Yes. Sample 6	Yes. 3 of 3 samples
483.0 to 487.2	4	No.	No. 0 of 3 samples
495.8 to 499.5	4	Yes. Sample 6	Yes. 3 of 3 samples
509.2 to 515.1	4	No	Yes. 2 of 3 samples
529.3 to 537.2	3	Yes. Sample 6	Yes. 1 of 3 samples
597.7 to 605.6	5	Yes. Sample 3	No. 0 of 3 samples

Figure 1. RF-540 Analysis chart of Sample 25 (water from washing Snowball Dining Room wall without bleach treatment).



Fluorescence peaks associated with exotic plant growth.

Exotic plant growth is common in portions of Mammoth Cave because of the presence of electric lights. The plant growth is generally restricted to moist areas, and much of Mammoth Cave is quite dry. The plant growth consists of algae, moss protonema, and sometimes moss.

We collected 11 samples (samples 14 through 24) which included algae. In addition, Sample 12 consisted of mildew. Sample 13 was moonmilk; moonmilk commonly consists of an aqueous suspension of bacteria. Samples 12 and 13 are included in this discussion of exotic plant growth as a matter of convenience.

Sample 12 had only one fluorescence peak; no other sample contained a similar peak. Sample 13 had fluorescence peaks which were also found in many of the algae samples.

Fluorescence peaks for Samples 13 through 24 were studied in detail. Table 5 identifies 13 wavelength ranges where four or more of the samples had fluorescence peaks. Ten or more of the 12 samples had fluorescence peaks in five of the identified wavelength ranges; these are highlighted in Table 5.

Table 5

Fluorescence peak wavelengths present in four or more samples associated with exotic plant growth; samples 13 through 24.

Range of Wavelength Peak (nm)	Number of Stations	Station Numbers
354.0 to 360.1	4	19, 20, 21, 23
380.6 to 384.3	4	14, 15, 18, 21
395.8 to 401.0	6	13, 14, 15, 16, 20, 21
408.0 to 409.4	8	14, 15, 16, 18, 19, 21, 22, 23
420.0 to 425.2	8	13, 14, 16, 17, 18, 20, 21, 24
453.9 to 455.3	12	13 through 24
471.0 to 471.7	11	14 through 24
496.9 to 499.4	10	13, 14, 15, 17, 18, 19, 20, 22, 23, 24
509.2 to 513.5	8	13, 14, 15, 17, 18, 20, 22, 23
529.3 to 537.2	11	13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24
549.7 to 551.4	6	16, 17, 19, 20, 21, 24
772.2 to 774.9	10	14, 15, 17, 18, 19, 20, 21, 22, 23, 24
785.1 to 788.3	9	13, 15, 17, 18, 20, 21, 22, 23, 24

Table 6

Samples which display common fluorescence peaks found in exotic plant growth samples. X indicates the presence of a fluorescence peak within or near the value shown.

Sample Number	453.9 to 455.3	471.0 to 471.7	496.9 to 499.4	529.3 to 537.2	772.2 to 774.9
1					
2					
3					
4					
5					
6	X	X	X	X	
7					
8	X	X	X	X	
9		X	X	X	
10	X	X	X	X	
11	X	X	X		
12					

Note: Samples 13 through 24 are of exotic plant growth.

25	X				
26	X	X	X		
27					
28					
29					
30					

Table 6 (continued)

Samples which display common fluorescence peaks found in exotic plant growth samples. X indicates the presence of a fluorescence peak within or near the value shown.

Sample Number	453.9 to 455.3	471.0 to 471.7	496.9 to 499.4	529.3 to 537.2	772.2 to 774.9
31					
32					
33					
34					
35					
36	X	X	X	X	
37	X	X	X	X	
38	X	X	X	X	
39					
40					
41			X		
42	X				
43					
44	X	X	X	X	X
45	X	X	X	X	
46					
47	X	X	X	X	X
48	X	X	X	X	
49		X	X		
50	X	X	X	X	

MONITORING OF PARTICULATE MATTER IN AIR

Introduction

There is substantial particulate matter present in the air of Mammoth Cave. It can often be seen in the beam of a bright light shown down a dark passage. It deposits as a black dust on light fixtures and on other features in the Cave. The particulate matter is a component of the unnatural black coatings found in the Snowball Dining Room.

Mammoth Cave National Park owns equipment for alpha radiation sampling of air within the cave. This equipment consists of a calibrated pump which pulls a known quantity of air through a filter. The filters collect substantial amounts of the particulate matter present in the cave air. During the course of both Phase 1 and Phase 2 of our study Mr. Bob Carson of the National Park Service operated this equipment continuously in the Snowball Dining Room and periodically sent us the resulting filters. The monitoring was conducted at a point near the food preparation area; it was along the passage leading from the elevator to the food preparation area. The period of sampling began on December 12, 1985 and ended when the equipment failed sometime between September 15 and 19, 1988. We thus have a total of 57 months of sampling data.

A total of 38 filters were collected. All of the filters were noticeably grey to black in color after the passage of various volumes of cave air. Selected filters were examined under a microscope. The discoloration in the filters is due primarily to small, flat flecks of black material. This black material apparently consists of carbon compounds.

Selected filters were tested for fluorescence with the RF-540 spectrofluorophotometer. Unfortunately, the unused filters have a substantial amount of background fluorescence, and none of the used filters displayed any significant fluorescence peaks which were not also present in the unused filters. In addition, we unsuccessfully attempted to wash materials from the used filters and then subject the resulting liquid to RF-540 analysis. The only fluorescence peaks which resulted from this approach were peaks also associated with unused filters.

One very noteworthy characteristic of the used filters is that they varied substantially in the amount of airborne materials which they had trapped. Because of this, we subjected them to two separate tests. The first of these tests we will call the "Particulate Matter Index" analysis. The second test we will call the "Darkness Index" analysis.

Particulate Matter Index

We numbered each filter consecutively, and placed them on a table. We then arranged them visually from the lightest in color to the darkest in color; none of the filters were as light in color as the unused filters. Two observers worked on the arrangement of filters, and the ultimate order in which the filters were placed was by mutual agreement. If two filters appeared to be identical, the filter which had been in place for the longer period of time was placed in the arrangement as though it had been lighter in color.

The next step was to divide the filters into ten groups based upon their relative darkness. The groups were numbered with group 1 being the lightest in color and group 10 being the darkest in color. We attempted to divide the groups as though they were on an arithmetic scale (such that filters in group 10 were twice as dark as filters in group 5, and that filters in group 8 were twice as dark as filters in group 4, etc.). Upon completion of this, we were convinced that we had developed a reasonable visual scale.

Table 7 summarizes data on the air filters from the Snowball Dining Room. This table indicates that the filters had passed varying quantities of air. To quantify the amount of material trapped in the filters relative to the amount of air passed through the filter we calculated a "Particulate Matter Index" value for each filter. This index value equals the ranking group of the filter (values 1 through 10) divided by the total volume of air (in liters) which had been passed through the filter. The resulting value was multiplied by 100,000 so that index values would always be in excess of 1.0. These values are also shown in Table 7. Observations on airflow patterns existing at the time filters were collected were made by Mr. Carson; they are summarized in Table 8 and are referenced to the filter numbers shown in Table 7.

Table 7
Air filter data and Particulate Matter Index, Snowball Dining Room

Filter Number	Date Placed	Date Recovered	Volume of Air Passed Through Filter (Liters)	Particulate Matter Index (see text)
1	12/12/85	12/18/85	8,580	35.0
2	12/18	12/31	18,765	10.7
3	12/31	1/14/86	20,164	24.8
4	1/14/86	1/31	24,250	28.9
5	1/31	2/21	29,585	16.9
6	2/21	3/7	20,160	34.7
7	3/7	3/27	28,825	3.5
8	3/27	4/15	27,151	25.8
9	4/15	5/2	24,660	8.1
10	5/2	5/21	27,353	14.6
11	5/21	6/19	41,692	9.6
12	6/19	7/9	28,860	6.9
13	7/9	7/31	31,546	3.2
14	7/31	8/21	30,397	9.9
15	8/21	9/12	31,640	6.3
16	9/12	10/3	30,240	3.3
17	10/3	10/30	38,790	15.5
18	10/30	12/1	46,130	17.3
19	12/1	12/29	41,920	19.1

Table 7 (continued)
Air filter data and Particulate Matter Index, Snowball Dining Room

Filter Number	Date Placed	Date Recovered	Volume of Air Passed Through Filter (Liters)	Particulate Mat- ter Index (see text)
20	12/29	1/20/87	31,650	28.4
21	1/20/87	2/24	50,280	17.9
22	2/24	3/18	31,730	22.1
23	3/18	4/20	47,380	16.9
24	4/20	5/20	43,260	13.9
25	5/20	7/2	61,920	4.8
26	7/2	8/4	47,610	2.1
27	8/4	9/2	41,805	2.4
28	9/2	10/16	63,180	6.3
29	10/16	11/18	47,700	16.8
30	11/18	12/28	57,570	13.9
31	12/28	2/1/88	50,285	15.9
32	2/1/88	2/29	41,750	21.6
33	2/29	3/31	44,780	20.1
34	3/31	5/6	51,540	19.4
35	5/6	6/14	56,305	8.9
36	6/14	7/28	63,335	6.3
37	7/28	8/29	46,120	8.7
38	8/29	breakdown between 9/15 and 9/19	24,480 est.	24.5 est.

Table 8
Miscellaneous observations made at time of air filter collections.

Filter Number	Observation by Bob Carson
1	Airflow from elevator shaft area toward Snowball Dining Room.
2	As above
3	As above
4	As above
5	As above
6	As above
7	With increasing surface temperatures the airflow at the Snowball sampling site has reversed and is now flowing from the Snowball Room toward the elevator area.
13	Airflow continues from Snowball toward elevator area.
14	Airflow remains in the general direction from Snowball Room to elevator area; from Snowball Room to Carmichael Entrance; and from Martha's Vineyard to Snowball Room.
17	Mammoth Cave is now in a transition month meteorologically. Daytime high temperatures are above the cave temperature and night time temperatures are below the cave temperature (approximately 54 to 56 degrees F) creating reversing airflow conditions, depending on the outside air temperature. Some of the air is flowing from the elevator area (Marion Avenue) to the Snowball Room (this would be during periods when the outside air temperature is below cave temperature). Other times the air is flowing from Snowball Room to the elevator area (this would be when the outside air temperature is above the cave temperature). This transition period will probably last until December 1 to 15 before the outside air temperatures become "committed" to being below the cave temperature.

Table 8 (continued)
Miscellaneous observations made at time of air filter collections.

