Cave Research Foundation Annual Report 2021

Cave Research Foundation
Annual Report 2021

The Cave Research Foundation was formed in 1957 under the laws of the Commonwealth of Kentucky. It is a private, non-profit organization dedicated to facilitating research, management, and interpretation of caves and karst resources, forming partnerships to study, protect, and preserve cave resources and karst areas, and promoting the long-term conservation of caves and karst ecosystems.

Cave Research Foundation 2021 Annual Report

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Front cover photo: Elizabeth Miller peers out of a lava tube, Lava Beds National Monument, California. Photo by Mark Jones.
Back cover photos: *top*, Rick Olson traversing edge of Bottomless Pit, July 9, 2021, Mammoth Cave, Kentucky. Photo by Ed Klausner. *Bottom*, Matt Bumgardner emerges from the horizontal entrance of Forest Trail Pit, Arkansas. Photo by Bethany Bruman.

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Cave Research Foundation Awards

The Cave Research Foundation awards Fellowship in the CRF to those CRF members who have made significant long-term contributions to the foundation. Individuals who have made significant contributions in a particular area are awarded Certificates of Merit. Both Fellowship and Merit awards are in appreciation of a member's efforts. The following people have received such recognition in 2021:

Fellows

Mary Schubert

Mary has been attending expeditions since 2008. She became an expedition leader three years ago. Mary is the kind of person who comes to help out even on days when she's not caving. She attends Hamilton Valley work weekends. As an interpreter at Mammoth Cave, she can spot likely recruits among the park staff and identify who would be a good fit. She provides them with an orientation to CRF and survey training. Her own caving skills are solid. Best of all, she is pleasant company, never complains, and has a great attitude. She always acts with intelligence and care.

Dennis Novicky

Dennis has helped with a variety of projects for some years, surveying in Missouri, Arkansas, and Oklahoma. He has helped draft several maps. He led the way on the Winona office renovation plus he has made numerous gating projects work. In the last couple of years he and Mark Jones have been the on-spot fixit crew for broken cave gates. He has previously been awarded a Certificate of Merit by CRF.

Brenda Goodnight

Brenda has previously been awarded a Certificate of Merit by CRF. Although less active now (health issues) she has helped a great deal in the past. Her current contributions include strong gating efforts, usually in the field of field cooking for volunteers and staff.

Kirsten Alvey-Mudd

Although only recently a member, Kristen has worked with CRF for years, particularly on bat censuses and cave gating efforts. She has become a leader in the Ozarks, working closely with Mark Jones and others to get priority work done on the Ozark Riverways in particular. A fellowship is appropriate because of not just what she has done but the promise of doing more under the broad CRF umbrella. A professional chef, participants at the August Mammoth expedition probably remember her good work in the kitchen where she acted as the chef and also went caving every day.

Certificates of Merit

Claty Barnett

Claty began working with us in 2019, and she has been an excellent asset to the team with her good nature, organization, and friendly persona. She has served as trip leader on several trips and has begun sketching too. She's a valuable member to the Buffalo National River project.

Rhett Finley

Rhett first came to the Ozarks Operations in 2017 when he was a student at Texas A&M Galveston. CRF hosted his biospeleology class for a few days, and he continued coming back ever since. He has begun leading trips and provides excellently detailed reports. His eye for cave life is invaluable, along with his zest for nature and the underground. Rhett, who is from Oklahoma, also joins the CRF trips to Three Forks Cave.

Bob Osburn

Bob completed scanning all of the original field survey books for Mammoth Cave National Park. This massive project required digitizing thousands of survey books going back over 60 years. The goal was to have digital versions kept in a secure online archive accessible to CRF cartographers and data managers. The books had to be scanned page by page, properly named, checked for quality, and uploaded.

Operations Areas and Projects

Riannon Colton ascends the vertical entrance of Forest Trail Pit with trash bag in tow.

