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Cave Dwelling Dust Bunnies: Lint Accumulation and Microplastics in Lewis and Clark Caverns State Park

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Cave Dwelling Dust Bunnies: Lint Accumulation and Microplastics in Lewis and Clark Caverns State Park

Senior Honors Thesis

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For Completion of Honors in Undergraduate Studies
B.A. Environmental Policy and Project Management
Carroll College, Helena, Montana
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Abstract

As Montana’s only “show cave”, Lewis and Clark Caverns attracts 65,000 people annually during the summer season, from May to September. Tours are guided, and visitors may pass through carefully but still leave lint particles behind. As these particles get deposited and build up, they have the potential to damage cave formations and alter the existing low energy environment. In order to understand how lint affects cave environments more exploratory information is needed. There does not appear to be methods developed for measuring lint accumulation, or identifying what the lint is made from. With this in mind, this study attempted to answer questions about lint accumulation and identification in Lewis and Clark Caverns State Park. Ultimately, the results from this study would be applied to help cave management decipher which areas are most impacted by lint, and therefore develop mitigation methods to lessen impacts.

Many other “show caves” have utilized lint suppression techniques such as using wind tunnels and misters to prevent lint from being deposited in the cave. Due to the unique nature and location of the Lewis and Clark cave system, lint suppression techniques used at other locations will not work; therefore low tech techniques such as using brushes to get fibers off before entering the cave, were explored instead.

Overall, this study was successful in setting up future research opportunities by providing a baseline of lint accumulation and composition, which can be used to compare with studies conducted in the future.
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Introduction

In the early 1900’s, Lewis and Clark Caverns, became Montana’s only “show cave”. Attracting 65,000 visitors a year, the cave shows signs of heavy human impact such as graffiti, broken formations, and the accumulation of lint on walls and cave formations. Of these impacts, lint is the most concerning because 1) it occurs even with well-supervised tours, 2) it is not as obvious as other impacts, and 3) it has the potential to cause more damage beyond simply being deposited in the cave. Very few studies have quantified the amount or composition of lint introduced to show caves, and the impacts of lint in cave systems is poorly understood (Burger and Pate, 2001). Lint accumulation in Lewis and Clark Caverns has never been studied or even described, although management efforts include removal of lint in certain areas based on conversations with current park staff. In order to gain some idea of the degree and potential impacts of lint deposition in Lewis and Clark Caverns, this study was developed with an exploratory approach in mind. Ultimately, this study is designed to understand how and where lint is being deposited in the cave in order to provide resource managers a better understanding of how they may control lint accumulation and/or mitigate impacts. Additionally, learning more about the composition of the lint, may improve our understanding of how it may impact the cave environment.

Background and Literature Review

Show Caves: Human Impacts, Preservation and Management Concerns

Show caves tend to attract a large number of visitors as they offer a safe way to get a glimpse of the lesser-known, but fascinating, underground world. Although visitation and guided tours are an excellent way to educate people about the wonders of these delicate resources, it’s also necessary to consider the impacts this recreational opportunity has on the cave systems. There are currently hundreds of developed “show caves” throughout the world, and each of these
are managed differently between private, state, and federal sectors. State and federal entities such as the National Park Service and state resource management agencies are often concerned with maintaining the resource not only for aesthetic reasons, but also due to the unique and delicate resources these caves contain. For example, Wind Cave National Park in South Dakota contains 98% of the world’s box work, (a unique and delicate calcite honeycomb formation on cave ceilings), and it is considered the world’s most complex cave. Improper management of this cave would result in an irreversible loss of valuable and unique resources. Wind Cave, fortunately, is one cave system where research on visitor impact, specifically lint, has been conducted (Jablonsky, 1993).

Human impact is obviously a concern when it comes to managing cave resources. Human impacts include litter, graffiti, vandalism, increased carbon dioxide levels, and the deposition of lint and organic matter (Burger and Pate, 2001). Cave stewards and managers must consider each of these human impacts when making decisions about how to develop and manage a “show cave”. In general, none of these impacts are very well understood, but lint has been identified as a recurring and persistent issue in “show caves” as it is both hard to prevent and hard to remove once deposited.

**Known Impacts of Lint in Show Caves**

Lint is introduced to cave environments by the excessive number of people that enter the delicate ecosystem. ‘Lint’, as defined by the Oxford dictionary, is “short, fine fibers that are separate from the surface of cloth or yarn.” It may also include dust, and skin particles that humans shed daily. Pat Jablonsky, who has investigated the impacts of lint accumulation, at Wind Cave National Park, notes that lint can harm cave formations directly by providing nutrients for acid producing organisms that can dissolve limestone (Jablonsky et al., 1993). In
her study, Jablonsky focused on the compositional makeup of the lint, using forensic methods to identify the natural versus synthetic fibers (Jablonsky et al., 1993). It has been discovered that lint can eventually alter the pH and nutrient load in cave environments (Jablonsky et al., 1993; Vaughan et al., 2011). It has been suggested that lint can also alter the biological ecosystem in caves, by adding nutrients to the naturally low energy environment, thus allowing high-energy organisms to out-compete low adapted energy organisms (Jablonsky et al., 1993). Jablonsky notes that during the 1991 cave cleanup in Carlsbad Caverns, volunteers were noticing that thick mats of lint were causing noticeable damage to formations beyond aesthetics. The formations were showing obvious pitting. Jablonsky goes on to note the cause of this damage is unknown; however, it is probable that the lint mats may cause dense microbial communities to form, which interact negatively with the cave formations (Jablonsky et al., 1993). Research conducted in Guadalupe Caves has suggested that microorganisms in biofilms may be producing acids as a byproduct of oxidizing reduced compounds from cave walls (Northup et al., 2000). These reduced compounds can include lint. Additionally, if left on formations for too long, the lint can be incorporated into the formations as they grow (Marech, 2014).

**Questions Remaining about Lint**

While it has been suggested that introduced lint poses a threat to sensitive cave microbiomes, it is still a relatively understudied problem (Jablonsky et al., 1993; Vaughan et al., 2011). In particular the potential impact and fate of natural vs. synthetic fibers has not been explored. In recent years, synthetic fibers have become a more common component of clothing. The International Union for Conservation of Nature has shown that between 1993 and 2010 there was a 79.3% increase in the use of synthetic materials (Boucher and Friot, 2017). Clothing articles such as sweatshirts and fleeces are often made of synthetic fibers entirely, or are a 50/50
blend of cotton and polyester. About 63% of our clothing is made of synthetic fibers (Boucher and Friot, 2017). This is represented in the fibers deposited as lint in cave environments. “Microplastics” (plastic fragments that are less than 5 mm in length) have become an environmental concern within the last decade (National Oceanic and Atmospheric Administration, 2017). Synthetic clothing fibers are one of the most abundant sources of microplastics in the environment (Boucher and Friot, 2017). As of this writing, no research has focused on microplastics in cave environments.

The study of the impact of lint in caves is in its scientific infancy, with methods for collection, analysis, and mitigation still being improved. Further, the use of quantitative lint studies has not been generally adopted into cave management programs. Since lint removal methods are both time consuming and have their own impacts (Maerch, 2014), the prevention or mitigation of lint entering a cave may be more valuable than removal and clean up after it has been introduced. The best-known technique currently is to scrub the rocks frequently with tooth brushes and small hand brushes (Marech, 2014). This study attempts to develop collection methods that will allow for repeat studies, long-term monitoring, and hopefully will help inform and evaluate mitigation techniques.

Study Area: Lewis and Clark Caverns

Lewis and Clark Caverns are located in the Jefferson Canyon near Whitehall, Montana (Figure 1).

The caverns were formed in the Mississippian-aged Madison Limestone, among

Figure 1: Location of Lewis and Clark Caverns (Google Maps, 2019).
multiple layers of carbonate rocks approximately 1500 feet thick. This formation is widespread across the Rocky Mountains and Great Plains. The limestone was formed through the deposition of calcium carbonate mud in warm, shallow seas that covered much of interior North America during the Mississippian period about 330 to 340 million years ago (Peale, 1893). The Madison Group in Montana includes two formations within, including a lower Lodgepole Formation containing more shale, clay and mudstones, and an overlying Mission Canyon Formation composed primarily of massively bedded fossiliferous limestone (Peterson, 1984). The caves have formed in the soluble limestones at the base of the Mission Canyon Formation, perched above the more impermeable Lodgepole (Aram 1979). Between their formation 330 million years ago and formation of the caves around 2 million years ago, the Mississippian-age limestones were buried by continuous sedimentation through the Mesozoic period. During the Late Cretaceous about 70 million years ago, The Laramide Orogeny caused regional folding and faulting of the sedimentary rocks in SW Montana, including those in the Madison group (Peterson, 1984). The folded mountain ranges and block-faulted valleys created during the Laramide tectonic event were then filled with Tertiary sediments derived from the eroding mountains and regional volcanic ash deposition.

The relative depth of the Madison limestone, age and thickness of younger sediments, and timing of valley incision led Aram (1979) to conclude that the caves most likely formed during the early Quaternary period when the Jefferson River began downcutting into the Tertiary
valley fill and eventually the limestones beneath. Once exposed by erosion of the overlying sediments, the Madison limestones were subjected to karst erosion by acidic surface waters characteristic of a climate wetter than today. As down-cutting of the Jefferson River continued, the karst features were left ‘high and dry’ above the valley. Karst erosion then ceased and the caves began accumulating small amounts of fine sediment washed in via localized drainages (Aram 1979).