Filter Number	Observation by Bob Carson
18	General airflow direction from Elevator area to Snowball Room.
24	Airflow pattern in Snowball Room is from Martha's Vineyard to Snowball Room, then dividing and heading toward the elevator shaft and toward Carmichael Entrance.
26	Air flowing from Martha's Vineyard to Snowball Room then splits to Carmichael Entrance or to elevator.
28	Airflow is oscillating due to surface temperatures alternately being warmer and cooler than the cave.
30	Airflow is from Marion Avenue toward Snowball Dining Room.
33	Airflow is beginning to reverse due to warm surface conditions. In a couple of weeks the airflow will be from Martha's Vineyard to Snowball Room, from Snowball out Marion Avenue and out Cleveland Avenue to Carmichael Entrance.
34	Airflow primarily from Marion Avenue into Snowball Room during this period. Airflow is switching to outcast at entrances, meaning airflow on next filter will be primarily from Snowball into Marion Avenue.
35	Airflow pattern is from Martha's Vineyard to Snowball Room, Snowball Room out to elevator in Marian Ave., and Snowball Room toward Carmichael Entrance. This flow pattern will hold until mid to late September.
36	Airflow is outcast at entrances. Pattern is still from Martha's Vineyard to Snowball Room, then Snowball Room out Marian Avenue (elevator has been downcast and outcast at base into Marian Ave.). Snowball Room airflow also toward Carmichael Entrance. The heat wave has provided exceptional ventilation for the cave.

Table 8 (continued)
Miscellaneous observations made at time of air filter collections.

Filter Number	Observation by Bob Carson
37	Airflow continued to be outcast at entrances. Martha's Vineyard to Snowball then forking at restrooms with some air heading toward Carmichael Entrance and the rest out toward the elevator shaft in Marian Avenue. Airflow has been flowing from base of elevator into Marian Avenue.
38	Motor on airpump failed between 9/15 and 9/19. Airflow has been fluctuating because of cooler surface temperatures, although the primary flow was from Martha's Vineyard to Snowball, then forking to Carmichael Entrance and out toward the Elevator Shaft in Marian Avenue. There were intermittent times of airflow from Marian Avenue to Snowball and out to Martha's Vineyard and Carmichael Entrance to Snowball Room to Martha's Vinyard.

The next step in our analysis was to determine if there were a seasonal pattern in the magnitude of the Particulate Matter Index. The mid-point of each sampling period was determined and was plotted on a graph against the Particulate Matter Index for the sample. Figure 2 shows the data plot. The curve is a 5th order polynomial fit by least squares; the correlation coefficient $r = 0.710$.

The smallest amount of particulate matter in the air filters was trapped during the period June, July, and August. This corresponds with the peak of the tourist season, and the period when the Snowball Dining Room receives the greatest amount of use. In contrast, the greatest amount of particulate matter in the air filters was trapped during December, January, and February. This corresponds with minimum tourism in Mammoth Cave. The particulate matter in the air filters is roughly three times as great under winter conditions as during summer conditions. However, it is worth noting that particulate matter always appears to be present.

Under summer conditions there is airflow from the Snowball Dining Room past the air pump installation to the elevator area. If activities in the Snowball Dining Room were largely responsible for the particulate matter in the air, then this should be the period when the filters would contain the most particulate matter; this is not the case. In fact, the data clearly indicate that activities in the Snowball Dining Room fail to correlate with increased particulate matter in the air filters.

Under winter conditions there is airflow into the cave through many entrances. Additionally, there is airflow from the Historic Tour areas toward the Snowball Dining Room area. Airflow from outside the cave would be an unlikely source for black flecks of carbon; airflow from areas with heavy soot deposits is the probable source for the black material on the air filters in the Snowball area. This corresponds with our fluorescence data discussed earlier.

Figure 2.
Graph of Particulate Matter Index for Air Filter Samples
from the Snowball Dining Room. 1985 through 1988.

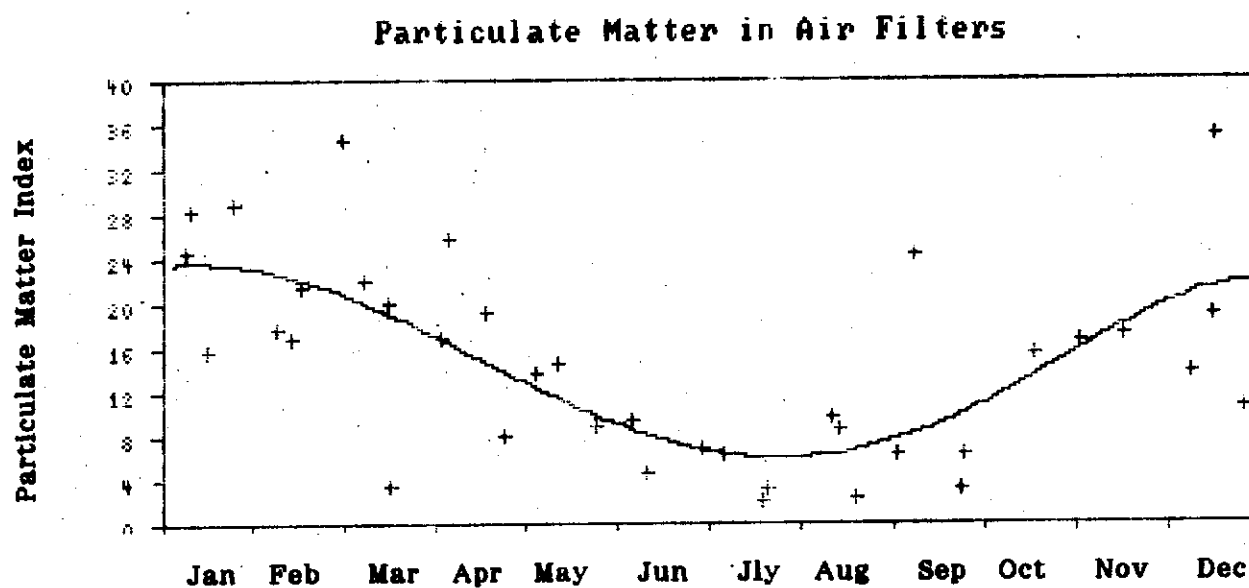


Figure 3 summarizes mean monthly temperature in the Snowball Dining Room area during calendar year 1985. Figure 4 summarizes mean monthly relative humidity during the same period. Similar graphs could be developed for other years. Please note that cave temperatures in the Snowball Dining Room are warmer during the summer than during the winter, and that relative humidity values are lower during the summer than during the winter. These seasonal fluctuations are a reflection of airflow patterns within the cave and interactions between the surface and the cave. Please notice the similarity between the seasonal pattern of relative humidity and the seasonal pattern of particulate matter in air filters.

Darkness Index

We noted earlier that the filters from the alpha radiation sampling equipment were subjected to two separate tests. The first test yielded a "Particulate Matter Index", and has been extensively discussed in the previous section. The present section deals with the second test conducted on the air filters. This second test resulted in the development of a "Darkness Index"

The Particulate Matter Index was based in part upon a qualitative ranking of the filters on a visual scale from 1 to 10. In contrast, the Darkness Index is a more quantitative assessment.

Figure 3. Mean Monthly Temperatures in the Snowball Dining Room, 1985. Data Source: Aley and Aley (1986).

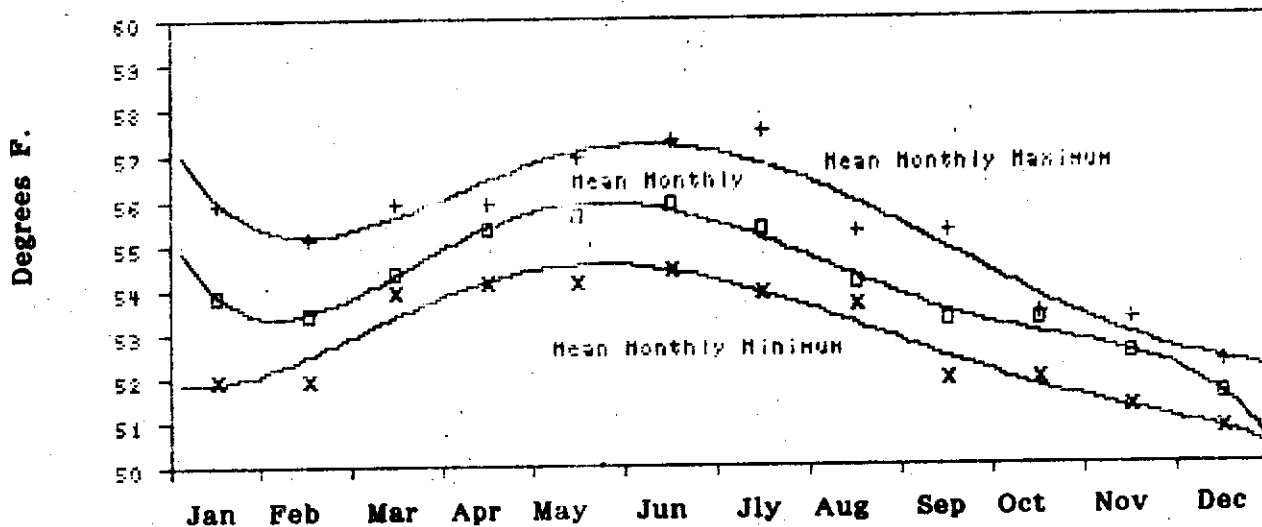
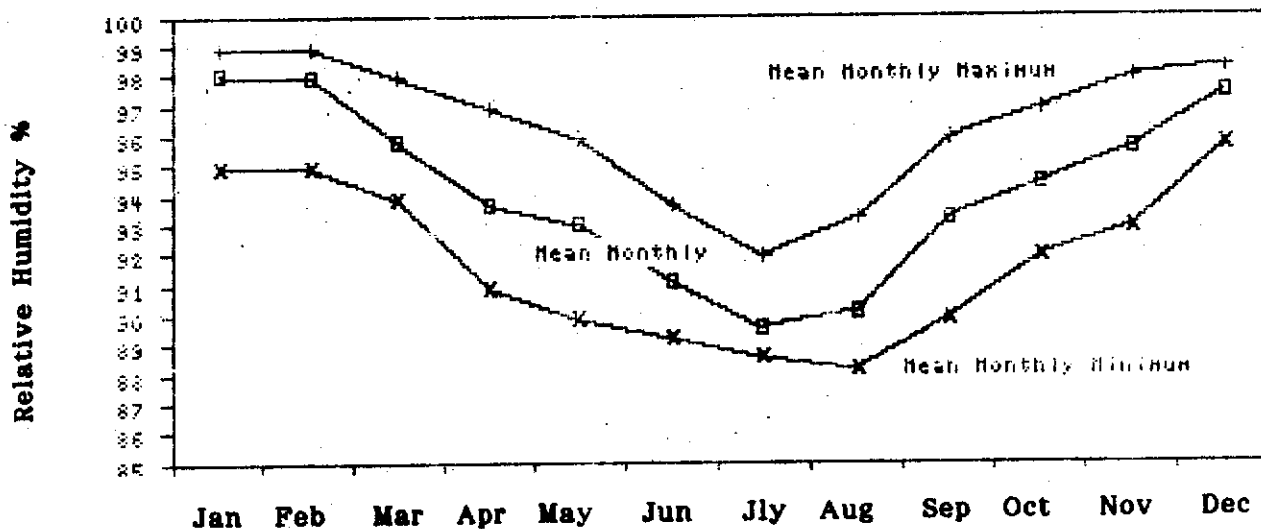


Figure 4. Mean Monthly Relative Humidity in the Snowball Dining Room, 1985. Data Source: Aley and Aley (1986).