Bethany Bruman

Eastern Operations 2020–21

Karen Willmes

Eastern Operations Manager

Mammoth Cave National Park

Overview and Highlights

- We signed an updated Operating Agreement between Mammoth Cave National Park and CRF.
- The new official length of Mammoth Cave is 420 miles. The Park sent out a press release with the news, highlighting CRF's involvement. As a result, articles were published in *Bowling Green Daily News*, *Lexington Herald-Leader, USA Today,* and *Epoch Times.* Determining the length required painstaking work by cartographers and data managers.
- Bob Osburn completed scanning all of the field survey books. This massive project required digitizing thousands of survey books going back over 60 years. The original survey books were moved from Ohio and are now stored in the vault at Hamilton Valley. The digital copies are kept in a secure online archive accessible to CRF cartographers.
- Thanks to Jim Borden, the Central Kentucky Karst Coalition (CKKC) books were brought to Hamilton Valley and placed in the vault.
- The part of the cave system which saw the most activity this year was the Turley Entrance to Morrison Cave. This technically difficult section leads to Logsdon River. Aaron Bird led the effort to put in a safe route, including a via ferrata across a tricky traverse. In late 2021, the entrance was donated to the park by the landowners.
- CRF contributed to an episode of *Underground Marvels* seen on the Discovery Science channel.

Mary Schubert between Bottomless Pit and Gorin's Dome.
Ed Klausner

The pandemic continues to affect operations. Two expeditions were cancelled during the winter surge in COVID infections, and another on account of weather. We ended up holding seven expeditions. Participants traveled 120,890 miles to attend. CRF volunteers spent 8,596.05 hours on work that benefitted Mammoth Cave National Park. They spent an additional 1,562.84 for work indirectly applicable to the park, for a total of 10,158.89 volunteer hours.

Between October 1, 2020 and September 30, 2021, 105 trips took place, supporting a variety of projects (some trips supported multiple projects):

- MCNP cartography—67
- Archaeology—1
- Biology—7
- Caves outside park (Biosphere Reserve)—26
- Paleontology—6
- Photography—1
- Roppel cartography—9
- Small cave inventory—21

Thermocline at Mammoth Cave entrance. *Ed Klausner*

- History—1
- Park requested support—5
- Signatures—1
- Technology—2

Park Support

Five CRF teams helped to collect shark remains, service data loggers, mark transects for cave aquatic biology monitoring, and replace locks.

Science Support

In addition to looking for shark teeth, CRF provided support for other scientific objectives.

Two parties assisted Dr. Maggie Osburn in placing microbiology experiments. A number of teams whose primary objective was surveying also collected sediment samples for the study.

Several small cave teams made biological observations.

Cartography

Inside Mammoth Cave National Park, 67 trips supported cartography.

Six teams went to Colossal Cave. One surveyed some previously unsurveyed passage along the Pearly Pools route. Four teams continued the resurvey of Hunt Trail and Ehman Trail.

Another party looked for an alternate route around the flood debris in the Bedquilt entrance.

In Crystal Cave, a team replaced survey along the Lost Paradise route.

One party headed to Salts Cave to draw cross sections along Salts Trunk.

Three teams entered Unknown Cave to mop up leads in Mather Avenue and Grund Trail. Another two parties began the resurvey of the route to the remote Northwest Passage.

Thirty-four teams went to various parts of Mammoth Cave.

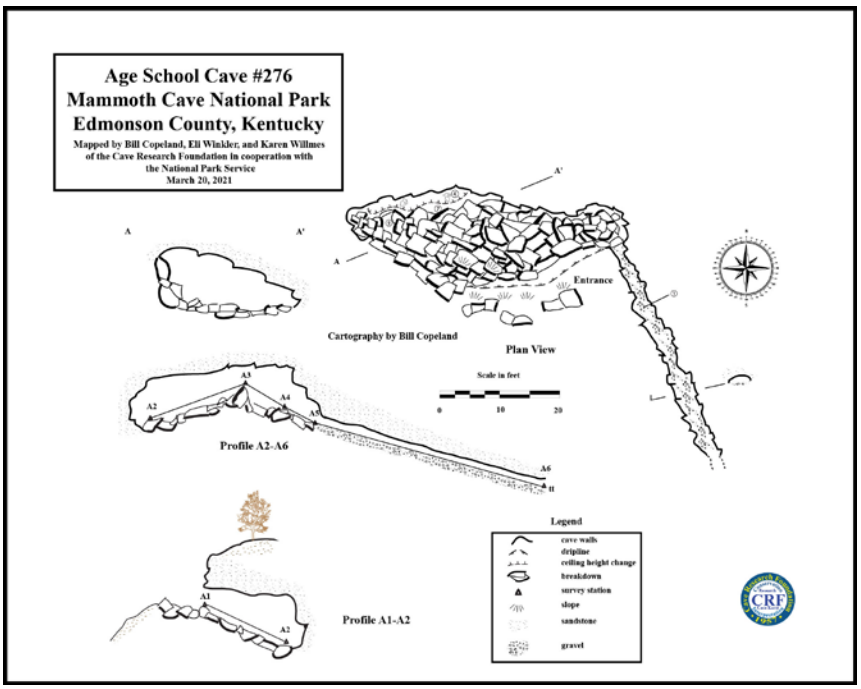
Five parties went to New Discovery. Two teams surveyed small, miserable leads off Onyx Avenue. Two parties finished the resurvey of the far reaches of the China Wall Passage. One team continued sketch enhancement and cross sections along Big Avenue.