Local Native American groups knew about the cave pre-contact, yet there seems to be little “cultural” use of it (Janiskee, 2010). The cave was first found by European settlers in 1892 (Janiskee, 2010). Local ranchers, Tom Williams and Burt Pannell, found the cave in 1892. Williams returned in 1898 and ventured into the first sections of the cave. Upon realizing its potential value, Williams approached Dan Morrison, a local miner who was operating in the area. Morrison, with the help of his miners, implemented a tour route that included thousands of wooden stairs (Janiskee, 2010). Morrison’s tours continued under the loose management of the National Park Service until about 1932 when Morrison passed away and the State of Montana acquired the cave for the development of a state park in 1935 (Janiskee, 2010). Today, as Montana’s only “show cave”, Lewis and Clark Caverns attracts about 65,000 visitors annually. There are several tour routes available including a heavily used “classic” tour, an occasionally
scheduled “Wild Cave Tour”, and a special candle light tour around Christmas time, with the majority of visitors during the summer between June and August.

The Civilian Conservation Corps (CCC) developed the modern tour route still used today referred to as the “Classic Tour”. The Classic Tour closely follows Morrison’s original route, but adds the bottom section of the cave and excludes several rooms used today only on the “Wild Cave Tour.” The Classic Tour route is about three-quarters of a mile, and includes about 600 stairs. To access the cave, visitors have a three-quarter mile hike to the entrance. The tour then spends about an hour and a half within the cave before exiting 300 feet directly below where it entered. To make the cave easier to access, various passages have been blasted larger and tunnels have been added to better connect cave locations.

The Wild Cave Tour initially follows the Classic Tour route, but adds 2.5 extra rooms originally used on Morrison’s tour. Although these extra rooms are not used by the Classic Tour Route, it is possible that there is impact from the heavier use on the nearby Classic Tour trail.

The other 70% of the cave, for safety and resource management reasons, is unused commercially. It is accessed sporadically (only one or two times each year) by FWP/cave guides and managers, and therefore provides a relatively ‘undisturbed’ area for study (this unused portion of the cave system is referred to as “Off Trail” in this study). In total, there is about 3 miles of explored and mapped passages (Aram, 1979; Richards, 2006) (Figure 3).
The cave is highly decorated and contains rare formations known as helictites (a seep stone that essentially overcomes the pull of gravity and forms “noodle like” formations (Figure 4). Other features include stalactites, stalagmites, seep-stone conglomerates (also known as popcorn), and numerous types of flowstones including ribbon rock (cave bacon). The cave formations, on average, grow about 1 cubic inch every 100 years with the exception of the last room in the cave. The 98% humidity in the Paradise Room, and close surrounding sections allows the formations there to grow at a rate of about 1 cubic inch every 10 years (Aram, 1979).

Lewis and Clark Caverns cave system provides an excellent study area for multiple reasons. First of all, I have worked for Montana FWP as a cave tour guide at Lewis and Clark Caverns State Park for 3 seasons, and therefore possess a reasonable understanding of cave structure, visitor behaviors, and potential study locations. The cave is easily accessible with developed trails leading to and from the cave, yet due to the nature of Montana’s weather, the park closes for the winter months. This means the cave experiences heavy use for 5 months, but is then allowed a “reset” time of low visitor impact and an opportunity for cleaning and conservation efforts. A defined time period of heavy visitor use combined with a known number of visitors and different frequencies of trail use provide an ideal setting to study the impacts of ‘visitor introduced lint’ in the cave. Systematic sampling methods and strategic sampling sites potentially provide a comprehensive baseline study. The cave also presents the opportunity to compare different levels of use. Overall, the cave presents the perfect opportunity to fully evaluate how lint and human
introduced particulates are deposited, what they are composed of, and what happens to them.

**Study Goal and Significance**

The overall goal of this study is to describe and quantify the amount, rate of accumulation, and composition of lint in Lewis and Clark Caverns. The results are might aid in resource protection. Currently, the lint problem is managed by annual ‘lint removal expeditions’. This study was developed to understand where the highest amount of particulate matter is being deposited, and to assist in targeted cleanup protocols. Additionally, this study was developed to gain a better understanding of the composition of the different fiber types, and what the longer-term impacts of different fiber types might be.

A better understanding of lint accumulation in the cave system will help inform park managers, tour guides, and the public about a previously understudied visitor impact. Additionally, the results of this research may also allow cave managers to direct cave cleaning efforts to areas that are most likely to accumulate lint and perhaps even develop ways to mitigate or reduce the amount of lint entering the cave. Generally, park staff and cavers are aware of the effects of touching formations, and leaving food and trash within cave systems. This study contributes to a better understanding of a less obvious but equally important impact of cave visitors and seeks to improve our overall understanding of visitor impacts on delicate cave ecosystems.

**Project Scope and Research Questions**

This reconnaissance level study is a first attempt to better understand and quantify the presence and potential impacts of lint in Lewis and Clark Caverns. This study is primarily descriptive, with specific research questions and hypotheses framed as follows:

**Research Questions and Hypotheses:**
1. **Can we quantify the amount and composition of lint accumulating in Lewis and Clark Caverns**
   Hypothesis I: By collecting and analyzing lint in traps, and lint accumulated on cave walls and pools, we can establish a general accumulation rate and persistence rate. Hypothesis II: By examining lint particles themselves, we can describe and quantify composition and identify potential sources of lint.

2. **Does the amount or composition of lint vary through the cave in relationship to trail use, distance from entrance, or over time?**
   Hypothesis I – Use: Heavily used trails (Classic Tour route) will have more lint accumulation than less used and unused areas of the cave. Hypothesis II – Trail Distance: The amount of lint and composition of lint particles will change in relationship to distance from the cave entrance. Hypothesis III - Time: Historical tour routes (pre-synthetic clothing) may have different lint composition than ‘modern’. Older lint deposits (on walls) will have different composition compared to lint caught in traps.

3. **Can better understanding of lint accumulation and composition improve resource protection and management practices?**
   Hypothesis: Baseline information on sources and distribution of lint in the cave may improve our methods for protecting the resource by educating visitors, managing human impacts, and also monitoring efficacy of mitigation efforts in the future.

**Objectives and Methods**

**Objective 1:** Develop methods to collect, describe, and analyze lint deposits in Lewis and Clark Caverns, and develop an understanding of the composition of deposited particulates.

**Methods:** In order to describe and quantify the lint accumulated throughout the cave we first had to: 1) develop standardized lint collection techniques that are repeatable and that provide both descriptive and quantitative data, then 2) describe and quantify composition of lint particles and
determine possible sources, and finally, 3) determine net accumulation rates at different sites over course of one season.

**Lint Collection - Lint Traps:** We designed and crafted lint traps modeled after Tauber pollen traps (Bittnera, 2017; Giesecke, 2010). Each trap consisted of a Tupperware container covered with a 1/2 inch metal mesh to prevent pack rats from trekking through deposited fibers. Traps were placed in strategic locations (see sample site discussion below) for the duration of the five-month tour season, beginning from May 15, 2018 to September 15, 2018. The traps were revisited once each month for the duration of the project to ensure they were not missing or disturbed. Any disturbance was noted as some traps were moved repeatedly by cave visitors. Some traps also accumulated enough water to almost fill the traps. This trap water was periodically emptied into sealed containers and stored in a refrigerator, and the trap returned to its previous location. At the end of the season all traps and supplemental storage containers were sealed and transported to Carroll College for analysis. The lint collected in each trap thus represents the net amount of ‘new’ lint introduced to the cave in one visitor season.

**Accumulated Wall Lint:** Lint stuck to the walls of the cave has accumulated over numerous seasons. In order to compare ‘older’ lint deposits from walls, with the ‘new’ or fresh lint from the current season (lint traps), we collected representative samples of different amounts of lint by plucking it off the walls with tweezers. The amount collected from sites was pretty loosely correspondent with the amount of total lint present at the site. Sites sampled for wall lint, or “fuzz balls” had a corresponding trap for later comparison.

**Transportation and Preparation of Samples:** On September 15th, we returned to the cave to collect all traps. They were sealed in 1-gallon Zip-Lock bags. Occasionally, the sharp edges on the metal mesh would puncture the bags, therefore the holes were covered with duct tape as they
occurred. Once in the lab, each trap was rinsed with a very small amount dilute solution of sodium hexametaphosphate ($\text{NaPO}_3)_6$ and water passed through a membrane via reverse osmosis to remove any adhered particulate matter. The sodium hexametaphosphate was intended to break static bonds between the fibers and the lint traps, thus allowing most of the particulates to be rinsed into sealed containers. The containers were then placed in the fridge to prevent evaporation and the breakdown of fibers.

**Identification and Description of Lint Particles:** Rinsed water samples were transferred to 100 mL beakers and evaporation-boiled down to just under 20 mL to make the sample volume easier to manage. The samples were then transferred back to their sealed containers and the beakers were rinsed to ensure that any lint transferred with the water got back to the sealed containers.