RF-540 scans were made of both used and unused air filters. This work demonstrated that some of the greatest fluorescence exhibited by the filters occurs in between about 380 and 480 nm. In general there is a fluorescence plateau relatively free of individual peaks between about 425 and 445 nm.; the plateau is found in both used and unused air filters. The scans also suggested that the magnitude of fluorescence in this wavelength range decreased as the samplers trapped particulate matter; in effect, the particulate matter was obscuring the fluorescence of the underlying filters.

Based upon the observations noted in the above paragraph, we determined the magnitude of fluorescence in all 38 used air filters and in three unused air filters using the RF-540 with the following values set:

Excitation Slit: 5 nm

Emission Slit: 2 nm

Excitation Wavelength: 413.0 nm

Emission Wavelength: 430 nm

This resulted in an index fluorescence value for each of the filters.

The fluorescent values for three unused air filters on the 16X ordinate scale were 56.7, 57.2, and 56.4 units; the mean was 56.8. All used air filters had fluorescence values of less than 56.8 units; this verified our initial impression that particulate matter was obscuring the fluorescence of the underlying filters. Next, we subtracted the observed fluorescence in each filter from the mean fluorescence value of 56.8 units and recorded the value. We called the value the "Darkness Value"; the darker the filter, the larger the Darkness Value.

The next step in our analysis was to incorporate the total volume of air which had passed through the filter into the analysis. We used an approach similar to that used in the calculation of the Particulate Matter Index described earlier. The new value calculated was called the "Darkness Index". The Darkness Index equals the Darkness Value X 100,000 divided by the total liters of air passed through the filter in question. Table 9 shows the Darkness Index values for all samples.

Table 9
Air filter data and Darkness Index, Snowball Dining Room

Filter Number	Date Placed	Date Recovered	Volume of Air Passed Through Filter (Liters)	Darkness Index (see text)
1	12/12/85	12/18/85	8,580	28.0
2	12/18	12/31	18,765	18.1
3	12/31	1/14/86	20,164	55.0
4	1/14/86	1/31	24,250	57.7
5	1/31	2/21	29,585	28.4
6	2/21	3/7	20,160	60.0
7	3/7	3/27	28,825	10.1
8	3/27	4/15	27,151	42.4
9	4/15	5/2	24,660	4.9
10	5/2	5/21	27,353	26.7
11	5/21	6/19	41,692	17.3
12	6/19	7/9	28,860	2.1
13	7/9	7/31	31,546	4.8
14	7/31	8/21	30,397	6.3
15	8/21	9/12	31,640	8.8
16	9/12	10/3	30,240	14.6
17	10/3	10/30	38,790	28.1
18	10/30	12/1	46,130	35.3
19	12/1	12/29	41,920	40.1

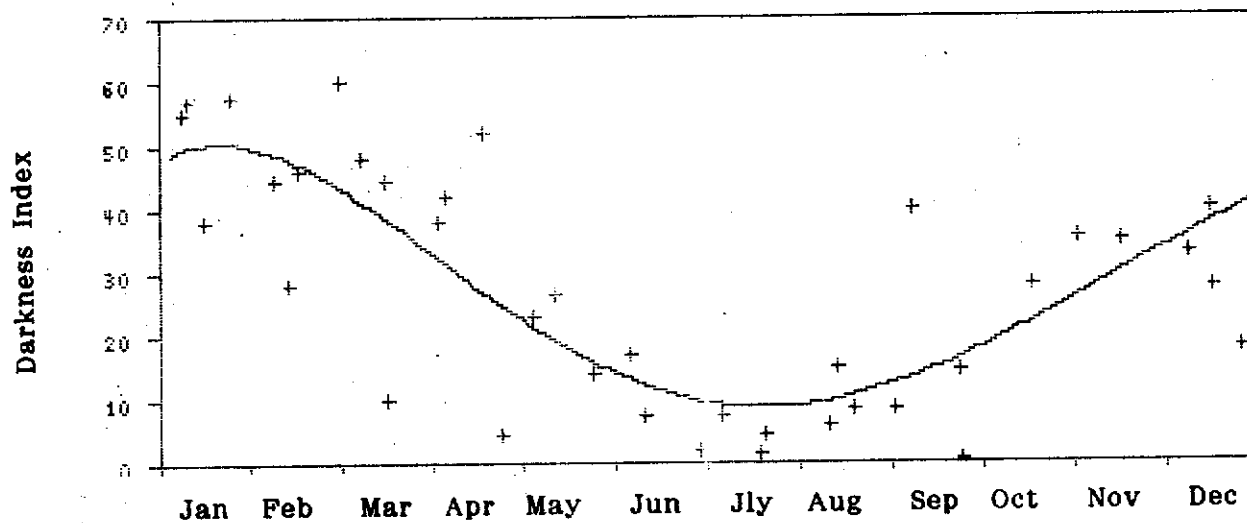
Table 9 (continued)
Air filter data and Darkness Index, Snowball Dining Room

Filter Number	Date Placed	Date Recovered	Volume of Air Passed Through Filter (Liters)	Darkness Index (see text)
20	12/29	1/20/87	31,650	57.2
21	1/20/87	2/24	50,280	44.6
22	2/24	3/18	31,730	48.2
23	3/18	4/20	47,380	38.4
24	4/20	5/20	43,260	23.1
25	5/20	7/2	61,920	7.8
26	7/2	8/4	47,610	1.9
27	8/4	9/2	41,805	8.9
28	9/2	10/16	63,180	0.9
29	10/16	11/18	47,700	35.6
30	11/18	12/28	57,570	33.4
31	12/28	2/1/88	50,285	38.4
32	2/1/88	2/29	41,750	46.5
33	2/29	3/31	44,780	44.7
34	3/31	5/6	51,540	52.2
35	5/6	6/14	56,305	14.2
36	6/14	7/28	63,335	7.9
37	7/28	8/29	46,120	15.4
38	8/29	breakdown between 9/15 and 9/19	24,480 est.	40.0 est.

The next step in our analysis of the Darkness Index was to determine if there were a seasonal pattern in the magnitude of the Index. The mid-point of each sampling period was determined and was plotted on a graph against the Darkness Index for the sample. Figure 5 shows the data plot. The curve is a 5th order polynomial fit by least squares; the correlation coefficient $r = 0.786$.

Figure 5 (which depicts the seasonal fluctuations in the Darkness Index) is remarkably similar to Figure 2 (which depicts the seasonal fluctuations in the Particulate Matter Index). This verifies our earlier interpretations relative to the Particulate Matter Index. The Darkness Index indicates that particulate matter in the air is four to five times greater during winter conditions than during summer conditions, and that there is a pronounced seasonal trend in the amount of particulate matter present.

Figure 5. Graph of Darkness Index for Air Filter Samples from the Snowball Dining Room. 1985 through 1988.



CONCLUSIONS ON THE NATURE OF THE UNNATURAL COATINGS IN THE SNOWBALL DINING ROOM

Findings

Let us summarize a number of findings which have been scattered through the previous discussions. For convenience, they are numbered.

1. Gas chromatograph analysis of the black coatings from the Snowball Dining Room failed to find kerosine, kerosine residues, or animal fats such as are found in canned chili. The failure to detect kerosine or animal fats means one of two things. The first possibility is that these constituents are not implicated in any of the unnatural cave deposits. Logic dictates that this is unlikely to be the case. The second possibility is that kerosine or animal fats may be implicated in the black coatings, but that they have been changed so as to no longer be identifiable as the initial material. Such changing of the initial material could occur through chemical, physical, and/or biological activity. This is the probable explanation. The reader must recognize that the gas chromatograph data do not demonstrate or indicate that kerosine and animal fats are not implicated in the black coatings.

2. The black material in the Snowball Dining Room is composed largely of fungus. Some algae are also present. The biological nature of much of the material is demonstrated by microscopic examination of samples. Additionally, as will be discussed elsewhere, most of the unnatural black coatings in the Snowball Dining Room can be removed by treating with a mist of 5.25% sodium hypochlorite solution. This finding is compatible with the coating consisting largely of fungus, but with some algae also present. In contrast, the black coatings in Salts Cave (derived from pre-Columbian Indian activity) does not include detectable fungal material. Furthermore, this black coating cannot be oxidized with 5.25% sodium hypochlorite.

Extensive scanning spectrofluorometric work was done of samples from the Snowball Dining Room and from other areas in an effort to "fingerprint" materials coating cave surfaces in Mammoth Cave. The resulting data contributed to conclusions #3 through #8.

3. Fluorescence peaks comparable with those present in a water suspension of the soup served in the Snowball Dining Room were not found in any samples from cave surfaces.

4. Fluorescence peaks comparable with those present in cleansing agents used in the Snowball Dining Room and the restroom could not be found in any of the natural cave surface samples. Similar fluorescence peaks were found in wipings from some of the lights in the Snowball Dining Room; this probably resulted from cleaning of the lights rather than via airborne deposition.

5. Unburned kerosine torches and one freshly burned torch contained a fluorescence peak at 616.0 nm; this is probably a kerosine-specific fluorescence peak. Other fluorescence peaks at this wavelength were not found in Mammoth Cave.

6. There is a close correspondence between fluorescence peaks found in the Snowball Dining Room area and those associated with the burning of both pre-Columbian and modern torches. However, it should be remembered that the unnatural black coatings in the Snowball Dining Room are relatively recent developments (and certainly post-date Indian activity).

7. A sample of water used to rinse a black-coated wall in the Snowball Dining Room showed a dominant fluorescence peak at 471.5 nm. Fluorescence peaks at or near this wavelength were found in a total of 4 samples from the Snowball Dining Room, in Sample 6 (remains of a burned NPS kerosine torch), and in all samples from Salts Cave. This clearly shows that deposits from torches are appreciable within the Snowball Dining Room Area.

8. Fluorescence peaks associated with exotic plant growth (primarily algae) are also found in many of the black coatings on cave surfaces both in the Snowball Dining Room and elsewhere. This may indicate that algae are present in many of the black coatings. The more likely explanation is that materials associated with the black coating are also associated with exotic plant growth.

9. Prolonged air sampling in the Snowball Dining Room demonstrated that the concentrations of black flecks of particulate matter in the cave air vary seasonally. Winter concentrations are three to five times greater than those found in the summer; spring and fall are intermediate periods.

10. There are no data to indicate that activities in the Snowball Dining Room are primarily responsible for the black flecks of particulate matter in the cave air. Instead, the data indicate that the black flecks are carbon derived from both National Park Service and Indian torches. Seasonal concentrations in the Snowball Dining Room vary

due to seasonal variations in airflow patterns. Particulate matter concentrations are greatest when airflow is strongly from the more heavily carboned portions of the cave (Historic Tour Area) toward the Snowball Dining Room; concentrations are smallest when airflow is in the opposite direction.

Conclusions

We now wish to provide the reader with an explanation of the black coatings found in the Snowball Dining Room which will assist the National Park Service in making prudent resource management decisions.