For the Cathedral Domes map, a party surveyed Cathedral Dome itself using modern technology to improve the accuracy. Five parties resurveyed along the Cox route and Genies Pass. One team tied in Nelson's Dome. Another party resurveyed Felicia's Dome and out to Belfry Avenue. At Markhoff's Dome, one party pushed leads in upper Boone and another party rigged and surveyed the pit.

A team improved the survey accuracy at the Cleaveland Avenue–Miller Avenue intersection.

One party worked on correcting foresight/backsight errors along El Ghor and Cleaveland Avenue.

A party set out to push to the end of the infamous Snail Trail, but it was too wet, so they settled for surveying leads along Kentucky Avenue. Two parties resurveyed from the



Hippodrome to Aero Bridge, concentrating on adding the new infrastructure to the map.

One party pushed leads in East Cocklebur, but nothing went.

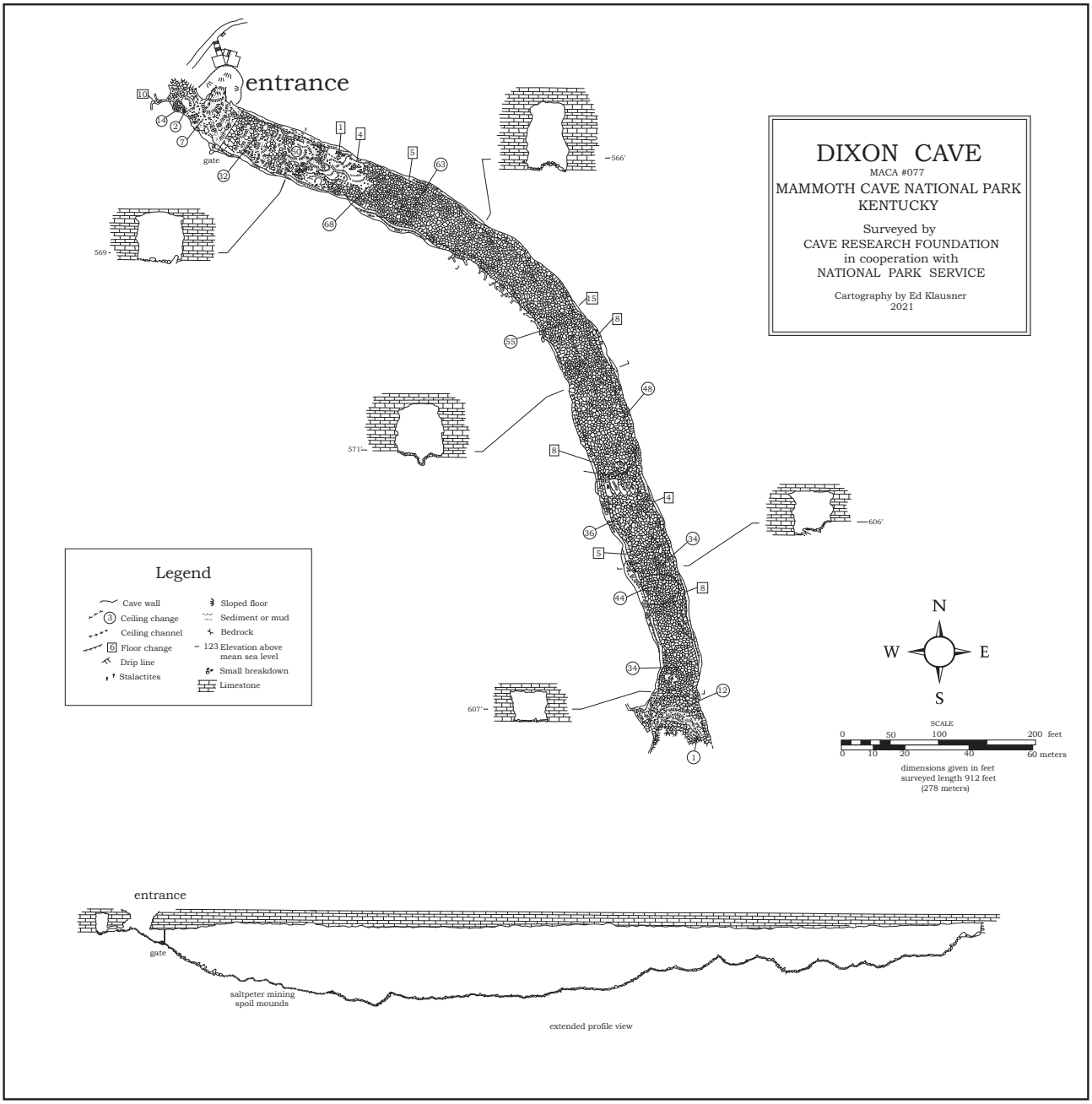
One team checked odds and ends at Wrights Rotunda.

