Flowstone in Jewel Cave

MCEN 4151-001 Flow Visualization

Teams Third Report

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Background & Introduction

"Flowstone in Jewel Cave," depicted in Figure 1 below, is my attempt to delve into the world of flow visualization, a medium that bridges the realms of art and physics.

Hidden deep within the Black Hills National Forest in South Dakota, there sits a deep and expansive cave network. Originally thought to be only a couple miles in length, it is now believed that Jewel Cave is one of the largest cave networks in the world with thousands of miles of unexplored passageways and caverns.

At a depth of 350 feet below sea level sits one of the largest open chambers available and open to the public. Offered through the Scenic Tour of Jewel Cave, provided by the National Parks Service, this tour educates and demonstrates the curious wonders of what lies beneath our feet.

For this project I attempted to visualize flowstone and how cave formations came to be. While not a dynamic experience, I believe flowstone tells a story. A story millions of years old, only told since Jewel Cave's discovery, 123 years ago.

This was a personal weekend trip into the Black Hills of South Dakota during my Fall Break. Because of this, I captured this image without any assistance outside of the cave tour guide who shined her flashlight.

Figure 1: "Flowstone In Jewel Cave"

Physics

Formed over millions of years through shifting water levels and calcite deposits emanating through porous limestone, Jewel Cave is considered a “breathing cave”. Via the chimney effect using a difference in air density throughout the volume of the cave, a breathing cave pushes out and sucks air in through its various surface openings [1].

Within the cave there are countless flowstone formations. Flowstone cave formations are still depictions of millions of years of calcite solution deposition. During the early years of Jewel Cave, carbon dioxide began settling in the water table of the Black Hills region, turning the water acidic over time. Over the past 40 million years, the slow-moving acid-rich water table carved out and dissolved the soft Pahasapa Limestone, forming the majority of the cave. While the cave was still partially filled with water, some of the calcium carbonate in the acidic water re-deposited on the walls of the cave, forming Nailhead Spar [1]. Nailhead Spar can be found surrounding the perimeter of the image in figure 1, resembling the head of a nail or popcorn. These cave formations can only form while the cave is partially or entirely filled with the acidic water. Because the water in the cave has drained away, Nailhead Spar formations can no longer form [1].

Once the water that filled the cave drained away, other cave formations, known as speleothems, were allowed to form. While the processes to create a cave formation takes millenia, many are still forming today.

As water makes it way through the carbon dioxide-rich higher level soil and rock, it dissolves the porous Pahasapa limestone, picking up calcite ($CaCO3$) along the way. Once this acidic solution enters the air filled cave chambers, it loses the carbon dioxide, returning to water once again. No longer able to hold the calcite in solution, the non-acidic water begins to deposit the calcite within the cave, forming stalactites, stalagmites, flowstone, draperies, or nailhead spar [1]. In figure 1 above, draperies can be found towards the center of the composition. At the end of these draperies, stalactites begin to form. If you zoom in close enough, water droplets can be seen at the tips of the stalactites, indicating that this cave formation is still forming. On average, stalactites grow at approximately 0.13 mm/year [2]. This growth rate is dependent on the rate at which the calcite rich water enters the cave before depositing. Higher flow rates would suggest higher growth rates, and vice versa. In general, the type of formation created through calcite deposition primarily depends on the rate at which the water enters the cave volume.

Photographic & Visualization Technique

“Flowstone in Jewel Cave” was taken by looking up at a distance of about 4.64 meters (determined from image metadata) while standing on the pedestrian cave tour walkway. “Flowstone in Jewel Cave” has a field of view of approximately one meter across. See figure 2 below for a sketch depiction of my setup.