The Snowball Dining Room received its name from the white masses of gypsum which resembled snowballs on the ceiling. The ceiling was very light colored at the time the elevator shaft, the restrooms, and the hot food cafeteria were constructed. A few years after all of the construction and changes in this area of the Cave the ceiling turned black (Aley and Aley, 1986).

The ceiling of the Snowball Dining Room turned black because of fungus growth. While there are other unnatural black coatings at other points in Mammoth Cave (and in Salts Cave), appreciable fungal growth does not appear to be associated with these other deposits. The unnatural black coating on the ceiling of the Snowball Dining Room can be removed by lightly spraying it with a 5.25% solution of sodium hypochlorite (which kills the fungus). Other unnatural black coatings tested in Mammoth Cave and Salts Cave cannot be destroyed in this way; that is because they are lacking the dominant fungal presence.

Fungus needs both nutrients and moisture for growth. Important nutrients which may be limited in cave systems are nitrogen, phosphate, and carbon. Mammoth Cave had extensive saltpetre deposits, thus nitrogen is unlikely to be a limiting factor in the cave. Phosphates can be provided from several sources, including lint from visitors clothing. Most detergents contain phosphates; lint routinely accelerates exotic plant growth in caves (Aley and Aley, 1985). The appreciable carbon load in the cave air (from torches and soot) provides a generous supply of this nutrient.

Moisture is undoubtedly a limiting factor for fungal growth in much of Mammoth Cave. Prior to the construction and use of the elevator shaft, the Dining Room, and the restrooms, the Snowball area was a very dry portion of the Cave; that is why gypsum speleothems

existed in the area. Under the unnatural present conditions, a number of activities in and around the Snowball Dining Room add moisture to the cave air and/or to cave surfaces. These include:

- A) Steam tables and similar facilities which keep foods warm.
- B) Steam rising from hot beverages and foods.
- C) Moisture added from washing of tables and the floor in the dining area.
- D) Respiration from people.
- E) Moisture introduced via airflow through the elevator shaft.
- F) Moisture added by hand driers and flush toilets in the restrooms, and by restroom cleaning.

Other portions of Mammoth Cave also have abundant nutrients and several of the activities listed in the previous paragraph, yet they do not have the fungal growth found in the Snowball Dining Room. An example is Great Relief Hall, where activities D and F are even more extensive than in the Snowball Dining Room.

Of the six activities which add moisture to the cave air and/or to cave surfaces, the first three listed are unique to the Snowball Dining Room area. Many of the show caves in the United States routinely wash trails; we have never seen a case where this resulted in extensive fungal growths on cave surfaces. It is the steam and steam mixed with food vapors which are the truly unique conditions found in the Snowball Dining Room.

Black fungal growth is common on the grout between ceramic tiles around showers and bathtubs in American homes. Similar fungal growth sometimes occurs in kitchens. Like the fungal growth in the Snowball Dining Room, the bathroom fungus can be killed and removed with a 5.25% solution of sodium hypochlorite. Also like the fungal growth in the Snowball Dining Room, the bathroom fungus is restricted to areas which routinely receive steam and nutrients for growth. In the bathroom many of these nutrients are provided by soaps (the classical soaps are derived primarily from animal fats). As a final similarity, the grout between the ceramic tiles in the bathroom is gypsum; the majority of the ceiling in the Snowball Dining Room is also gypsum.

In summary, the unnatural black coatings on cave surfaces in the Snowball Dining Room are primarily due to fungal growth. Fungal growth occurs when conditions for such growth are favorable. Nutrients and moisture are essential for fungal growth. The only portion of Mammoth Cave where we have found conditions adequate for extensive fungal growth are within the Snowball Dining Room. We conclude that

this is because of the presence of steam and steam with food vapors in and around the Snowball Dining Room. However, the appreciable amounts of carbon derived from torches burned in the cave provide nutrients for the fungal growth, and thus are a component of the total problem of unnatural black coatings on cave surfaces both in the Snowball Dining Room and elsewhere in the cave.

**POTENTIAL PROBLEMS, LIMITATIONS, AND ADVERSE IMPACTS OF
RESTORATION**

Recommended Restoration Approach

The unnatural black coating found in the Snowball Dining Room is different from soot and other black deposits found elsewhere in Mammoth Cave in that fungal growth is associated with the Snowball Dining Room deposits. Fungal growth is not a major component of other black deposits which we have studied in Mammoth Cave or in Salts Cave. The reader should recognize that the sodium hypochlorite treatment is designed to oxidize the fungal growth found in the Snowball Dining Room. In general, other black deposits elsewhere in Mammoth Cave will not be affected by the sodium hypochlorite treatment.

All restoration work in the Snowball Dining Room must recognize that gypsum speleothems (such as the "snowballs") are very fragile, and that they cannot be physically scrubbed. They are subject to damage from anything more than relatively low water pressures.

Treatment Methods

Our studies indicate that 95% or more of the unnatural coatings on gypsum and limestone surfaces in the Snowball Dining Room can be removed by the following procedure:

1. Apply a mist of bleach (5.25% sodium hypochlorite) to the area to be treated. The first application of the 5.25% sodium hypochlorite solution should use a pump-up tank type sprayer with a wand at least three or four feet long. The sodium hypochlorite should be applied at a rate heavy enough to moisten the surface being treated; however, the application rate should be light enough to minimize drippage from the treated surface. Some drippage will occur and is expected. All drippage and all rinse waters must be collected and removed from the Cave.

2. The treated areas should be rinsed with clean water after the first treatment with the sodium hypochlorite solution. We recommend that treated areas not be rinsed for at least two hours after treatment; a 24 hour period between treatment and rinsing is generally a good approach. This allows time for full utilization of the oxidizing potential of the sodium hypochlorite solution. Shorter periods of time will sometimes be appropriate; an example would be if personnel not involved in restoration work might need to pass beneath a treated area. Because of weekends and holidays, some treated areas may need to remain unrinsed for up to four days; this is satisfactory. Field experience

and logistical considerations should dictate the amount of time between sodium hypochlorite application and rinsing, but a two hour minimum and a four day maximum interval is generally recommended.

The rinsing after the sodium hypochlorite solution treatment is intended to remove as much of the unnatural coating and foreign debris as easily possible. It is intended to rinse the treated surface, not to wash it clean. The rinsing must use low water pressure. We tested a garden hose connected to the water system in the Snowball Dining Room; it produced too much water at too great a pressure. A pump-up pressure tank which applied rinse water as a mist produced adequate results.

3. Re-treat areas with the 5.25% sodium hypochlorite solution as necessary. In most cases a second treatment will be needed on most surfaces; similar treatment equipment to that used in the initial treatment will generally be appropriate.

4. Re-treated areas should be rinsed as in Step 2.

5. Additional sodium hypochlorite and rinse treatments will be needed on a few surfaces. These will be spot treatments, and should be accomplished with spray bottles so that only areas needing treatment receive it. The amount of water used for rinsing should be minimized by rinsing only areas where unnatural coatings are still visible until such time as all treatment has been completed. When all treatment has been completed, the entire surface should receive a final rinse of water.

A "Water-Pik" can be used for detail work where the gypsum crust or rock surface is particularly irregular. Only water should be applied with the "Water-Pik".

Some final detail work can be done with white vinegar (as sold by grocery stores; this vinegar is typically adjusted to 5% acidity prior to packaging). Vinegar treatments are applied by spray bottles to localized areas. The intent of the vinegar treatment is to dissolve the bond between the foreign material and underlying cave surfaces. In the Snowball Dining Room many of these underlying cave surfaces are gypsum. Vinegar treatment will be needed to remove graffiti or to make scratched graffiti less obvious. Repeated treatments with vinegar may be necessary every few minutes; rinsing with water between treatments can be done as seems appropriate. The treated area should be rinsed with water to remove all vinegar and its residue after the

last treatment. Vinegar treatments and sodium hypochlorite treatments should not be conducted in the Snowball Dining Room on the same day since toxic gas may be generated.

Our field testing required about 1 ounce of 5.25% sodium hypochlorite solution for each square foot of surface to be treated. This allowed for two full treatments of all the exposed surface plus one "touch-up" treatment of problem spots. The amount of water used was not measured, but we anticipate that about 10 ounces of water will be needed for rinsing each square foot of surface area. In reality, the amount of water needed will vary with the nature of the surface being treated. We see no sound reason for establishing either a recommended or maximum amount of treating solutions to be applied. Our volume estimates are intended only for general guidance.

Protection of the Cave

Four mil plastic sheets without holes should be placed on natural cave surfaces beneath areas being treated. We have found that plastic sheeting and "kiddle wading pools" are useful for collecting drippage and rinse waters. The wading pools we use are typically about 5 feet in diameter and about 8 inches deep; they can be purchased at toy stores. They are portable and useful in the cave.

We have conducted extensive plant growth studies in Blanchard Springs Caverns, Arkansas; Carlsbad Caverns, New Mexico; and Oregon Caves, Oregon. These studies have demonstrated that 5.25% sodium hypochlorite solutions appear to be ideal for work in caves. We anticipate that weaker solutions would be less effective, and would actually result in heavier application rates to attain the same results. Furthermore, our test indicate that sodium hypochlorite solutions of more than 5.25% are not needed.

Calcium hypochlorite solutions must not be used. Calcium hypochlorite is not as strong an oxidizing agent as is sodium hypochlorite. As a result, more calcium hypochlorite must be applied to attain results comparable to those with sodium hypochlorite. Finally, calcium hypochlorite applications in Carlsbad Caverns (Aley and Aley, 1984) resulted in unnatural calcium chloride deposits on speleothems.

The use of sodium hypochlorite will create unnatural odors in the cave. The odors will decrease over a period of a few hours to a day or so. Small applications on several days is a better approach than a large application on a single day. Odor problems, and many other problems, can be minimized by the use of a small treatment team which

is well trained and well supervised. Damage to the cave can be minimized by having the same team do all of the treatment work; most damage is likely to occur as people get the "feel" of the work.

Careful control of the rinsing phase of the restoration will be necessary to protect cave resources. Water must be applied sparingly; it appears that the best approach will be to use a pressurized tank with a treatment wand. Our tests demonstrated that a garden hose with a pistol grip nozzle was not a desirable approach for washing; it did not provide the degree of application precision needed.

Protection of Workers

Rubber clothing and a full-face respirator appropriate for chlorine gas environments will be required for each person doing the restoration work. Rubber gloves must be worn. All workers must understand that bleach can damage the lungs and other body tissues. Label instructions on bleach bottles should be followed.

Worker safety can be insured by a good treatment protocol and by good training and supervision of workers. Additionally, safety equipment such as respirators and goggles must be both effective and comfortable. It has been our experience that some of the less expensive respirators and goggles are extremely uncomfortable for extended use. Uncomfortable or awkward safety equipment provides an unwarranted incentive for workers to dispense with the equipment.

Our field tests indicate that reasonably large areas (on the order of several hundred square feet) can be treated with 5.25% sodium hypochlorite solution during each work day without creating significant problems. Smaller daily treatment areas are likely to result because of the amount of "detail work" needed.