For the Echo River map, two parties went to Abo Avenue to investigate survey discrepancies and a vertical lead. Two parties surveyed in the Napoleon's Dome complex. A team went to the pit at Wilson's Way.

Two parties went in the Ferguson Entrance to survey and check leads.

José Klausner and Elizabeth Miller in Dixon Cave.

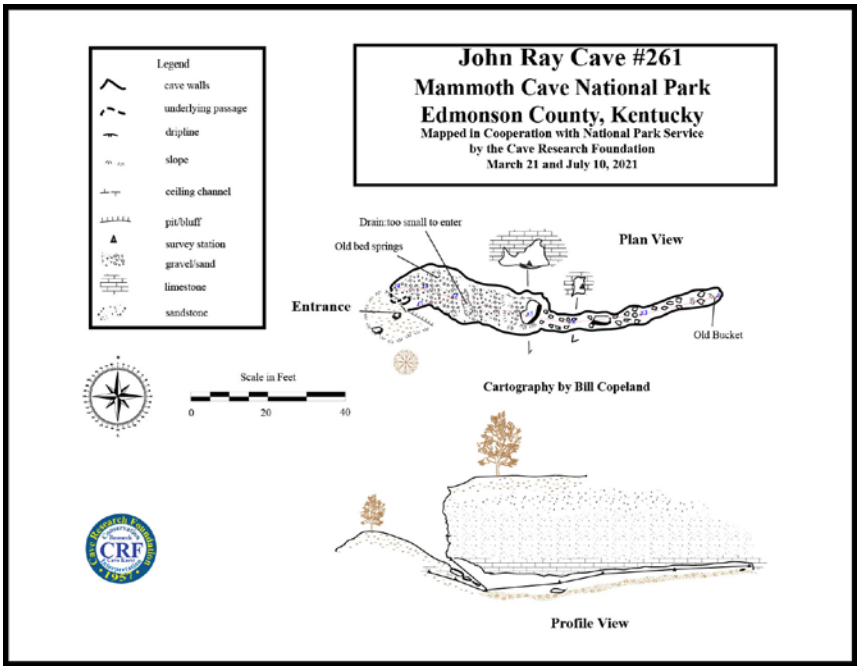
Ed Klausner

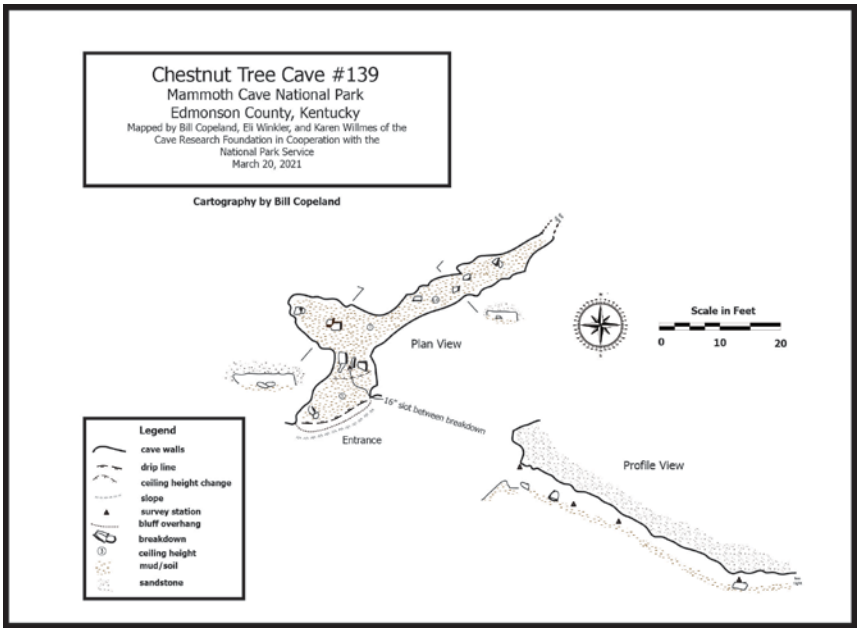


In Historic Mammoth, a team fixed foresight/backsight and loop errors. A team placed tie in stations for future dives at Echo River Springs. One team worked on vertical leads in Lee's Cistern and the Labyrinth. Two teams checked a high lead at the Water Clock and a vertical lead at the end of Lively's Way.

Twenty-one parties worked on small cave objectives. A party resurveyed in Dixon Cave to support drawing a profile view for the map. Age School Cave, Chestnut Tree Cave, John Ray Cave, and Rutherford Sandstone Cave were mapped. A party heading to the Bedquilt Entrance found a small sandstone cave. Three parties went to July Cave, which turns out to be over 600 feet long and has formations, evidence of historic blasting, and a 1929 signature by A. E. Hanson. A party attempted to reach Logsdon Cave by motor boat but decided kayaks would be better. Two teams mopped up leads in Smith Valley Cave. A party attempting to reach Bridged Creek Cave was turned back by a rattlesnake. Sandhouse Cave is an impressive shelter cave near the river, and finding the best route to it took several tries.