**Particulate Composition and Description:** The entire 20 mL sample for each trap was poured into a gridded petri dish and analyzed under a dissecting microscope at 10X power (Figure 5). The samples were first described in detail (see Appendix A), including descriptions of unusual particles, and general appearances of the sample. From these initial descriptions a scheme to classify the majority of identifiable particles into categories was devised. The categories include Fiber, Mineral, Hair, Plant, and Other. “Other” includes particles that were unidentifiable or includes organics such as packrat and mouse waste. To then determine the relative percentage of particles in each sample, the petri dishes were shaken gently to randomly disperse particles throughout the dish. Because traps placed in different locations of the cave contained significantly varied amounts of lint, I scaled my counting and classification of particles accordingly (details
regarding tour routes and logic of trap placement are further described in ‘Sampling Strategy’ section below).

- **Classic Tour Route:** first 50 particles identified within two randomly located fields of view (10x power) for total of 100 particles
- **Wild Cave Tour:** first 100 particles identified in the entire dish
- **Off Trail Cave:** first 50 particles identified in the entire dish.

After analysis, the fibers and water were transferred back to their sealed containers for later measurement of net weight. The percentages for each class of particulate matter per trap were calculated then used as a series of data to look for significant differences between particle classes. I used two-tailed t-tests with an alpha level of 0.05 to make pairwise comparisons between sites for each fiber type. For example, fiber particulate percentages for the Classic Tour were compared to fiber particulate percentages for the Wild Cave Tour, and so on, to test the null hypotheses of no significant difference in particle percentage. This was done for each particulate type in each of the three frequencies of use.

**Fiber Types:** A large proportion of the particles in the traps were classified as ‘fiber.’ Since the origin, impact, and fate of fiber from clothing are so important to the understanding of cave lint, I further classified fibers into four categories: **cotton, wool, human-hair, synthetic and ‘other’**. This was done by subsampling the fiber component of the lint from each petri dish after particle counts. The subsamples were taken after shaking the sample to randomize distribution of fibers. Using a pipet, fibers and water were extracted from areas of the containers that had visually high amounts of fibers. Since I was only

![Figure 6: Fiber types were distinguished using identification keys and characteristics applied in forensic studies (Bernoti 2012). As an example, cotton fibers resemble flattened firehoses, where polyester and other synthetic fibers are larger with round or other distinctly ‘manufactured’ cross-section shape. Wool and hair have scales, however wool is noticeably thicker than hair](image-url)
interested in fibers during this stage, I avoided drawing from the bottom where mineral particulates had accumulated. Two subsamples from each trap sample were placed on separate microscope slides and viewed at 250X. Using fiber identification tools developed for forensic analyses each fiber was visually identified and categorized as cotton, wool, human-hair, synthetic and ‘other’ fiber types (Jablonsky, 1993; Bernoti, 2012) (Figure 5 and 6). The ‘Other’ category included unidentifiable fibers that were too significant in size to ignore. The first 15 fibers observed in each of the two slides were recorded. Then the percentages of each fiber type were calculated based on all 30 fibers detected. The subsamples were then rinsed back into their respective sealed containers so as not to lose any lint fibers for net weight analysis. The percentages of the fibers for each trap were then used as a data series to look for significant differences between each of the three use levels and fiber types. For example, synthetic fiber percentages for the Classic Tour Route were compared to the synthetic fiber percent for the Wild Cave Tour Route. This step was repeated for each fiber type until all of the fibers within each use frequency had been compared the other two use frequencies.

**Lint Accumulation Rate per Site (Net Weight):** Lint accumulation rates from different areas of the cave were determined by weighing total mass of particles caught in individual traps over the course of one five-month visitor season. The net weight of particles was very small for some traps, therefore a very high precision scale was necessary. Bison Engineering in Helena was kind enough to let us use their analytical scales. In order to measure net weight, each sample was filtered through 47 mm diameter Nylon filters, with pore size of 41 microns. This particular filter type was selected because it would allow the sodium hexametaphosphate and other solutes from sample processing to be rinsed through without adding to the net weight.
The weighing process required desiccating the filters for 24 hours to remove water weight. They were subsequently re-weighed, desiccated again for 6 hours and re-weighed again, and the average of the two re-weighed measurements was used as the tare weight of the filter. Each sample was then filtered through a pre-weighed filter, using Buchner funnels and a vacuum to help move water more quickly through the filters. Filters with captured particulates were then dried in an oven at a low heat for two hours to evaporate any excessive water. The filters were then desiccated and weighed twice again following the same procedure described above. The tared filter weight was then subtracted from the total weight, leaving only the weight of the lint from each sample. This information was important to determine the net amount of particulate matter deposited in the traps, and therefore how different use levels affect overall amount of lint deposition (Jablonsky et. al, 1993). The data on particle composition, fiber type, and net weight were then used for comparison between different samples sites at different locations around the cave in order to explore and test potential correlations and relationships between lint and trail use as well as other variables.

**Objective 2: Testing variables that might influence introduction, accumulation and fate of lint in caves: Trail Use, Distance/Proximity, Age of Lint**

Methods: The variables or factors that could influence the presence, impact, and ultimate fate of lint particles were identified as 1) *trail use / visitor numbers*, 2) *proximity to cave entrance* or trail and 3) *age of the lint* (time since deposition). To test these variables, a strategic sampling strategy was devised to collect samples from sites representing different settings covering: heavy to light trail use and visitor numbers, distance along trail from entrance, and ‘new’ vs ‘older’ lint deposits. Descriptions of the different settings and sampling sites are described below:
Variable Trail Use: As described above, we defined three “classes” of cave tour routes corresponding to the amount of visitor use. They differ as described below:

- **Classic Tour:** This ¾ mile in cave route receives the heaviest level of visitation at about 65,000 visitors passing through annually.
- **Wild Cave Tour:** Receives a considerably lower number of visitors with about 150 people in a season.
- **Off-Trail:** Minimum level of use. Tour guides are the only ones that can access these areas, and do so only occasionally based on level of interest. Group sizes are restricted to 12 people for certain areas and trips typically occur only once a season.

For this study, 11 traps were placed on the Classic Tour route, 5 in the extra 2.5 rooms of the Wild Cave Tour route, and 5 traps in off-trail portions of cave. (Figure 7).

*Figure 7:* Displays the Classic Tour route and trap locations throughout the cave (Richards, 2006).
**Distance from Entrance or Proximity to Trail:** To test the hypothesis that lint accumulation will be greatest near entrance and closest to trails, traps were placed at regular intervals along the Classic Tour route and in several locations at progressive distances from the trail itself. Trap content data (particle type, fiber type, net weight) was then graphed along an axis representing distance from cave entrance along the classic tour route. It was difficult to systematically select trap locations based on distance from entrance or trail. This was challenging because I needed to consider multiple factors (beyond variables we were testing) including potential visitor disturbance, convenient access, and other environmental factors. Some traps were located directly on the trail, while others were up to 10 feet from the Classic Tour Route. However, traps were placed with spatial relationships in mind when possible.

Other environmental factors potentially influencing lint deposition include things like changes in humidity and/or air flow throughout the cave. For example, it is known that humidity increases as the route gets closer to the final room of the tour, therefore this trap site location may exhibit variations in lint deposition due to variation in humidity levels. Likewise, certain sites such as The Wind Tunnel and Half Way Room experience perceptibly higher airflow. Lint traps located here might provide insights to how fine particles may be transported through the cave.

A polynomial regression analysis was also completed to decipher how lint composition changes throughout the cave. After obtaining other results, it came to my attention that the lint is not uniform in composition, therefore it was necessary to evaluate potential causes. Distance into the cave is the dependent variable. Trophic activity with the lack of sunlight and other resources decreases in the areas of the cave further away from entrances and exits, therefore leading to a needed analysis of how natural and synthetic fibers accumulate throughout the cave system.
Lint ‘Age’ (time since deposition): Lint persisting on cave walls is assumed to represent many years of accumulation relative to the ‘fresh’ lint caught in traps that particular season. Comparing the content of lint from walls to lint in traps provides insights on the fate of lint once deposited, or might possibly reflect changes in clothing fabric over time.

Analysis of wall lint: The lint collected from cave walls was analyzed for comparison to corresponding traps in the same location. Since fibers were the most abundant particle found in traps, and the most likely component of lint to change over time, only fiber analysis was done on samples collected from cave walls. Measuring net weight did not make sense since no control for surface area or orientation was possible or comparable to trap samples. The larger lint balls were sub-sampled to obtain a roughly similar sized ‘lint ball’ as that captured by a given trap. The wall lint was then submerged in about 20 mL of water and then subsampled again for two microscope slides following the same protocol of fiber identification as with the traps. I then calculated relative percentages of fiber type per 30 total fibers from the wall for comparison with the “new” lint from the traps. Lint Traps and Wall Samples were obtained in areas of the cave representing all three visitor use levels. Wall samples primarily focused on the Classic Tour Route as that is the most impacted area, and for time purposes it was easier to collect lint in densely deposited areas.

Objective 3: Provide useful and informative results for future resource protection and cave management practices.