Literature Review

This literature review focuses solely on potential problems, limitations, and adverse impacts of restoration.

Extensive fungal growth is an uncommon problem in caves. As a result, there is no literature available on the subject. However, moss and algal growth in electrically lighted caves is a major management problem and has received moderate attention in the literature. Detailed discussions of the literature are found in Aley & Aley (1985) and Aley & Aley (1984). These were both contract reports to the National Park

Service, and dealt with the control of exotic plant growth in caves. The standard control procedure involves the application of mist concentrations of 5.25% sodium hypochlorite solutions.

Aley and Aley (1984) conducted studies on the impacts of repeated treatments of 5.25% sodium hypochlorite solutions on calcite speleothem colors in Carlsbad Caverns, New Mexico. They color indexed speleothem and then subjected them to 25 cycles of 5.25% sodium hypochlorite immersion. Some of the test speleothems were rinsed between treatments; others were not. Aley and Aley (1984) were unable to detect any changes in the color index values of any of the test speleothems.

The speleothems found in the Snowball Dining Room are composed of gypsum, not calcite. However, we find no reason to expect any color shifts in the speleothems resulting from the recommended treatments. During our studies in Mammoth Cave and in the associated laboratory work we continually watched for any evidence of speleothem color changes; we saw none.

Aley and Aley (1985) conducted a 480 day study to determine if repeated treatment of calcite speleothems with 5.25% sodium hypochlorite solutions impacted subsequent speleothem deposition. They found no apparent impacts.

Once again, the speleothems in the Snowball Dining Room are composed of gypsum. Calcite speleothems grow at the tips (the end of the stalactite, the top of the stalagmite). In contrast, gypsum speleothems grow at their bases. As a result, the recommended treatment cannot affect speleothem growth in the Snowball Dining Room.

In summary, there is no technical literature to indicate that the recommended restoration work, if it follows the outlined procedure, will result in any significant adverse impacts upon Mammoth Cave.

FINAL FIELD TESTS

Two sets of final field tests were conducted in the Snowball Dining Room. The first set (conducted during March, 1988) consisted of 16 small plot tests (typically involving about 1 square foot) scattered in and around the Snowball Dining Room. We attempted to field test the full array of conditions likely to be encountered during actual restoration work. Before and after photographs were taken of all treatment areas; the resulting photos are of very good quality. They are on file at the Ozark Underground Laboratory.

The black fungal coatings can be almost completely removed from all surfaces tested. Careful rinsing with water produces negligible damage. Some spots will need to be treated several times; "touch-up" (or "detail") work will be a major part of the entire restoration project. It must be emphasized that protection of cave resources requires that all restoration work be done with great care; the cave features are inherently delicate.

A few test plots treated in conjunction with Phase 1 studies were partially re-treated during the March, 1988 studies. The rate of fungal growth re-establishment appears to be slow, at least in the test plots. This does not mean that fungal growth will not become re-established in the Snowball Dining Room even if no management changes are made. The extensive fungal growth did not become established for several years after the start of major nutrient additions and microclimate changes in this portion of the Cave.

Some graffiti has been scrawled on cave surfaces with soot from candles and perhaps from lard-oil lamps. A substantial part of this can be removed using 5.25% sodium hypochlorite solutions followed by water rinses. Additional removal can be accomplished by repeated treatments with vinegar. Note: Sodium hypochlorite solutions and vinegar must never been used at the same time nor should they, or their fumes, be allowed to mix in any way.

Other graffiti has been scratched onto cave surfaces with knives and other sharp metal objects. The scratches are highly visible because of the rock powder trapped in the scratches. This powder can be partially dissolved, and certainly made less obvious, by treating the scratches with vinegar.

Soot from kerosine-soaked rags is found on cave surfaces at various points around the Snowball Dining Room. Sodium hypochlorite solutions do not appreciably affect these unnatural coatings. Much of the dry soot deposits could be collected with a good vacuum cleaner and disposed of outside the Cave. Water, and as necessary vinegar, can be used to remove much of the remaining soot deposits. All produced liquids must be collected and removed from the Cave. A wet/dry vacuum might be a useful tool for use in the restoration work.

The second set of field tests was conducted in May, 1988. During these tests we restored an area of 50.2 square feet in the area above the "Comfort Area" sign in the Snowball Dining Room. Most of the treated area was a vertical surface; most of the surface consisted of gypsum crust containing some irregular pockets.

The May, 1988 field testing required about 1 ounce of 5.25% sodium hypochlorite solution for each square foot of surface to be treated. This allowed for two full treatments of all the exposed surface plus one "touch-up" treatment of problem spots. The amount of water used was not measured, but we anticipate that about 10 ounces of water will be needed for rinsing each square foot of surface area. In reality, the amount of water needed will vary with the nature of the surface being treated. We see no sound reason for establishing either a recommended or maximum amount of treating solutions to be applied. Our volume estimates are intended only for general guidance.

Mr. George Gregory, National Park Service, was present during much of our 1988 field work and became familiar with the cave restoration approaches being used.

The final field tests have clearly demonstrated that the vast majority of the unnatural black coatings in the Snowball Dining Room can be removed by the treatment procedures we have developed. The recommended treatment approach incorporates the findings from the final field test work.

**ASSESSMENT OF OTHER DEVELOPED PORTIONS OF MAMMOTH CAVE
WHERE RESTORATION WORK IS WARRANTED.**

General Conditions

Essentially all developed portions of Mammoth Cave urgently need restoration work to re-establish the natural integrity of the cave system. Unlike the Snowball Dining Room, most of the restoration work would not involve the treatment of almost all cave surfaces. Instead, most of the restoration work needed is localized.

Some unnatural coatings, such as those associated with Indian use of the Cave, should be retained. Such coatings can be identified and maintained. There may also be a few signatures in the Cave of prominent persons; these should be identified and consideration given to retaining them. At present, the coatings of archeological significance, and signatures which may have some historic relevance, are degraded and obscured by debris, graffiti, dirt, and other materials exotic to Mammoth Cave. The point is this; cave restoration will enhance and maintain features of archeological and historic significance. Cave restoration work does not represent a threat to any meaningful cultural resources.

Restoration of cave surfaces to restore near-natural conditions is needed to offset eight identified situations which have developed in Mammoth Cave. Each of these situations is described in the following paragraphs.

Graffiti

Initials, names, and obscenities are scratched, carved, lipsticked, pencilled, smeared, and painted onto cave surfaces throughout Mammoth Cave. The resulting impression is more in keeping with the world's longest service station restroom than with a unit of the National Park System. There is unquestionably more graffiti in Mammoth Cave than in any other American show cave, whether private or public. Furthermore, unlike other American show caves, large amounts of graffiti are annually added to the defacement of Mammoth Cave. Graffiti appears to breed graffiti; the defacement is an epidemic problem at Mammoth Cave. The graffiti epidemic is at its worst along the Historic Tour.

Development of a set of techniques for removing graffiti or decreasing its visibility is beyond the scope of the present contract. However, there are some useful techniques that warrant at least brief mention.

Scratches in rock or speleothems can be made substantially less visible by treating them with vinegar. This "ages" the scratches. We suspect that fresh graffiti provides an encouragement to other visitors to add their own defacement; treating the scratches will reduce this encouragement. Some smoked or painted graffiti can be removed with vinegar; this works particularly well with gypsum substrates.

A water slurry of five or more parts of cave sediment to one part of Portland cement will closely approximate the color of many cave surfaces. Other cave materials, such as powdered fragments of broken gypsum, can also be used in slurry preparation. The slurry can then be applied, with an artist's paint brush, on scratches and carved letters. The slurry should not be applied to unscarred surfaces. After drying, the treated area is sprayed with vinegar and then rinsed with water. Control over color balances can be attained by using Munsell color charts for soils to obtain the color of the marred surface. With standard mixes of sediments, cement, etc., one can appropriately match color tones and do a good job of restoring the marred surface.

Solutions of 5.25% sodium hypochlorite will remove some foreign substances adhering to cave surfaces. Peanut oil will "lift" some lipsticks from cave surfaces. A Water-Pik is a particularly useful tool for washing off graffiti; it tends to be less destructive than brushes, although an assortment of brushes (including tooth brushes) have their place in graffiti removal work.

Much graffiti can be removed by washing cave surfaces with water. It is not always necessary to scrub. Other limestone surfaces can be restored by lightly scrubbing affected areas and then rinsing with a mist of water. In a test area in Great Relief Hall we were able to almost totally remove all scratched-in graffiti using this procedure. The rinsing with a mist of water helps remove brush marks.

Kerosine Torch Debris

Cotton rags soaked in kerosine are used in lighting displays in various parts of Mammoth Cave. They produce large amounts of smoke which contains substantial amounts of particulate matter ("soot") which is transported through the cave by air currents. There are many soot deposits in the Cave as well as unburned remnants of torches.

Areas with heavy soot deposits can be washed to restore the natural integrity of the cave surfaces. Unburned torch fragments can be picked up; some of the soot in the vicinity of the torch fragments can be collected with a portable vacuum cleaner.

Exotic Plant Growth

We found algae, moss, moss protonema, lichens, and fungus growing on cave surfaces in various portions of Mammoth Cave. This material can be oxidized with 5.25% solutions of sodium hypochlorite; some such work is already being done in parts of the Cave.

Lint

Visitors to the Cave add large amounts of lint, hair, and other foreign material. Substantial accumulations of these materials can be found in various places in Mammoth Cave. Caves are enclosed spaces unwashed by rains; like buildings, they are not self-cleaning. Collection and removal of lint from show caves is a component of the normal "house-keeping" of such facilities.

Dust

Many of the trails in Mammoth Cave are unpaved; they consist of compacted cave sediments. The passage of tours over such trails, particularly during periods of lower relative humidity, adds substantial dust to the cave air. This dust ultimately deposits on all cave surfaces. After the passage of a tour one can beam a light down a cave passage and readily see the dust in the air. The dust, which includes organic materials tracked into the Cave by visitors, is an important source of unnatural coatings in Mammoth Cave.

This problem could be reduced by installation of concrete trails in place of the compacted sediment. Such trails would need to be routinely cleaned; if water were used for the washing it should be disposed of outside of the Cave. Once such trails were installed, the dust could be washed from cave surfaces.

Clay Worms

Clay worms (vermiculations) consist of mixtures of sediments, lint, and exotic plants. They are limited to areas where cave surfaces are at least occasionally wet. They are common in areas near the vertical shafts on the Historic Tour, and are undoubtedly found elsewhere. They are unnatural deposits associated with use of the Cave. They can be removed by treating with 5.25% sodium hypochlorite solutions (to kill the exotic plant growth), and then washing to remove them from the natural cave surfaces.

Cement, Concrete, and Mortar

Careless workmanship, particularly by those installing lighting systems, has left substantial amounts of cement, concrete, and mortar on cave surfaces. Cement dust adheres to cave surfaces and must be dissolved to remove it. It can sometimes be removed with vinegar; it is sometimes necessary to use muriatic acid such as routinely used for the cleanup of mortar work. Dilute sulfuric acid can also be used.