In Wilson Cave Hollow, a party examined Hornet Hole, and two other teams did additional ridgewalking. The Wilson Cave team pursued leads on the near side of the Netherdomes. They also surveyed a very dry, gypsum-encrusted crawlway which went beyond the known footprint of the cave. It ended in a mud plug, but leads remain.





Cartography Outside of Mammoth Cave National Park

One party drew cross sections in Hidden River Cave. One team went to Sides Cave to do a bolt climb at Miss Chamber's Pit. Three parties improved the rigging in Stan's Well and surveyed at the base of New Year's Shaft.

In Roppel Cave, two teams returned to the Beginner's Luck passage in Ursa Avenue and finished all the leads, including a virgin dome complex. Another team resurveyed part of Ursa Avenue and tried to push Resurrection Canyon. A team pushed a lead in Snorkland. A team replaced survey in Pete's Puzzle. Four teams pushed drains in Walter Way and were rewarded with a walking canyon.

Thirteen trips went to the Turley Entrance of Morrison Cave. They improved the safety of the route and began the resurvey. They named the impressive dome Westcott Junction after the landowners. The exciting news is that the next time I report, it will be for cartography inside the park rather outside. The landowners generously donated the entrance to the park.

Rick Olson traversing edge of Bottomless Pit. *Ed Klausner*

Hailee Gibadlo and Elizabeth Winkler in El Ghor.
Ed Klausner

History

Stan Sides led a party to the TB huts in Mammoth Cave to look for wall signatures of consumptive invalids living in the cave, but didn't find any.