This study was intentionally designed to be repeatable and to provide information that is valuable to resource managers. Baseline data on lint composition and accumulation rate, and relationships to visitor use and other factors, may help managers devise lint-reduction mitigation
strategies. Additionally, the systematic methods devised for this study, can be used in repeated monitoring efforts and to evaluate future mitigation strategies deployed in Lewis and Clark Caverns. Finally, it is necessary to understand the fate of lint in depth, in order to fully understand the best approaches for removal and/or dealing with potential impacts of lint in the future.

**Results**

**Development of Standardized Lint Collection Techniques - Traps:**

Overall the cave lint collection methods were demonstrably successful, and yielded consistent usable results allowing for the measurement and identification of lint particles. Specific factors relating to water accumulation in the traps, barriers/obstacles, and other siting conditions could improve uniformity of data collection. For example, traps with water may collect more lint, and some traps may have been in the path of rodents.

**Identification and Quantification of Lint Composition**

The relative percentage of different particle types (fiber, mineal, plant, etc) among all traps were similar in proportion even across different use level areas. Fibers were the most

![Graph](image-url)

**Figure 8:** Total count of all particles collected in lint traps over one season, along different use areas of the cave.
abundant particle type found in all sites, followed by mineral, with relatively much lower percentages of plant, hair, and ‘other’ at all sites (Figure 8). Statistical analysis was used to determine if the differences in particle composition among the levels of trail use are significant using a two tailed t-test with an alpha value of 0.05. All samples are relatively similar based on the statistical analysis. The one significant difference seen was between the Wild Cave Tour route and the Classic route, with significantly less hair counted on the Wild Cave Tour than the Classic Tour (p=0.002). Generally, people tend to tie their hair back in braids and pony tails on the Wild Cave Tour, allowing less hair to be deposited. The makeup of particle type was not drastically different. Figure 8 demonstrates that that fiber is most abundant in the off-trail parts of the cave than the other two levels of use. Mineral is the next highest percentage among all traps.

**Figure 9:** Shows the break-down of particulate type throughout the cave.
Figure 9 displays a similar lack of any clear trend or variation in particulate type as function of distance from cave entrance. Fiber content is the highest ranging between 40-70% across all sites, and appearing to increase slightly in traps sited further into the cave. The mineral fragment is moderate throughout the cave (~10-20%). The spikes in relative fiber abundance and lowest mineral content, occur at the Wind Tunnel, the front of the Princess Palace, and Peg Leg Hill. These are the most humid parts of the cave, based on previously obtained information from the park. All traps contain very small amounts of plant fibers and hair (<10%). The Upper Cathedral Room, ½ Way Room, and the last 4 rooms sampled on the Classic Tour Route all have above-average fiber percentages.

The Wild Cave Tour showed numerous traps with unique and interesting particle count data as well. Hair is a very small percentage of the particulates in general, however there is statistically significantly less hair on the Wild Cave Tour route than there is on the Classic Tour route (Appendix C). The Wind Tunnel has high fiber counts, along with the Horse’s Barn. These traps could not have mineral kicked into them as easily when cavers came near, therefore explaining the decrease in numbers of mineral particles. The Wind Tunnel and Horses Barn show above average fiber count, and are the only samples with below average mineral count.
Fiber Identification:

Similar to the particulate identification, the type of fiber (synthetic, cotton, etc) does not differ significantly across different trail use levels. In general, synthetic fiber is more abundant throughout the cave than natural fiber like wool and cotton. As expected, cotton fibers are more abundant than other natural fibers like wool. This assumption was originally based on the fact that cotton t-shirts are popular summer attire, and sweatshirts are often a 50/50 blend of synthetic and cotton fibers. Figure 10 shows the average percentages of each fiber type found in traps representing trail use levels. Synthetic fibers are clearly the most abundant fibers, followed by cotton. “Other” is classified as unidentifiable fibers such as plants or other organic/mineral matter clearly unrelated to clothing fibers.

**Figure 10:** The breakdown of fiber type based on average percentage for each use level.

Figure 11 illustrates how synthetic fibers are most abundant, relative to other fiber types, throughout the cave and especially at the very beginning (first 380 feet) of the cave on the Classic Tour Route. There is a slight increase in percentage of cotton fibers as the traps get further into the cave, and thus a corresponding relative decrease in synthetic fibers. The Brown
Waterfall Room shows a spike in synthetic fibers, possibly because it was located below a lint deposit that hadn’t been cleaned recently. Older fibers may have fallen from the ceiling, and into the trap, potentially altering the fiber percentages (see old vs. new results below).

There is a statistical difference in “wool” between the Classic Tour, and the Wild Cave tour. There is a noticeable difference in the amount of wool evident on the Wild Cave tour route, which is significantly less (statistically), than the Classic Tour route (see Appendix C).

![Figure 11: The breakdown of fiber type throughout the cave based on all samples.](image)
Net Weight:

The traps placed along the Classic Tour route clearly collected the most net mass of particulate matter (Figure 12), with 75.53% net weight of all particles trapped throughout one season. The off-trail traps accumulated the least amount of lint cumulatively with only 10.24%. Of the Wild Cave Tour traps, the Back of the Lower Cathedral Room accumulated noticeably more lint than other Wild Cave Tour traps. The highest net weights were collected in the first 380 feet of the cave. It is important to note that the net weight include mineral weight and that separate weights of different particles is impossible with the small sample sizes used in this study. Also, traps in the Upper Cathedral Room Front trap and Paradise Room lost water and potentially some particulates due to poorly sealed collection containers used on one of the collection trips.

In Figure 13 it appears that net weights of traps from the different trail types might be significantly different. A two tailed t-test (with an alpha value of 0.05) comparing the net weights of each trap from the three use levels suggests that that the only significant difference in net weight is between the Off-Trail traps and the Classic Tour route (p=0.002). The Wild Cave Tour does not have a significantly different amount of lint when compared to the off trail and Classic Tour route portions of cave. In general, these statistics show that the level trail use corresponds to the net amount of lint deposition.

Two samples were obtained for each level of the Cathedral Room. One sample in each level represented two levels of use. This room is unique as it has use from both the Classic Cave Tour and the Wild Cave Tour routes. Due to the limited samples obtained in this study, it is
statistically impossible to compare only the two samples from each tour route. Therefore, it is indeterminable if rooms with routes for both the Wild Cave Tour and Classic tour are impacted more based on lint accumulation when compared to rooms with only one tour route. To make comparisons it must be done without statistical analysis. For example, the front of the Upper Cathedral room has 0.001 grams more weight than the back of the Upper Cathedral room, therefore suggesting that this weight difference may be significant when compared to other samples. More data will have to be obtained to understand the differences in rooms with both routes when compared to other rooms.

**Lint Trap vs. Cave Wall Collected Lint (Lint Ball):**

The “old lint” collected from cave walls noticeably contains more synthetic fibers throughout the cave than the traps do, with the exception of the Wind Tunnel (Figure 13). Statistical analysis showed that the lint from cave walls contains significantly more synthetic (p=0.02) and wool fibers (p=0.0005) than lint that accumulated in the traps.

![Synthetic Fibers: Trap Samples vs. Cave Wall Samples](image)

**Figure 13:** Comparisons between Cave Wall samples and corresponding traps.
Discussion

Standardizing Lint Collection Techniques

The lint traps overall were demonstrated to be an effective sampling technique. Some traps did collect water, therefore regular emptying was necessary to prevent overflow, and may have resulted in some loss of net weight of particulate matter. The water may have affected lint deposition as it may have stuck to the water, and lint may have blown out of the traps that remained dry. The dry traps essentially mimicked dry parts of the cave, however, the cave is also wet so wet traps in appropriate locations might be an effective method. The formations that are wet are noticeably harder to clean, suggesting that lint adheres to wet surfaces better than dry ones. Collecting lint from the walls was a fairly straightforward task and followed the same techniques that lint cleaning crews use.

If I were to repeat this study, I would add a small amount of water to traps, and pair them with dry ones to determine if water affects lint accumulation and net weight results. Ideally it would improve the study if traps were placed so that they could not be disturbed by visitors. In an attempt to keep visitors from disturbing traps many of them were placed in locations behind formations and away from the trail in some places. Concealing the traps may have affected how much lint was deposited into the traps as it would have landed on the obstructing formations. It is important to understand how much lint gets deposited on formations in direct view of the trail versus those that are concealed behind formations when establishing baseline information.

Particulate Identification

Overall, the results did not seem to follow a pattern corresponding to location or distance traveled in the cave. The methods used did allow for a clear identification and classification of particle types as: plant, mineral, fiber, hair, and ‘other’. The use of the quarter – inch grid was
helpful in describing the samples, then further breaking down the description into actual numbers. Future studies may include skin cell quantification. Those were grouped into “other” originally as it was not immediately obvious what they were, and how abundant, yet there was often enough of them to be notable. Skin cells are organic matter like cotton and wool, and may also potentially provide nutrients for microbial communities in the cave. A better understanding of this source of added nutrients would help strategize management decisions, while also determining if skin cells occur in enough abundance to be impactful similar to natural fibers.

**Fiber Identification**

Identification and classification of different fiber types was achieved using basic microscopic methods established in the forensic sciences. More advanced methods to identify specific synthetics, or staining plastics could improve the number of identifiable fibers and reduce those relegated to ‘other’.