Much of the concrete and mortar can be removed by careful chisel work. It often bonds poorly to the underlying dirty surfaces. Final cleanup requires muriatic acid or dilute sulfuric acid.

Disturbed Cave Floors

Floors of show caves are yet another surface which needs, yet seldom receives, management attention. Most cave floors within toured (or formerly toured) portions of Mammoth Cave have been extensively disturbed and often substantially modified. Rock and soil debris from trail construction (let's call this material "rubble") has typically been piled or thrown on cave surfaces. This material needs to be removed from the cave or else it should be moved to a point where it can be incorporated in the trail. The "rubble problem" is found throughout National Park Service caves; it is also found in some private show caves. Within the National Park System major efforts are underway at Oregon Caves National Monument to remove such rubble; lesser efforts are underway at Wind Cave and Carlsbad Caverns to deal with this situation. Efforts at rubble removal (or at least rubble incorporation within trails) should begin at Mammoth Cave.

Cave trails should enhance visitor enjoyment of a cave while protecting cave resources. Most of the trails in Mammoth Cave provide little protection for those cave resources present on the floor of the cave. Many trail segments within Mammoth Cave are not of "trail" dimensions; instead, they more nearly approximate the width of county roads. Trails need to be narrowed to protect more of the natural resources found on the cave floors.

Many of the cave trails consist of packed earth rather than concrete. Such trails cannot be washed; as a result of this and the wearing away of the trail by foot traffic, tours put substantial amounts of particulate matter into the cave air. Cave trails should be made of concrete rather than earth. Cave trails should not be paved with asphalt as it has deleterious impacts on cave features.

Unused trail segments, old restroom walls, and other similar facilities should be removed when they are no longer of use. There are "monuments" found in portions of the cave; they date from periods when guides would encourage visitors to pick up rocks and stack them as part of cave "development". While a few of the monuments might have some historical interest, the majority are simply inappropriate human modifications of cave features. Most of the "monuments" should be torn down and the rocks restored to a more nearly natural positioning.

Restoration Priorities

Passages in the Vicinity of the Snowball Dining Room

Restoration work should be done in the Snowball Dining Room first. The restoration should include adjacent passages to which the problems of the Snowball Dining Room have spread.

We conducted studies during our May, 1988 field work to assess the extent of areas in the vicinity of the Snowball Dining Room which warrant restoration treatment. Our study approach was to select one foot square sites at 50 foot intervals along each of the three passages leading from the Snowball Dining Room. Each selected site was treated with 5.25% sodium hypochlorite solution and then rinsed after approximately 1/2 hour. The extent of restoration was then qualitatively noted. The results are summarized in the following three tables (Tables 10, 11, and 12).

Table 10

Cleveland Avenue from Snowball Dining Room Toward Specimen Avenue.

0 feet is edge of chained-off dining room area.

Distance	Extent of Restoration
50 ft.	Little improvement noticeable from trail, but much unnatural material is removed. Substrate gypsum crust.
100 ft.	Significant improvement. Limestone surface is changed from a black surface to its original golden tone.
150 ft.	Very significant improvement. Gypsum crust; total cleaning of knobs on the gypsum which had been black.
200 ft.	Minor improvement. Gypsum crust; most of black on crust was not removed by the treatment.
250 ft.	Modest improvement. Gypsum crust with small crystal blades. Much material was removed, but visual impact was not very pronounced.
300 ft.	No detectable change. Gypsum crust with small, slender gypsum flowers.

Table 11

Tour Route Extending Beyond the Restrooms.
0 feet is edge of large paved area past the restrooms.

Distance	Extent of Restoration
50 ft.	Very little change. Substrate is a lumpy gypsum crust.
100 ft.	Restoration is very noticeable when examined closely. From the trail the extent is not very noticeable. Substrate is gypsum crust.
150 ft.	Little change with sodium hypochlorite treatment. Substrate is gypsum crust. Cement dust has been thrown on the ceiling in this area; it needs to be removed. Removal will require repeated applications of vinegar. Use of the Water-Pik will probably help dislodge flecks of the cement. If similar flecks of cement or concrete are found elsewhere on limestone substrates, our experience in cave restoration at Oregon Caves National Monument suggests that treatment will require muriatic acid as available in building supply stores for the clean-up of masonry work. Dilute sulfuric acid could also be used. All treated surfaces must be rinsed with water.
200 ft.	Some restoration accomplished, but it is not dramatic. Substrate gypsum crust with small blades.
250 ft.	Very little restoration accomplished. Substrate is gypsum crust with coral-like appearance.
300 ft.	Very little restoration. Substrate is lumpy gypsum crust.

Note: There is some cleaning at all stations along this passage. There is dust and lint present on most surfaces.

Table 12

Passage from Cafeteria to Elevator.
0 feet is at the first light post next to kitchen.

Distance	Extent of Restoration
50 ft.	Major restoration accomplished. Substrate is limestone with a gypsum band in the center.
100 ft.	Major restoration. Substrate is gypsum with a very fragile weathering crust that breaks with anything more than a gentle mist of water. Demonstrates need for careful and observant restoration workers.
150 ft.	Very noticeable restoration. Substrate a lumpy gypsum crust.
200 ft.	Visual impact of restoration not very noticeable. Substrate is limestone.
250 ft.	Very little change. Substrate is limestone.
300 ft.	Major restoration. This station is just past the elevator, and it located near the end of the unnatural black coatings on the ceiling.

Restoration Recommendations for Passages in the Vicinity of the Snowball Dining Room.

1. Localized restoration work will be needed along all three passages leading from the Snowball Dining Room. There is appreciable dirt and lint on most of these surfaces; a water rinse of all rock and gypsum surfaces prior to any sodium hypochlorite treatment would be appropriate for most of these passages. This will generally reduce the amount of sodium hypochlorite needed. However, the approach outlined for the Snowball Dining Room (application of sodium hypochlorite prior to any water rinsing) should be applied to all areas where the unnatural coatings are extensive and appear to be generally similar to those found in the Dining Room area.

2. Restoration work should extend for about 300 feet along all three of the passages leading from the Snowball Dining Room.

Historic Tour Area

A segment of the Historic Tour is being relighted. One objective of the relighting is to lessen the visual impacts of the existing graffiti and to decrease the frequency with which new graffiti is added. We strongly recommend that cave restoration work be conducted in conjunction with this relighting work for two primary reasons. First, it will provide a good example of the natural resource benefits which can be achieved with appropriate lighting and cave restoration work. Secondly, the unnatural cave surface alterations which have occurred in this area are different from those found in the Snowball Dining Room. As a result, this area will be an appropriate area for developing other necessary cave restoration approaches.

Restoration of Other Areas

Restoration of other areas of Mammoth Cave is also needed, yet we recommend that they generally be deferred until such time as restoration work has been completed in the Snowball Dining Room area and along the Historic Tour.

**MANAGEMENT RECOMMENDATIONS FOR PREVENTING OR MINIMIZING
UNNATURAL COATINGS ON CAVE SURFACES**

Introduction

This section of the report is concerned with the following issues:

1. Development of a history of use in Mammoth Cave which will be useful in characterizing the nature and extent of activities associated with the unnatural coatings in Mammoth Cave.
2. Identification and evaluation of visitor use and management activities which appear to be associated with unnatural coatings in Mammoth Cave.
3. Development of specific management recommendations relative to preventing of minimizing unnatural coatings on cave surfaces.

Our studies have focused primary attention on the Snowball Dining Room. The unnatural coatings in the Snowball Dining Room are associated with fungal growth. This is not a significant problem elsewhere in Mammoth Cave. Because of this, we have divided our discussions into those primarily relevant to the Snowball Dining Room area and those primarily relevant to other portions of Mammoth Cave.

Unnatural Coatings in the Snowball Dining Room Area

The Snowball Dining Room is located in a natural chamber within Mammoth Cave. This chamber is about 190 feet long and averages about 45 feet wide. Much of the ceiling is relatively flat, and is typically 7 to 8 feet above the floor. The highest ceiling areas in the Snowball Dining Room are in the cooking and serving area where they are 12 to 15 feet high.

The floor of the Snowball Dining Room has been covered with concrete. There are 51 dining tables in the chamber as well as counters, tables, and other features characteristic of a 1960 vintage roadside cafeteria which serves simple, but hot, lunches.

Adjacent to the Snowball Dining Room are restroom facilities with flush toilets and hot air hand driers. Another passage from the Snowball Dining Room leads to an elevator which connects with the surface. Adjacent to the walkway and the elevator is a sewage pumping station which pumps raw sewage from the cave to the surface for treatment and disposal.

The Snowball Dining Room was named for the white and light yellowish brown gypsum which coats about 60% of wall and ceiling surfaces in the chamber. The remainder of the surfaces are limestone bedrock which is not coated with the gypsum crust. The natural gypsum crust consists of somewhat translucent crystals; the surface is both irregular and fragile. Many pieces of the gypsum crust have been broken by previous visitors and removed from the cave (presumably for souvenirs). However, the remaining gypsum (were it not coated with the unnatural deposits which are the focus of this study) is extremely beautiful.

The Snowball Dining Room area was a common stopping point for tours for many years prior to the construction of the elevator shaft. Visitors ate box lunches, drank wine (as indicated by the bottle fragments along the trail), and undoubtedly enjoyed "the snowballs" on the ceiling.

In the late 1950's, as a part of Mission 66, the elevator shaft and all other improvements in the area were constructed. The ceilings and walls remained reasonably white until after these facilities were installed. Aley and Aley (1986) included as a fronticepiece a photo of the Snowball Dining Room taken about 1960. The ceiling was relatively white at the time, but some grey coatings were already appearing on the ceiling. Aley and Aley (1986) also included a photo of the Snowball Dining Room copyrighted in 1977. It showed black deposits on the ceiling. By 1986 the magnitude of the black deposits was substantially greater than in the 1977 photograph.

Fungus, with some incorporated algae, is the primary material producing the black coatings on cave surfaces in and around the Snowball Dining Room. In order for fungus to grow one needs organic material, nutrients, and moisture. All of these necessities are provided by the facilities constructed in the late 1950's. Our recommended strategy for preventing or minimizing fungal growth on cave surfaces is to restore more nearly natural organic material, nutrients, and moisture budgets to this part of Mammoth Cave.

Reducing the Addition of Organic Material

Some organic material is transported into the cave by visitors. Some results from the cooking and/or heating of foods. Some is transported into the cave by air flows. The following management actions will reduce the addition of organic material to the Snowball Dining Room area.