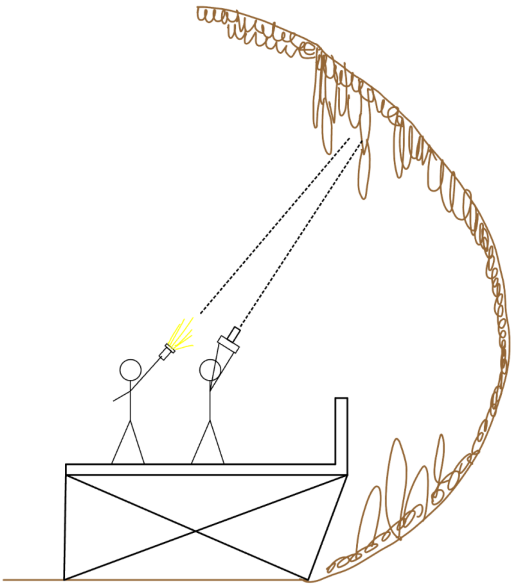

Figure 2: Sketch depiction of my setup

"Flowstone in Jewel Cave" was shot on my Canon EOS R6 Mark II mirrorless camera with a kit 24-105mm zoom lens. No discrete visualization techniques, such as adding dye or smoke to the system, were used. Instead, to capture the image I used a longer exposure.

The exposure of an image is primarily tied to the shutter speed. In a sense, the longer the shutter remains open on the camera body, the longer light has to hit the sensor. To capture instant movement and in a sense 'freeze' the target in frame, shorter shutter speeds are often used. Examples of fast shutter speed action shots include photographing a Formula1 race car flying around the circuit, or the motion of a bird soaring through the air. These can often be shot at shutter speeds ranging from 1/200 to 1/5000 of a second. Longer exposure shots, sometimes 2 to 10+ seconds, are often used to take night shots of the moon or stars. Because I shot the image handheld without a tripod, I used a 1/60s shutter speed with a 2s shutter delay to avoid the effects of camera shake when activating the shutter.

Since I decided to use a shutter speed of 1/60s, I used a medium aperture stop at f/7.1 to not blow out the image with too much light. This is the largest aperture size my zoom lens can hit at a focal length of 99mm. This medium aperture stop constricted the amount of light able to enter the camera by closing the iris diaphragm. See figure 3 below for a pictorial representation of different aperture settings [3].

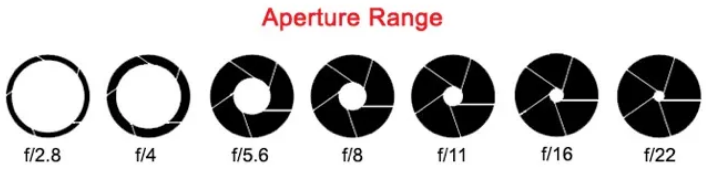

Figure 3: Pictorial representation of different aperture settings

The last setting that affects the amount of light the sensor can pick up is the ISO setting. This setting is directly tied to the camera sensor's sensitivity to light. Low ISO numbers means the camera is at its least sensitive setting. While high ISO settings can allow the camera to pick up more light by being more sensitive, it can often lead to image graining where the resulting image looks fuzzy. Sometimes this can be an artistic preference, but given the low light environment and the constrictions forced by my camera hardware and image setup (no tripod therefore medium shutter speed), I decided to set my camera to 8000 ISO to increase the camera sensor's sensitivity to light. 8000 ISO is on the cusp of adding too much noise to the image, making it grainy, but it was a trade off I had to make given the nature of the system.

The resulting image I decided to use for my project was shot at a focal length of 99mm at about 4.64 meters from the target. This image was shot in the Canon native 6000 x 4000 px RAW format. Given image capture settings and the flow rate of flowstone, the image is spatially and time resolved with 0 motion blur and multiple decades of resolution.

During post processing I decided to crop down the original image to 3943 pixels wide by 3121 tall. The source of light in this image was from the tour guide's personal flashlight. At this moment in the tour she turned off the installed cave lighting and used her flashlight to focus our attention on important cave formations. This light source was positioned behind my left shoulder by about 1 meter. Because the flashlight has a brightspot localized towards the center of the image, I decided to locally decrease the exposure in that location. I decided to keep changes to a minimum to preserve the natural beauty of the cave. I felt that any major color corrections would disrupt the scene. See figure 4 below for the RAW image taken directly from the camera and figure 1 for final image after post processing.