The fiber identification, unlike particulate matter did show some specific changes in both abundance and fiber type throughout the cave. The synthetic fibers in traps do seem to decrease overall in abundance further into the cave (Figure 11). The beginning of the cave had the highest amounts of synthetic fibers, most notably the first 380 feet, with the relative percentages decreasing after the Sample Room. This emphasizes the importance of preventing lint from entering the cave in the first place, and the value of adaptive management.

Clothing tends to be a 50/50 blend of cotton and synthetic fibers, or composed of synthetic fibers entirely (Boucher and Friot, 2017). This information matches the data collected in our traps, considering that cotton and synthetics make up the biggest percent of fibers throughout the cave. Historically, wool and cotton may have been the more prevalent fibers worn into the cave. With the shift to synthetic fibers these persistent plastic fibers are becoming more
evident in even the most isolated locations.

Net Weights

The net weight of total particulates matter accumulating in different areas of the cave was successfully measured by filtering and weighing the matter caught in lint traps. These weights provide a better understanding of areas that accumulate the most lint, therefore allowing more focused lint cleanup approaches. Currently, cave cleanups occur twice a year. Due to the extensive area of cave to clean, focusing on the most impacted areas is crucial to protecting the resource. Although the net weight did include mineral material that could be considered ‘natural’ to the cave. Silt/mud build-up has an aesthetic impact and may increase algae growth, a largely negative impact on the biotic community in the cave.

The net weights for some traps stood out as anomalously high. Specifically, the Back of the Lower Cathedral Room had a much higher weight than other traps on the Wild Cave Tour route. The difference is not likely attributable to a higher mineral content as it was only 0.6% higher than the average for the Wild Cave Tour route traps. The weight differences could be attributable to air flow and humidity, considering moisture may affect where the lint gets deposited and how well it stays. Air flow is potentially the main vector used to transport the lint away from the trail. Additionally, as noted above, this trap had water accumulated in it. The water may have assisted in capturing more lint from the air.

Trail Use

The number of visitors and level of trail use is clearly an important factor affecting lint deposition. Traps on the Classic Tour route captured 76% net weight of lint in all traps (Figure 12). Although the Wild Cave Tour and Classic Tour routes did not present significant statistical differences when comparing the net weights among the use levels, there was still a noticeable
difference if the back of the Lower Cathedral Room trap is excluded. The data may be skewed due to high net weight in the Lower Cathedral Room Back trap. The accumulation in this trap did not match traps set in similar locations, suggesting other factors other than trail use may affect the lint in certain areas. Further study of conditions such as airflow, humidity, and wall dripping will help identify other factors that might influence lint in specific locations or cave settings.

**Distance from Entrance**

The distance from the entrance seemed to be a minor influential factor. The net weight of total particulates was highest in the first 380 feet of the cave, as was synthetic fiber accumulation. The synthetic fibers are almost double the average in the Discovery Hole trap. This area is the last location after entering the cave that sunlight is visible, therefore there is likely a higher degree of biotic activity in this area. The greater percentage of synthetic material relative to cotton, could be the result of more microbes actively using natural fibers for energy, similar to what happens with old lint deposits. Interestingly, there appears to be a faint inverse relationship between synthetic and cotton fibers, with more cotton fibers in the middle sections of the cave, with synthetics in higher relative abundance near the entrance and exit (Figure 14).

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**Figure 14:** Relative percentages of synthetic vs cotton fibers along classic tour route as shown by 2nd order polynomial trend line.
This may further suggest that biotic activity is greater near the exit and entrance and that the organic fibers are being consumed or decomposed at a greater rate when closer to external influences of light and microbial communities. An area for future study would be to investigate the microbial communities in the cave.

Although cumulative lint deposition was high in areas closest to the entrance, fibers in particular are still being deposited on distant surfaces within the cave. This suggests that line transport may be related to air flow and humidity. Although airflow and humidity levels have not been systematically measured in the cave, there are areas known by guides and managers to exhibit higher airflow and/or humidity levels. Traps such as the one located in “Wind Tunnel” have low levels of mineral yet high fiber counts that are easily explained by higher airflow transporting particles even to lightly traveled areas. Additional measurements of airflow and humidity at sites throughout the cave would provide a better understanding of how internal ‘cave weather’ and airflow might impact lint transport and deposition. There is currently only general knowledge about the internal airflow in the cave. A more in-depth study about internal cave processes regarding air flow and humidity is necessary to understanding how these processes may show the known human impact.

**Age of Deposited Fibers (Walls vs. Traps)**

While there is concern for the amount of synthetic and natural fibers introduced into the cave, this study suggests that that synthetic fibers will persist in the cave longer than natural fibers such as cotton and wool. In this study I compared ‘old’ lint deposits collected from cave walls with ‘new’ lint collected just in one season. The older lint from walls showed a considerably higher percentage of synthetic and wool content, whereas the recently trapped lint
had higher percentages of cotton, especially in the central parts of the cave. This pattern has been observed in other studies (Jablonsky at. al, 1993) and it is suggested that the organic fibers will break down eventually leaving mostly synthetic plastics behind. This is of concern not only in terms of residual plastics, but also the impact of introduced organic material on cave ecosystems. These natural fibers may be adding nutrients and possibly altering the cave’s natural low energy ecosystem. As noted previously, lint mats may possibly contribute to biofilms that don’t naturally exist in these cave systems (Northup et. al, 2000; Vaughn et. al, 2011). As biotic processes occur, the synthetic fibers get left behind as they do not offer the correct nutrients for organisms in the cave existing naturally or introduced. Ultimately, the altered ecosystem is not only damaging to the naturally existing microorganisms, but it also permits damage to the formations within the cave. The formations slowly dissolve due to acids produced in microbial films, therefore affecting the aesthetic value of the cave (Jablonsky et. al, 1993).

**Value to Management**

This study effectively identifies areas of the cave that experience higher lint accumulation rates and therefore in greater need of regular cleaning. Although 75.53% of the captured particulates were found along the Classic Tour Route, where cleaning efforts are currently focused, both the Wild Cave Tour and the Off Trail locations also accumulated significant amounts of lint. Therefore, it may be worth putting cleaning efforts toward areas not on the Classic Tour Route. Although my traps collected less than half a gram of particulates on average, it was only for the period of one season and over a 12.7 cm x 17.78 cm area. A simple calculation, scaling the sum of the sampled net weights collected in 12.7 cm x 17.18 cm footprints over a roughly estimated cavern floor area (1.2km long x 3.04 m wide), suggests that up to 907 kilograms of lint could be deposited in a single season. Of that net mass added to the cave each
year, a significant amount may consist of organic fibers or human skin cells all of which have potential to impact the cave ecosystem.

Considering 30,000-40,000 skin cells fall off each minute, an average season of 65,000 people in the cave for two hours would result in about 207 billion skin cells (half a pound of skin) in one season (Durani, 2015; Melina, 2011). Additionally, people could shed about 6.25 hairs during the length of a tour, which totals about 406,000 hairs per season (Watson, 2018). This human introduced organic matter is just part of what makes up the accumulated lint, and as the above numbers suggest, hair is a very minimal part of the lint makeup. Overall, it is crucial to maintain each part of the cave, with a specific focus on the very beginning of the cave, and the Classic Tour Route.

Finally, a good approach to minimize the build-up of lint in the cave would be to prevent the lint from entering in the first place. Show caves throughout the world have employed techniques ranging from wind tunnels to misting with water as people enter to minimize the deposition of lint (Pate, 1999; Maerch, 2014). Other techniques include lint curbs, which are essentially cement curbs along the trail to prevent lint from spreading off the edge of the trail. I would suggest Lewis and Clark Caverns specifically invest in bristled brushes for people to brush themselves off with before entering the cave to remove loose fibers and lint before people enter the cave, potentially reducing impact. Education is also an important factor as it would allow a better understanding of the impact individuals have as they enter the cave system. This can be achieved by simply explaining to people verbally, or even creating a visual aid, similar to what has been done to educate about White Nose Syndrome. Education and preventive techniques would ultimately allow the best success at lint minimization. Additionally, cleaning should be focused on the first few rooms of the cave due to the high amount of lint deposited.
early on the tour.

Overall, this study shows a definite, quantified accumulation of lint on high and low-use areas. It displays the transport of fibers to areas that shouldn’t show high accumulation rates (Lower Cathedral Back) and presents a need for more information to understand the fate and transport of lint in cave environments. Additionally, if a lint mitigation technique is deployed, it is possible to test the effectiveness and efficiency of the techniques used. This can be done with the repeatable techniques developed in this reconnaissance study. The results can then be compared to the results achieved in this study to determine effectiveness. The baseline numbers established are useful for future management of Lewis and Clark Caverns.

Need for Future Research

This project is largely exploratory and experimental in developing lint-sampling techniques. Although the traps were successful to a certain extent, there a numerous opportunities to improve the demonstrated collection methods. Future research could include a focus on how water may affect lint deposition with the use of side-by-side traps. Additionally, the aspect of how formations that are upright/in direct view of the trail collect lint compared to those that are not directly visible may provide useful information about which formations to prioritize cleaning. Data on humidity and airflow in various areas of the cave would enhance our understanding of how the lint travels through the cave. This information could be obtained via a season-long study perhaps with guides participating, or preliminary information collected at several points in time.