1. Substantial organic material is tracked into the cave on visitors shoes. Much of the cave floor is dirt, so walkways cannot be cleaned. This results in appreciable amounts of dust being raised by tour groups; the dust consists of cave sediments and the organic materials tracked into the cave. Much of this dust is trapped on cave walls and ceilings, especially if these surfaces are rough textured or moist. Paved trails which could regularly be cleaned would reduce the accumulation of unnatural coatings on cave surfaces.
2. The elevator shaft is an obvious entry route for organic materials. Effective air-lock door systems at both the top and bottom of the elevator shaft would reduce the input of organic material and would help re-establish more natural microclimate conditions in the Snowball Dining Room portion of the Cave.
3. There are no mats or grates for wiping shoes at either the top or bottom of the elevator. Such mats, if periodically cleaned, will reduce the input of organic matter into the Cave. Similarly, periodic washing of the concrete trail from the elevator to the Snowball Dining Room will help; the wash waters should not be disposed of in the Cave.
4. Heating or cooking of foods and beverages adds appreciable organic material to the Cave. Furthermore, convective air flows bring much of this organic material into contact with the cave ceiling and walls. The food service area does not have any of the ceiling grease chutes normally found in restaurants; as a result, the organic matter is permitted to escape into the Cave. Any hot food or beverage is a part of the problem. The problems could be reduced by doing no cooking or heating of foods within the Cave; hot food might be brought into the Cave in vacuum jugs or similar containers. Prevention of the problem would require the end to all hot food and beverage service.
5. The restrooms at the Snowball Dining Room use electric hand dryers. Not only do these put substantial amounts of moisture into the air, but they also transfer organic compounds from visitors' hands into the cave air. These hand dryers should be removed and replaced with paper towels.

Reducing the Addition of Nutrients

The following management actions will reduce the addition of nutrients to wall and ceiling surfaces in the Snowball Dining Room area:

1. Large amounts of lint derived from visitors' clothing is added to show caves. The lint is high in phosphates (derived from laundry soaps and detergents). Studies in Carlsbad Caverns and Oregon Caves have shown that lint greatly accelerates exotic plant growth in caves; it is likely that it also contributes to fungal growth. There is a large amount of lint present on cave surfaces throughout Mammoth Cave; it is highly visible in the Snowball Dining Room if one examines walls and ceilings with a strong ultraviolet light. More effective housekeeping of the Cave will tend to reduce lint accumulations.

2. Carbon is also a plant nutrient. The throwing of torches (made of cotton soaked in kerosine) in the cave adds substantial amounts of carbon particulates and unburned hydrocarbons (some of which are probably carcinogenic) into the cave air. Many of these particulates will plate out on cave surfaces. In addition, the torch throwing in Mammoth Cave results in major defacement of the natural features of the Cave, and may increase the health risk associated with natural alpha radiation in the Cave. There are a number of reasons why this practice should be ended. It is likely that some carbon from the torch throwing does reach the Snowball Dining Room area.

3. We have noticed concession employees sweeping cave sediments and other materials from paved surfaces near the cooking area onto adjacent sediment slopes. This adds dust (and incorporated nutrients) to the air and, ultimately, to cave surfaces. Use of wet vacuums would seem to be a more appropriate housekeeping technique.

4. Storage of cardboard boxes and other items seems to provide favorable conditions for cave crickets. The close proximity of the elevator entry may also be implicated in the large cricket populations noted in the Snowball Dining Room. Cave biology studies have found that cricket guano can be an important component of cave food chains; cricket guano may also be a significant source of nutrients for fungal growth in the Cave. Management actions should be taken to rectify situations which unduly enhance cave cricket populations in the Snowball Dining Room area.

Reducing the Addition of Unnatural Moisture

The following management actions will reduce unnatural moisture additions to the Snowball Dining Room area.

1. Air-lock door systems for both the top and bottom of the elevator.
2. Removal of electric hand dryers from the restrooms.

3. Removal of the steam tables from the Dining Room.

Unnatural Coatings Elsewhere in Mammoth Cave

A previous section of this report titled "Assessment of Other Developed Portions of Mammoth Cave Where Restoration Work Is Needed" detailed the nature and extent of unnatural coatings in portions of Mammoth Cave other than the Snowball Dining Room. The reader may wish to review this section.

Mammoth Cave has been visited by people for centuries. Indians lighted their way with torches, and probably (as was the case in Salts Cave) built fires within the Cave for light. Saltpetre workers also added to the soot accumulation within the Cave. Underground tours with lard oil lamps, kerosine torches, and kerosine lanterns also added to the soot. The continued use of kerosine torches continues to add to the carbon deposits within the Cave; this has been discussed at length earlier in this report. The net result of all of these activities is that there is a tremendous amount of soot within the Cave system.

Studies discussed earlier in this report clearly show that carbon particles (soot) are transported through the cave by air currents. The carbon particles deposit on features throughout the cave. The extent of this carbon deposition is nicely demonstrated by old light fixture along Cleveland Avenue; they are noticeably coated (and discolored) by the deposition.

Sediment from cave floors has also become airborne and has deposited unnaturally on cave walls and ceilings and degrades cave features. Undoubtedly, the sediment has been derived from dust associated with the saltpetre mining; from trail construction and passage clearing; and from visitors walking along unpaved and unwashed trails.

If the use of torches were discontinued, and if visitors did not walk on unpaved surfaces, would the deposition of unnatural soot and sediment on cave surfaces cease? The answer is no, although the magnitude of the deposition would be decreased (and probably by a substantial amount). The solution to the problem is to clean the cave of all unnatural deposits (except perhaps for a few which could be retained as a historical curiosity), and then to prevent activities which would contribute to a new wave of the same problems. These activities include the use of unpaved trails and the continued throwing of kerosine-soaked torches.

Management Recommendations

1. National Park Service management must recognize that, unlike some modern ovens, caves are not self-cleaning. Mammoth Cave needs an extensive cleaning and restoration program to restore the cave to near-natural conditions. Components of this cleaning and restoration program are listed below.

2. All trash must be removed from the cave. Many tons have been removed as a result of actions by the present Superintendent; the work must continue.

3. Construction debris and rubble must be removed from the cave or else must be incorporated as fill material in restored trails.

4. Widths of cave trails must typically be reduced to allow visitors to see a more nearly natural cave system and to reduce the extent of cave trampling by visitors. The final trails should be paved to reduce the amount of dust put into the air by tour groups. Paving must not allow cement dust to enter the cave atmosphere. The trails must be designed so that they can periodically be washed to remove unnatural materials from the cave; the wash waters must be collected and pumped out of the cave. This can be done with a properly designed trail.

5. The nature of the cave passages and the desired quality of the tour to be provided must determine the location, design, and size of the restored cave trail. The resulting trail in turn determines the maximum size of tour groups and the necessary spacing interval between tour groups.

6. Disturbed areas along trails must be restored to near-natural conditions. Soot deposits on cave floors must be collected and removed. Graffiti must be removed from cave surfaces and the surfaces restored to near-natural conditions. Cement, concrete, lipstick, and all other unnatural materials must be removed from cave surfaces. Walls and ceilings must be washed with water; the wash water should generally be collected and removed from the cave. Steam cleaning of some cave surfaces may be necessary or desirable. In simple terms we are recommending a full restoration of the cave passages.

7. After full restoration of cave passages, adequate lighting systems must be installed. These lighting systems must provide an excellent display of the significant features of Mammoth Cave.

8. Periodic cleaning and restoration work are just as necessary in a show cave as they are in any other indoor space accessible to the public. This must be recognized by National Park Service management, and it must receive adequate budgets.

REFERENCES

Aley, Thomas and Catherine Aley. 1984. Control of exotic plants in Carlsbad Caverns. Final Report. Contract report to National Park Service by the Ozark Underground Laboratory. 131p. + map.

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Aley, Tom and Cathy Aley. 1986. Restoration techniques for removing unnatural black coatings from cave surfaces in the Snowball Dining Room, Mammoth Cave, Mammoth Cave National Park, Kentucky. Contract report to Mammoth Cave National Park by the Ozark Underground Laboratory. 106p.

APPENDIX A

**Fluorescence Peaks for 50 Samples Collected in Mammoth Cave and
Salts Cave.**

Observed Fluorescence Peaks by Sample Number, RF-540 Analysis

Station Number	Fluorescence Peak
1.000000	405.000000
1.000000	609.400000
2.000000	356.500000
2.000000	554.200000
3.000000	593.000000
4.000000	616.000000
5.000000	616.000000
6.000000	372.400000
6.000000	396.100000
6.000000	415.400000
6.000000	428.300000
6.000000	454.000000
6.000000	471.200000
6.000000	495.900000
6.000000	533.200000
8.000000	424.000000
8.000000	454.200000
8.000000	471.500000
8.000000	496.900000
8.000000	510.500000
8.000000	533.200000
8.000000	570.000000
9.000000	338.100000
9.000000	421.700000
9.000000	471.400000
9.000000	496.700000
9.000000	531.800000
9.000000	592.100000
10.000000	409.000000
10.000000	423.900000
10.000000	454.500000
10.000000	471.200000
10.000000	497.900000
10.000000	511.800000
10.000000	532.000000
10.000000	549.200000
10.000000	774.500000
11.000000	352.700000
11.000000	409.100000
11.000000	454.700000
11.000000	471.400000
11.000000	497.200000
11.000000	511.300000
11.000000	787.900000
12.000000	494.000000

Observed Fluorescence Peaks by Sample Number, RF-540 Analysis

Station Number	Fluorescence Peak
13.000000	397.900000
13.000000	413.500000
13.000000	425.200000
13.000000	453.900000
13.000000	467.000000
13.000000	496.900000
13.000000	509.200000
13.000000	532.700000
13.000000	786.300000
14.000000	380.600000
14.000000	400.000000
14.000000	408.800000
14.000000	423.000000
14.000000	455.300000
14.000000	471.100000
14.000000	484.500000
14.000000	497.000000
14.000000	510.300000
14.000000	529.300000
14.000000	645.900000
14.000000	772.400000
15.000000	334.200000
15.000000	384.300000
15.000000	395.800000
15.000000	408.000000
15.000000	453.900000
15.000000	471.000000
15.000000	497.100000
15.000000	510.800000
15.000000	532.200000
15.000000	774.800000
15.000000	787.500000
16.000000	401.000000
16.000000	408.000000
16.000000	425.100000
16.000000	454.500000
16.000000	471.700000
16.000000	500.800000
16.000000	537.200000
16.000000	551.400000

Observed Fluorescence Peaks by Sample Number, RF-540 Analysis

Station Number	Fluorescence Peak
17.000000	420.000000
17.000000	454.100000
17.000000	471.400000
17.000000	497.900000
17.000000	511.600000
17.000000	532.500000
17.000000	549.700000
17.000000	772.900000
17.000000	786.300000
18.000000	382.900000
18.000000	408.900000
18.000000	421.100000
18.000000	454.200000
18.000000	471.400000
18.000000	497.600000
18.000000	510.400000
18.000000	533.000000
18.000000	773.600000
18.000000	786.800000
19.000000	360.100000
19.000000	409.100000
19.000000	454.200000
19.000000	471.200000
19.000000	499.200000
19.000000	537.100000
19.000000	550.300000
19.000000	774.100000
20.000000	330.900000
20.000000	354.600000
20.000000	399.600000
20.000000	424.100000
20.000000	454.500000
20.000000	471.600000
20.000000	498.200000
20.000000	513.500000
20.000000	533.100000
20.000000	549.700000
20.000000	774.900000
20.000000	788.300000