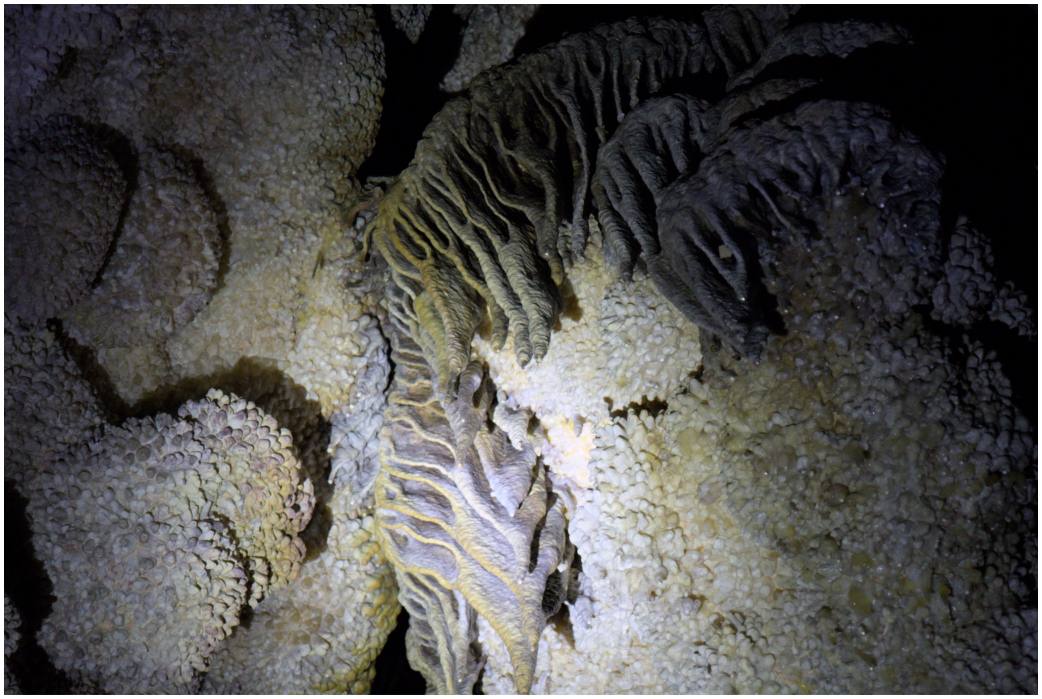

Figure 4: RAW image taken of Jewel Cave imported directly from camera.

Artistic Revelation

In this captivating image, nature's forces are on display as we can see millions of years of cave evolution revealed right before our eyes. Jewel Cave was undiscovered by man until 1900. Because of this, I am one of the few people (despite being a public attraction) that has gotten to experience this wonder of the world. For this reason, I made the decision to base my project on my experience because I felt that sharing what I experienced would be eye opening to the members of the class. I believe I was successful in capturing the flow evolution within the cave and exploring the elementary physics on how such cave formations are made. I believe the image is of appropriate class quality and accurately represents the principles of flow physics I aimed to capture. Moving forward I would like to explore other caves and document my findings if given the chance. It really is amazing what lies beneath the ground.

References

[1] “Geology of Jewel Cave.” *National Parks Service*, National Parks Service, 12 Sept. 2023, www.nps.gov/jeca/learn/nature/geology-of-jewel-cave.htm#:~:text=The%20carbon%20dioxide%20transformed%20the,the%20majority%20of%20Jewel%20Cave.

[2] Kramer, Stephen P.; Day, Kenrick L. (1995), Caves, Carolrhoda Books (published 1994), p. 23, ISBN 978-0-87614-447-3

[3] Werner, Danielle. “Seeing in Depth of Field: A Simple Understanding of Aperture.” *Digital Photography School*, Digital Photography School, 2015, digital-photography-school.com/seeing-in-depth-of-field-a-simple-understanding-of-aperture/.