This is a baseline study that can be used to compare with future monitoring work and for assessing the impacts of any attempted mitigation efforts. Due to the unique location of the cave, misters and fans are not an option for controlling lint, however something as simple as
asking visitors to wear natural fibered clothing and to brush themselves off before entering the
cave could drastically reduce how lint deposition occurs within the cave system. These
sustainable tourism techniques can also be tested for efficiency using the baseline data produced
in this study.

A great deal remains to be learned about microbial communities in caves and the
potential impacts of lint on microbes and vice versa. It is known that lint alters cave ecosystems.
The interesting patterns in cotton vs synthetics may be driven by microbial or other biotic
activity and much could be learned by a study on microbial communities. The biotic
community of course expands beyond microbes and includes the bat and pack rat species in the
cave. Understanding how synthetic fibers might affect cave resources, such as water, is also
crucial to understanding how these particles may impact different animal species. This
exploratory study could form a basis from which many different areas of research could stem
from this work.

Conclusion

In conclusion, it is possible to measure lint accumulation in caves with the methods
developed and refined for use in Lewis and Clark Caverns. Further refinement may improve
some of the results, but in general they successfully accomplished the objectives of this study.
The lint traps were overall successful in performing their intended use. Additionally, they open
the door for more ways to test lint accumulation. Net weight was arguably the most important
metric from this study as it allows cave managers to know where particulate accumulation occurs
in the highest quantities, and potential ways to minimize this. Additionally, the makeup of lint
and particulate matter is useful in understanding the impact that humans can have on the cave
based on simply the clothes people wear on the tours. Finally, there is now a better understanding
of the fate of lint once it enters the cave ecosystem. The breakdown of natural fibers is supplying unnatural organisms the nutrients needed to survive, while also damaging formations and the aesthetic appeal of the cave. There is also an accumulation of synthetic fibers over time as they cannot break down like organic fibers.

Overall, the study can be used to apply, monitor, and assess sustainable management techniques for the Lewis and Clark cave system. Although this study was largely exploratory, it illuminated many important links between lint deposition and the potential for lint management and clean up.
Works Cited


pollen trapping experiments to the Pollen Monitoring Programme. *Vegetation History and Archaeobotany*. 19(4). 247–258. DOI: [https://doi.org/10.1007/s00334-010-0261-3](https://doi.org/10.1007/s00334-010-0261-3)

Google. (2019), Lewis and Clark Caverns State Park. Retrieved from [https://www.google.com/maps/place/Lewis+%26+Clark+Caverns+State+Park/@45.8253407,111.8683183,14.33z/data=!4m5!3m4!1s0x0:0xf615637a55fb1b7c!8m2!3d45.823455!4d-111.8572494](https://www.google.com/maps/place/Lewis+%26+Clark+Caverns+State+Park/@45.8253407,111.8683183,14.33z/data=!4m5!3m4!1s0x0:0xf615637a55fb1b7c!8m2!3d45.823455!4d-111.8572494)


Northup, D.E., Dahm, N.C., Melim, A.L., Spilde, N.M., Crosse, J.L., Lavoie, H.K., Mallory,