Observed Fluorescence Peaks by Sample Number, RF-540 Analysis

Station Number	Fluorescence Peak
21.000000	354.000000
21.000000	384.200000
21.000000	396.100000
21.000000	408.500000
21.000000	422.300000
21.000000	454.700000
21.000000	471.700000
21.000000	536.200000
21.000000	551.100000
21.000000	773.400000
21.000000	786.600000
22.000000	340.300000
22.000000	409.400000
22.000000	454.100000
22.000000	471.400000
22.000000	497.400000
22.000000	512.000000
22.000000	772.900000
22.000000	787.400000
23.000000	357.000000
23.000000	409.400000
23.000000	454.400000
23.000000	471.500000
23.000000	497.300000
23.000000	510.700000
23.000000	530.800000
23.000000	773.100000
23.000000	785.100000
24.000000	408.500000
24.000000	423.900000
24.000000	454.500000
24.000000	471.400000
24.000000	485.000000
24.000000	499.400000
24.000000	535.800000
24.000000	549.800000
24.000000	772.200000
24.000000	786.700000
25.000000	455.500000

Observed Fluorescence Peaks by Sample Number, RF-540 Analysis

Station Number	Fluorescence Peak
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26.000000	513.400000
26.000000	454.900000
26.000000	471.500000
26.000000	483.000000
26.000000	495.800000
26.000000	504.800000
28.000000	356.300000
28.000000	408.000000
28.000000	487.200000
28.000000	541.400000
28.000000	591.700000
29.000000	602.300000
30.000000	605.000000
30.000000	647.700000
31.000000	599.200000
32.000000	349.800000
32.000000	590.000000
33.000000	599.800000
34.000000	357.500000
34.000000	382.000000
35.000000	605.600000
36.000000	422.900000
36.000000	454.000000
36.000000	471.400000
36.000000	484.200000
36.000000	497.100000
36.000000	510.700000
36.000000	534.400000
37.000000	421.300000
37.000000	454.400000
37.000000	471.600000
37.000000	498.700000
37.000000	515.100000
37.000000	536.300000
37.000000	549.300000
37.000000	572.300000

Observed Fluorescence Peaks by Sample Number, RF-540 Analysis

Station Number	Fluorescence Peak
38.000000	361.800000
38.000000	381.100000
38.000000	396.300000
38.000000	409.200000
38.000000	454.000000
38.000000	471.400000
38.000000	484.900000
38.000000	496.400000
38.000000	511.000000
38.000000	531.800000
38.000000	550.000000
38.000000	571.500000
38.000000	650.000000
40.000000	345.000000
40.000000	595.000000
41.000000	345.000000
41.000000	496.700000
41.000000	597.700000
42.000000	456.300000
42.000000	474.000000
43.000000	600.100000
44.000000	410.100000
44.000000	454.100000
44.000000	471.200000
44.000000	497.400000
44.000000	511.000000
44.000000	529.600000
44.000000	550.000000
44.000000	774.600000
45.000000	412.000000
45.000000	424.100000
45.000000	454.500000
45.000000	471.500000
45.000000	497.800000
45.000000	511.200000
45.000000	531.000000
46.000000	539.900000
47.000000	374.700000
47.000000	409.100000
47.000000	454.200000
47.000000	471.200000
47.000000	497.800000
47.000000	510.400000
47.000000	530.700000
47.000000	773.800000

Observed Fluorescence Peaks by Sample Number, RF-540 Analysis

Station Number	Fluorescence Peak
---------------------------	--------------------------

48.000000	409.000000
48.000000	424.600000
48.000000	454.700000
48.000000	471.900000
48.000000	498.500000
48.000000	510.100000
48.000000	531.000000
48.000000	756.600000
49.000000	341.400000
49.000000	353.000000
49.000000	471.300000
49.000000	498.500000
49.000000	502.000000
50.000000	454.700000
50.000000	471.600000
50.000000	499.500000
50.000000	512.500000
50.000000	536.000000
50.000000	776.600000

Observed Fluorescence Peaks by Wavelength, RF-540 Analysis

Fluorescence Peak	Station Number
330.900000	20.000000
334.200000	15.000000
338.100000	9.000000
340.300000	22.000000
341.400000	49.000000
345.000000	40.000000
345.000000	41.000000
349.800000	32.000000
352.700000	11.000000
353.000000	49.000000
354.000000	21.000000
354.600000	20.000000
355.300000	28.000000
356.500000	2.000000
357.000000	23.000000
357.500000	34.000000
360.100000	19.000000
361.800000	38.000000
372.400000	6.000000
374.700000	47.000000
380.600000	14.000000
381.100000	38.000000
382.000000	34.000000
382.900000	18.000000
384.200000	21.000000
384.300000	15.000000
395.800000	15.000000
396.100000	6.000000
396.100000	21.000000
396.300000	38.000000
397.900000	13.000000
399.600000	20.000000
400.000000	14.000000
401.000000	16.000000
405.000000	1.000000
408.000000	15.000000
408.000000	16.000000
408.000000	28.000000
408.500000	21.000000
408.500000	24.000000
408.800000	14.000000
408.900000	18.000000
409.000000	10.000000
409.000000	48.000000

Observed Fluorescence Peaks by Wavelength, RF-540 Analysis

Fluorescence Peak	Station Number
409.100000	11.000000
409.100000	19.000000
409.100000	47.000000
409.200000	38.000000
409.400000	22.000000
409.400000	23.000000
410.100000	44.000000
412.000000	45.000000
413.500000	13.000000
415.400000	6.000000
420.000000	17.000000
421.100000	18.000000
421.300000	37.000000
421.700000	9.000000
422.300000	21.000000
422.900000	36.000000
423.000000	14.000000
423.900000	10.000000
423.900000	24.000000
424.000000	8.000000
424.100000	20.000000
424.100000	45.000000
424.600000	48.000000
425.100000	16.000000
425.200000	13.000000
428.300000	6.000000
453.900000	13.000000
453.900000	15.000000
454.000000	6.000000
454.000000	36.000000
454.000000	38.000000
454.100000	17.000000
454.100000	22.000000
454.100000	44.000000
454.200000	8.000000
454.200000	18.000000
454.200000	19.000000
454.200000	47.000000
454.400000	23.000000
454.400000	37.000000
454.500000	10.000000
454.500000	16.000000
454.500000	20.000000
454.500000	24.000000
454.500000	45.000000

Observed Fluorescence Peaks by Wavelength, RF-540 Analysis

Fluorescence Peak	Station Number
454.700000	11.000000
454.700000	21.000000
454.700000	48.000000
454.700000	50.000000
454.900000	26.000000
455.300000	14.000000
455.500000	25.000000
456.300000	42.000000
467.000000	13.000000
471.000000	15.000000
471.100000	14.000000
471.200000	6.000000
471.200000	10.000000
471.200000	19.000000
471.200000	44.000000
471.200000	47.000000
471.300000	49.000000
471.400000	9.000000
471.400000	11.000000
471.400000	17.000000
471.400000	18.000000
471.400000	22.000000
471.400000	24.000000
471.400000	36.000000
471.400000	38.000000
471.500000	8.000000
471.500000	23.000000
471.500000	26.000000
471.500000	45.000000
471.600000	20.000000
471.600000	37.000000
471.600000	50.000000
471.700000	16.000000
471.700000	21.000000
471.900000	48.000000
474.000000	42.000000
483.000000	26.000000
484.200000	36.000000
484.500000	14.000000
484.900000	38.000000
485.000000	24.000000

Observed Fluorescence Peaks by Wavelength, RF-540 Analysis

Fluorescence Peak	Station Number
487.200000	28.000000
494.000000	12.000000
495.800000	26.000000
495.900000	6.000000
496.400000	38.000000
496.700000	9.000000
496.700000	41.000000
496.900000	8.000000
496.900000	13.000000
497.000000	14.000000
497.100000	15.000000
497.100000	36.000000
497.200000	11.000000
497.300000	23.000000
497.400000	22.000000
497.400000	44.000000
497.600000	18.000000
497.800000	45.000000
497.800000	47.000000
497.900000	10.000000
497.900000	17.000000
498.200000	20.000000
498.500000	48.000000
498.500000	49.000000
498.700000	37.000000
499.200000	19.000000
499.400000	24.000000
499.500000	50.000000
500.800000	16.000000
502.000000	49.000000
504.800000	26.000000
509.200000	13.000000
510.100000	48.000000
510.300000	14.000000
510.400000	18.000000
510.400000	47.000000
510.500000	8.000000
510.700000	23.000000
510.700000	36.000000
510.800000	15.000000
511.000000	38.000000
511.000000	44.000000
511.200000	45.000000
511.300000	11.000000

Observed Fluorescence Peaks by Wavelength, RF-540 Analysis

Fluorescence Peak	Station Number
511.600000	17.000000
511.800000	10.000000
512.000000	22.000000
512.500000	50.000000
513.400000	26.000000
513.500000	20.000000
515.100000	37.000000
529.300000	14.000000
529.600000	44.000000
530.700000	47.000000
530.800000	23.000000
531.000000	45.000000
531.000000	48.000000
531.800000	9.000000
531.800000	38.000000
532.000000	10.000000
532.200000	15.000000
532.500000	17.000000
532.700000	13.000000
533.000000	18.000000
533.100000	20.000000
533.200000	6.000000
533.200000	8.000000
534.400000	36.000000
535.800000	24.000000
536.000000	50.000000
536.200000	21.000000
536.300000	37.000000
537.100000	19.000000
537.200000	16.000000
539.900000	46.000000
541.400000	28.000000
549.200000	10.000000
549.300000	37.000000
549.700000	17.000000
549.700000	20.000000
549.800000	24.000000
550.000000	38.000000
550.000000	44.000000
550.300000	19.000000

Observed Fluorescence Peaks by Wavelength, RF-540 Analysis

Fluorescence Peak	Station Number
551.100000	21.000000
551.400000	16.000000
554.200000	2.000000
570.000000	8.000000
571.500000	38.000000
572.300000	37.000000
590.000000	32.000000
591.700000	28.000000
592.100000	9.000000
593.000000	3.000000
595.000000	40.000000
597.700000	41.000000
599.200000	31.000000
599.800000	33.000000
600.100000	43.000000
602.300000	29.000000
605.000000	30.000000
605.600000	35.000000
609.400000	1.000000
616.000000	4.000000
616.000000	5.000000
645.900000	14.000000
647.700000	30.000000
650.000000	38.000000
756.600000	48.000000
772.200000	24.000000
772.400000	14.000000
772.900000	17.000000
772.900000	22.000000
773.100000	23.000000
773.400000	21.000000
773.600000	18.000000
773.800000	47.000000
774.100000	19.000000
774.500000	10.000000
774.600000	44.000000
774.800000	15.000000
774.900000	20.000000
776.600000	50.000000

Observed Fluorescence Peaks by Wavelength, RF-540 Analysis

Fluores- cence Peak	Station Number
785.100000	23.000000
786.300000	13.000000
786.300000	17.000000
786.600000	21.000000
786.700000	24.000000
786.800000	18.000000
787.400000	22.000000
787.500000	15.000000
787.900000	11.000000
788.300000	20.000000