## Appendix A: Trap Content Qualitative Description

<table>
<thead>
<tr>
<th>Trap #</th>
<th>Trap Location</th>
<th>Description</th>
<th>Trap Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Discovery Hole</td>
<td>Spilled in water reduction stage. Water is dirty...Kinda yellowy. Most particulate matter recovered. Lots of heavy material and seemingly lots of organic matter (not plant…Pack rat waste and a bug-small may fly thing, and a beetle carcass). Lots of Plant material…Seeds of some sort (I think) Fibers = 2 or 3 hairs, mostly black, non colored particles. One Red fiber. Some tangled blue fibers. Most large fibers collect when water is spun, smaller fibers tend to not connect to larger particulate mass. Trap orignally located close to the natural entrance to the cave. Seed things were fairly large. 25mm ish. Mineral deposits were fairly large, trap was located essentially on the trail.</td>
<td>Classic</td>
</tr>
<tr>
<td>2</td>
<td>Sample Room</td>
<td>Smells very cavey/a lot like packrat urine. Water is Yellow. Multiple hairs, probably packrat? Small bug/fly like from disco hole. Large red fiber lump, visible without microscope. Lots of plant bits, and heavy mineral bits on the bottom of dish (sunk). Larger lint ball fits into a 50 mm square mostly. Lint collects lots of &quot;other&quot; stuff maybe skin cells/dust? Lots of plant fiber was fairly large bits based on width and length. The plant fibers were fairly large both in width and length. Mineral sizes were also large as the trap was essentially on the trail.</td>
<td>Classic</td>
</tr>
<tr>
<td>3</td>
<td>Wind Tunnel</td>
<td>This section of cave was only visited by the three of us that did the project throughout the season, however it has significant lint accumulation for minimal visitation. This is likely a result of the constant wind that either blows into the tunnel, or out of it. The trap was placed just on the other side of the tunnel from the classic tour. As far as we know, the wind tunnel is the only way to access this portion of the cave. There is little to no mineral fraction, however there is a lot of hair. We do know bats frequent this area, however packrat use is unknown, so it could be either as with anything above the bottom of the pit. There is also significant dust/skin accumulation. The point count for this trap will be based on 50 random &quot;things&quot; as there is still not very much accumulation in the trap. There is a harvestman spider as well. It is only about 12.5mm in size (see picture).</td>
<td>Off-Trail</td>
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<tr>
<td>No.</td>
<td>Location</td>
<td>Description</td>
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<tr>
<td>4</td>
<td>Upper Cathedral Front</td>
<td>Less lint than previous sample. Water is heavily mineralized with calcium carbonate, therefore it appears to be white in color/milky. Lint ball is not a ball, but elongated and about 1cm in length. There appears to be less mineral, but more small fibers. This sample was spilled during the collection phase in August as the containers we used were not great for the job. Some lint fibers may have been lost as a result of this. Less packrat waste, and more mineral. The trap was near the trail, however protected by formations. Calcium Carbonate seems to accumulate on the bottom of dish after the water settles.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Upper Cathedral Back</td>
<td>There is lint accumulation in a relatively small amount. This is on the wild tour so some lint accumulation was expected, and at a lower level than places on the classic tour. The trap was located close to the trail, but not in a place that would have dirt disturbance landing in the trap. The mineral fraction is fairly small and there isn't a lot. A majority seems to be skin/dust fibers. There isn't many large lint fibers. There is some clearly red fibers, but also many black longer fibers. There is a hair. The lint did not naturally cling together and it took a little herding to get it together. To get to 50 fibers I did have to randomly push the fibers to one side or the other to get to 50 in one field of view.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Lower Cathedral Front</td>
<td>Low amount of lint compared to upper cathedral room trap. Mineral fibers are also lesser and are less than 25mm. Plant fibers are 25mm and smaller as well. Plastic Fiber of something…Looks like a piece of tarp? Maybe a piece of a glove? Fiber sizes are about 25mm when separated from the lint ball. The lint ball is about 30mm in size when loosely connected/tangled together. There is very small mineral fraction as well as fairly large fractions of mineral. There is also hair and lots of dust accumulation.</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Section</td>
<td>Notes</td>
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</tr>
<tr>
<td>7</td>
<td>Lower Cathedral Back</td>
<td>This trap was on the wild cave tour route. The trap was placed underneath formations dripping more than usual. The water has a milky color indicative of higher levels of calcium carbonate. The trap was not on the trail closely, but was close enough to potentially collect lint, however could not have ash particles kicked in from the ash pits. There is a piece of pack rat poop, but not a large lint ball visible. The lint fibers all seem to be smaller in size, and therefore do not ball up as much. The largest piece of lint appears to be about 50 mm long. There is some plant matter and a small amount of mineral fraction. The point count did not include field views. I just counted the 1st 100 things seen within the dish after collecting the lint together as things are not in large numbers and it was difficult to get 50 different things into one field of view. After doing point count I realize that there are many very small lint fibers, however also a lot of deteriorating plant fibers, likely brought to the trap by a packrat. The plant fibers ranged from less than 25mm to slightly larger than that.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1/2 way room</td>
<td>Mostly lint fiber and dust. The trap was in a passage that has an almost constant breeze, but was set into an offset hole. This kept it out of the area for foot traffic to kick mineral into, however did have a piece of pack rat poop upon collection. The trap also was growing a weird blue/green mold that died shortly after collection. Fibers in the sample seem to be mostly lint and dust, with minimal amount of mineral and plant. There are visible hairs in the trap as well. Smaller fibers seem to be less than 25mm and not larger than 50mm. There are longer fibers, however likely less than there are shorter ones. Plant Fibers=Very Small</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Princess Palace Front</td>
<td>The trap here was closer to the classic trail than the one at the back of the room. This trap got forgotten, there is minimal information on how the trap accumulated lint throughout the season. The wild cave tours would have been the ones most damageing to this section of the cave, however the classic tour may also have an impact as the trap was so close to the classic trail. There is a very small mineral fraction and some plant bits that are fairly small. There is also some hair. The point count was done the same as other wild cave tour traps. I did not use only 2 views to count the 100 fibers as they are sparcse.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Location</td>
<td>Description</td>
<td>Type</td>
</tr>
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<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td>10</td>
<td>Uncle Sam's Room</td>
<td>There was not much in this trap. It was fairly far off of the classic trail and was not in a place that had direct wind flow on it. The trap was only visited by wild cave tour groups and a group of employes. There is no packrat waste visible and the water is not white with calcium carbonate. There is a piece of plant of some sort and a relatively small amount of larger lint fibers. There is a small little lint ball in there, but majority of visible lint fibers are smaller in size. Less than 25 mm. There's also not as much dust clinging to the lint fibers that are present. Although there is lint, it is minimal. I counted the first 50 fibers seen.</td>
<td>Wild</td>
</tr>
<tr>
<td>11</td>
<td>Top of G of G</td>
<td>Large amount of mineral...looks like it's flat and potentially calcite? Larger lint ball takes up about 100 mm of space in the grid. Small particles are about 25 mm or smaller. There's a super long hair and lots of dust accumulation including skin cells. There are some plant fibers of small size. Less than 25 mm. There is a large plant fiber in there bigger than other average plant particles, slightly larger than 25 mm long, but fairly wide. This trap wasn't very close to the stairs, so the mineral fraction is interesting. There appears to be a piece of plastic in there as well that's about 6 mm squared.</td>
<td>Classic</td>
</tr>
<tr>
<td>12</td>
<td>Bacon Room</td>
<td>There is more lint in this than I expected there to be. The trap was located below a bottleneck hole, which would arguably have stopped much lint from getting through. It was also fairly isolated, and the breeze in there tends to blow away from where the trap was located, up out of the hole toward the rest of the cave. There is not much mineral in here, but there may be more mineral than lint. Lint fibers are about average with the smaller fibers in all other traps, and the longer fibers are not much longer than about 50 mm. There's also not as much dust clinging to the lint fibers that are present. Although there is lint, it is minimal. I counted the first 50 fibers seen.</td>
<td>Off-Trail</td>
</tr>
<tr>
<td>13</td>
<td>Princess Palace Back</td>
<td>This trap has noticeably less lint in than the princesses palace room did. There is a small mineral fraction. The trap was placed out of the way, just in the final room of the off trail portion of the tour. There is still a small piece of plant visible and there appears to be a metallic mineral/plastic in there. there is a small lint ball consisting of longer fibers than elsewhere, roughly 55mm in length. the smaller fibers are comparable to what was seen in Uncle Sam's room. there also does not appear to be hair in this trap. The point count follows the same protocol as other wild cave tour sites.</td>
<td>Wild</td>
</tr>
<tr>
<td>14</td>
<td>Bottom of G of G</td>
<td>This lint trap got a little abused and moved frequently as visitors tried to help keep the cave clean or stepped on it. It was originally out of the trail, but not everyone stays where they should. Therefore, total lint accumulation here is not known as it was frequently disturbed. There is a large mineral piece though that's about 50mm which is odd for the traps. There is a large amount of mineral deposit and a piece of packrat poop that's about 50mm long and 25mm in width. There is a small lint ball, however not very big. the small lint fibers also appear to be smaller than they are in other traps, which may be a result of the frequent disturbance this trap experienced. most of the mineral fraction is about sand size pieces.</td>
<td>Classic</td>
</tr>
<tr>
<td>15</td>
<td>Brown Water Fall Rm</td>
<td>Packrat poop! 50mm long and 25 mm in width. Mineral fraction is minimal and pieces are really small. This trap was off the trail, however was underneath a lintcicile on the ceiling so may contain both new and old lint. Synthetic fiber count may be higher as a result (Joblonsky). There is a really small piece of plant particle in there and there appears to be a &quot;normal&quot; (relative) amount of dust such as skin and small dirt particles. Lint fibers are fairly small if they are separate from larger lint ball, averaging about 25mm or small as usual. The lint ball take up about 1 100 mm square tightly packed, and 2.5 100mm square loosely tangled together..</td>
<td>Classic</td>
</tr>
<tr>
<td></td>
<td>Location</td>
<td>Description</td>
<td>Edition</td>
</tr>
<tr>
<td>---</td>
<td>----------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>16</td>
<td>Poison Rock</td>
<td>Got forgotten…Didn't get collected for about 2 extra weeks. Lint ball is about 100 mm long loosely gathered. There is a fair amount of mineral deposit, which is unexpected as the trap was not near the trail, but actually right about it. There is a small plant fiber, and the mineral sizes are about average size compared to other traps. There is a hair in there and the uncollected lint fibers are significantly smaller than normal…They are about 6 mm. The lint ball has some longer pieces, however they are similar to pieces about at no longer than about 50 mm for the most part. Lots of dust (Skin and small dirt fibers)</td>
<td>Classic</td>
</tr>
<tr>
<td>17</td>
<td>Horses Barn</td>
<td>All though this trap is considred off trail, it is still easily accessible from the trail. It can technically be accessed from 3 directions, 2 of which lead directly to the trail, either by ladder or short stairway. The fact that there is lint is not surprising. Although it is fairly close to the trail there is still less lint in the trap than other parts of the cave that had traps about the same distance from the main trail. I'd compare this to the wild cave tour route. This is closer to the most humid room in the cave, therefore that may play a roll in the smaller amount of lint accumulation. There is much less dust/skin cell accumulation and there is some plant bits, as well as mineral. If there are any hairs they will either be human or pack rat/mouse as bats will not be seen in this area commonly. The mineral fraction is also a small amount and pieces are small as well. Point count still followed wild cave numbers with only 50 items counted.</td>
<td>Off-Trail</td>
</tr>
<tr>
<td>18</td>
<td>Top of Peg Leg Hill</td>
<td>Not much of a lint ball! The trap does have like a paper towel looking thing in it. It is about 150 mm. and a piece of pack rat poop. There does not seem to be much mineral fraction and there is only a very small piece of plant identifieable when it's bunched together. Fibers when counted were VERY small, as were the mineral fraction that did exist. Fair amount of hair, likely due to pack rat use.</td>
<td>Classic</td>
</tr>
<tr>
<td>19</td>
<td>Musket</td>
<td>Off-Trail</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>---------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>There is a large mineral fraction in this sample. They are larger than normal, but still small. There is a hair, and some dust. There isn't much fiber as far as lint goes, however there is still sum. This location is similar to the wind tunnel, however is in a more humid part of the cave and does not have the constant wind flow into, or out of it. there does ot appear to be much plant matter in here thought. the fibers that are present include a long hair, and shorter one that's about 50mm in length and some lint fibers. the longest lint fiber is slightyl less than 50mm long. Point count is based on the first 50 fibers seen.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>20</th>
<th>Goats Walk</th>
<th>Off-Trail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This trap had more lint than I anticipated as this is a fairly isolated location. It is also in the most humid part of the cave. There is a fairly long hair that's about 600mm long. There is also some lint, but not much mineral fraction. The trap can be accessed from 2 directions, only one of which is safe and permitted. This passage does connect into the paradise room through the musket as well as back towards Ray Kelly's tunnel. There is a long plant fiber that's about 75mm long. There is also a lot of dust accumulation (skin). Other fibers are fairly small and seemingly not very abundant in the sample. Point count is again based no only the first 50 fibers seen.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>21</th>
<th>Paradise Room</th>
<th>Classic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water is milky colored, and therefore probably contains a fair amount of calcium carbonate. There's lots of lint particles, but getting them to bunch up is fairly difficult. I did get a small lint ball to form about 25mm in size. Humidity in this room is 98% which may lead to less lint leaving the people in this room. There is marginally more people in this room than the rest of the cave due to paradise tours. This trap was fairly far off the trail, but likely under a dripping stalactite. Water was collected from the trap twice throughout the season. The mineral fraction is very minimal and the lint fibers appear to be small, similar to those on peg leg hill.</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix B: Particulate Identification

#### Classic Tour

<table>
<thead>
<tr>
<th>Location Name</th>
<th>Distance in Cave along Classic Tour Route (ft)</th>
<th>Fiber</th>
<th>Plant</th>
<th>Mineral</th>
<th>Hair</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td>Discovery Hole</td>
<td>120</td>
<td>40%</td>
<td>5%</td>
<td>30%</td>
<td>2%</td>
<td>23%</td>
</tr>
<tr>
<td>Sample Room</td>
<td>380</td>
<td>41%</td>
<td>9%</td>
<td>28%</td>
<td>7%</td>
<td>15%</td>
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<tr>
<td>Upper Cathedral Front</td>
<td>605</td>
<td>65%</td>
<td>9%</td>
<td>21%</td>
<td>0%</td>
<td>5%</td>
</tr>
<tr>
<td>Lower Cathedral Front</td>
<td>650</td>
<td>52%</td>
<td>2%</td>
<td>34%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>1/2 way room</td>
<td>915</td>
<td>60%</td>
<td>1%</td>
<td>33%</td>
<td>6%</td>
<td>0%</td>
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<tr>
<td>Top of G of G</td>
<td>1,040</td>
<td>44%</td>
<td>7%</td>
<td>39%</td>
<td>6%</td>
<td>4%</td>
</tr>
<tr>
<td>Bottom of G of G</td>
<td>1,230</td>
<td>54%</td>
<td>5%</td>
<td>34%</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>Brown Water Fall Rm</td>
<td>1,305</td>
<td>63%</td>
<td>2%</td>
<td>26%</td>
<td>8%</td>
<td>1%</td>
</tr>
<tr>
<td>Poison Rock</td>
<td>1,370</td>
<td>44%</td>
<td>5%</td>
<td>38%</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>Top of Peg Leg Hill</td>
<td>1,510</td>
<td>63%</td>
<td>4%</td>
<td>29%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>Paradise Room</td>
<td>1,635</td>
<td>65%</td>
<td>0%</td>
<td>33%</td>
<td>0%</td>
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</tr>
<tr>
<td><strong>Total Average</strong></td>
<td></td>
<td>54%</td>
<td>4%</td>
<td>31%</td>
<td>4%</td>
<td>6%</td>
</tr>
</tbody>
</table>

#### Classic Tour Percentage of Particle Type

- **Fiber**
- **Plant**
- **Mineral**
- **Hair**
- **Other**

The diagram illustrates the percentage of particulate matter by fiber type at various locations along the Classic Tour route. Each location is marked with its respective fiber type composition, showing the variation in particle types as one progresses through different areas of the cave.
<table>
<thead>
<tr>
<th>Location Name</th>
<th>Depth in Cave along Classic Tour Route (ft)</th>
<th>Fiber</th>
<th>Plant</th>
<th>Mineral</th>
<th>Hair</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Cathedral Back</td>
<td>625</td>
<td>39%</td>
<td>7%</td>
<td>47%</td>
<td>1%</td>
<td>6%</td>
</tr>
<tr>
<td>Lower Cathedral Back</td>
<td>660</td>
<td>41%</td>
<td>20%</td>
<td>35%</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>Princess Palace Front</td>
<td>1005</td>
<td>66%</td>
<td>7%</td>
<td>21%</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>Uncle Sam's Room</td>
<td>1035</td>
<td>54%</td>
<td>5%</td>
<td>32%</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>Princess Palace Back</td>
<td>1195</td>
<td>52%</td>
<td>7%</td>
<td>37%</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Total Average</strong></td>
<td></td>
<td>50%</td>
<td>9%</td>
<td>34%</td>
<td>2%</td>
<td>4%</td>
</tr>
</tbody>
</table>

### Wild Cave Tour Percentage of Particle Type

![Bar chart showing the percentage of particle type across different locations in the cave.](chart.png)

- **Other**
- **Hair**
- **Mineral**
- **Plant**
- **Fiber**

**Distance in Cave Based on Classic Tour Route (ft):**
- Upper Cathedral Back: 625 ft
- Lower Cathedral Back: 660 ft
- Princess Palace Front: 1,005 ft
- Uncle Sam's Room: 1,035 ft
- Princess Palace Back: 1,195 ft
## Off-Trail

### Total Particulate Count

<table>
<thead>
<tr>
<th>Location Name</th>
<th>Depth in Cave along Classic Tour Route (ft)</th>
<th>Fiber</th>
<th>Plant</th>
<th>Mineral</th>
<th>Hair</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Tunnel</td>
<td>525</td>
<td>68%</td>
<td>4%</td>
<td>12%</td>
<td>10%</td>
<td>6%</td>
</tr>
<tr>
<td>Bacon Room</td>
<td>1135</td>
<td>52%</td>
<td>6%</td>
<td>38%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Horses Barn</td>
<td>1445</td>
<td>74%</td>
<td>10%</td>
<td>14%</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Musket</td>
<td>1610</td>
<td>54%</td>
<td>12%</td>
<td>26%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Goats Walk</td>
<td>1620</td>
<td>56%</td>
<td>4%</td>
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<td>6%</td>
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### Total Average

<table>
<thead>
<tr>
<th></th>
<th>Fiber</th>
<th>Plant</th>
<th>Mineral</th>
<th>Hair</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>61%</td>
<td>7%</td>
<td>24%</td>
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<td>4%</td>
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</table>
## Appendix C: Fiber Identification

### Classic Tour

<table>
<thead>
<tr>
<th>Location Name</th>
<th>Depth in Cave along Classic Tour Route (ft)</th>
<th>Synthetic</th>
<th>Wool</th>
<th>Cotton</th>
<th>Hair</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td>Discovery Hole</td>
<td>120</td>
<td>80%</td>
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<td>10%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Sample Room</td>
<td>380</td>
<td>43%</td>
<td>7%</td>
<td>10%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Upper Cathedral Front</td>
<td>605</td>
<td>30%</td>
<td>13%</td>
<td>40%</td>
<td>0%</td>
<td>17%</td>
</tr>
<tr>
<td>Lower Cathedral Front</td>
<td>650</td>
<td>53%</td>
<td>3%</td>
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<td>0%</td>
<td>17%</td>
</tr>
<tr>
<td>1/2 way room</td>
<td>915</td>
<td>27%</td>
<td>7%</td>
<td>53%</td>
<td>0%</td>
<td>13%</td>
</tr>
<tr>
<td>Top of G of G</td>
<td>1,040</td>
<td>27%</td>
<td>3%</td>
<td>27%</td>
<td>17%</td>
<td>27%</td>
</tr>
<tr>
<td>Bottom of G of G</td>
<td>1,230</td>
<td>30%</td>
<td>10%</td>
<td>20%</td>
<td>17%</td>
<td>23%</td>
</tr>
<tr>
<td>Brown Water Fall Rm</td>
<td>1,305</td>
<td>43%</td>
<td>3%</td>
<td>33%</td>
<td>7%</td>
<td>13%</td>
</tr>
<tr>
<td>Poison Rock</td>
<td>1,370</td>
<td>53%</td>
<td>0%</td>
<td>27%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Top of Peg Leg Hill</td>
<td>1,510</td>
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<td>3%</td>
<td>40%</td>
<td>3%</td>
<td>23%</td>
</tr>
<tr>
<td>Paradise Room</td>
<td>1,635</td>
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<td>0%</td>
<td>17%</td>
<td>10%</td>
<td>33%</td>
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<tr>
<td><strong>Total Average</strong></td>
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<td><strong>5%</strong></td>
<td><strong>28%</strong></td>
<td><strong>8%</strong></td>
<td><strong>18%</strong></td>
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</table>

### Classic Tour Percentage of Fiber Type

![Classic Tour Percentage of Fiber Type](chart.png)

- Other
- Hair
- Wool
- Cotton
- Synthetic

**Distance in cave along Classic Tour Route(ft):**

120, 380, 605, 650, 915, 1,040, 1,230, 1,305, 1,370, 1,510, 1,635
<table>
<thead>
<tr>
<th>Location Name</th>
<th>Depth in Cave along Classic Tour Route (ft)</th>
<th>Synthetic</th>
<th>Wool</th>
<th>Cotton</th>
<th>Hair</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td>Upper Cathedral Back</td>
<td>625</td>
<td>40%</td>
<td>7%</td>
<td>23%</td>
<td>7%</td>
<td>23%</td>
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<tr>
<td>Lower Cathedral Back</td>
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<td>7%</td>
<td>33%</td>
<td>3%</td>
<td>20%</td>
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<tr>
<td>Princess Palace Front</td>
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<td>10%</td>
<td>37%</td>
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<td>10%</td>
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<tr>
<td>Uncle Sam's Room</td>
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<td><strong>31%</strong></td>
<td><strong>5%</strong></td>
<td><strong>21%</strong></td>
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**Wild Cave Tour**

**Total Particulate Count**

<table>
<thead>
<tr>
<th>Location Name</th>
<th>Distance in cave along Classic Tour Route (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Cathedral Back</td>
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<tr>
<td>Lower Cathedral Back</td>
<td>660</td>
</tr>
<tr>
<td>Princess Palace Front</td>
<td>1,005</td>
</tr>
<tr>
<td>Uncle Sam's Room</td>
<td>1,035</td>
</tr>
<tr>
<td>Princess Palace Back</td>
<td>1,195</td>
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</table>

**Wild Cave Tour Percentage of Fiber Type**

- Other
- Hair
- Wool
- Cotton
- Synthetic
### Off-Trail

<table>
<thead>
<tr>
<th>Location Name</th>
<th>Depth in Cave along Classic Tour Route (ft)</th>
<th>Synthetic</th>
<th>Wool</th>
<th>Cotton</th>
<th>Hair</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Tunnel</td>
<td>525</td>
<td>57%</td>
<td>3%</td>
<td>17%</td>
<td>10%</td>
<td>13%</td>
</tr>
<tr>
<td>Bacon Room</td>
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<td>47%</td>
<td>3%</td>
<td>13%</td>
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<td>30%</td>
</tr>
<tr>
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<td>1445</td>
<td>27%</td>
<td>3%</td>
<td>40%</td>
<td>7%</td>
<td>23%</td>
</tr>
<tr>
<td>Musket</td>
<td>1610</td>
<td>43%</td>
<td>0%</td>
<td>37%</td>
<td>3%</td>
<td>17%</td>
</tr>
<tr>
<td>Goats Walk</td>
<td>1620</td>
<td>23%</td>
<td>3%</td>
<td>43%</td>
<td>3%</td>
<td>27%</td>
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**Total Average**

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<th>Wool</th>
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<td>1,195</td>
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</table>

- Other
- Hair
- Wool
- Cotton
- Synthetic

Distance in Cave along Classic Tour Route (ft)