Technology

A party went to Adwell Cave to calibrate the BRIC4 survey device and collect video of its use. Another team did photography in Crystal Cave in conjunction with a LIDAR survey performed by the BRIC4.

Rick Olson above the Water Clock. *Ed Klausner*

Other Updates

Aaron Addison and Bob Osburn ordered and installed new Windows 10 computers to replace the cartography and client computers at Hamilton Valley.

The lesser caves database is now hosted by a Filemaker hosting service for improved accessibility by park staff as well as CRF's small caves project leader.

Cumberland Gap National Historical Park

No cave activity due to the pandemic, but they had a meeting with the Cumberland Gap GIS specialist to prepare for integrating their data with the NPS GIS.

Cave Hollow–Arbogast Cave Survey Project

No activity due to the pandemic.

TAG Region: Levi Cave, Hamilton County, Tennessee

Hannah Lieffring

While waiting at the parking area on January 9, 2021, for grotto members to arrive, Jason Weyland and I struck up a conversation with the neighbor that came out to get his mail. Danny, who had lived in the neighborhood for nearly 30 years, was a friendly fellow and was quick to talk caves with us. He had many stories from his youth of stumbling upon dozens of "bottomless holes" that punctured the side of Signal Mountain. Intrigued by his vast knowledge of the area, I asked him if he could point us toward any other interesting holes. Danny didn't hesitate to tell us a few of his secrets, and we were happy to listen.

The time was nearing 10:30 a.m. and no sign of the grotto. Jason and I gathered our tools, and the two of us headed towards the cave. First, we took Danny's word and wandered over to a small hole just southeast of Levi Cave. According to Danny, this was a small inlet passage that eventually leads over to Levi. The opening was just as he described and extremely tight. First, we decided to hike up and drop our packs at Levi. Foolishly thinking, we imagined we would be back there shortly, maybe after connecting this new-to-us cave with our project cave.

Although we were skeptical, we had high hopes that we wouldn't have to climb back out of the same terrible entrance. Slowly inching down the vertical shaft, we could see where the canyon passage continued on. The entire time, the cave trended downward. Following the elephant tracks of past explorers back to an 8-foot climb down, it was very slick and muddy, similar to some of the climbs in Levi Cave. Encountering a crawl, we continued on, making sure to analyze our surroundings. Soon after, we were met with yet another vertical obstacle was even tighter than the entrance. Gravity made it easy to get down to the bottom. Looking back up, we estimated it to be about 25 feet. We were losing hope that this cave would connect to Levi, when abruptly, we found the end of the cave. Later, we found out the proper name for this cave is Armpit Cave, and we have plans to create a map of it once we finish our main priority.

About an hour later, we routed back to the surface and made our way to Levi Cave. It was nearly noon when we broke out the scrub brushes. Before mudding over the graffiti, we tried as hard as we could to use water and a bit of elbow grease. The hard bristles of the wire brushes had to be used carefully so that the rock was not damaged. Jason began by removing a large, red heart on a boulder that measured 6 feet tall by 4 feet wide. Slowly but surely, the red faded and soon, the heart disappeared completely!

We were pleased by our progress but could not deny that it was going to be a long process. Neon colors proved much more difficult to remove. Brighter colors were subdued with scrubbing; however, a layer of mud was required to fully conceal the graffiti. Over a period of three hours, with just two people, we had the entrance area looking much nicer! Satisfied with our work, we gathered our tools and went back to the vehicle. As we were putting our dirty gear into the trunk, a member from the Chattanooga Grotto made an appearance. Homero Rivera, a cave diver, stopped by to say hello, a nice surprise. He was excited to hear more about the project and agreed to help out the following weekend.

Returning to Levi Cave the following weekend with Mark Jones, we began our survey in the lower level of the Southwest Passage of Levi Cave. While examining the heavily impacted, vandalized, passages, a carbide script read "The Slides." Names and dates of old cavers revealed that the cave had been explored frequently since the 1920s. In later years, careless visitors spray painted over the carbide writing. We marked this area on our maps to plan a future cleanup trip.

No doubt, there were passages hidden within the far reaches of "The Slides." Continuing on, we passed beneath rocks the size of trucks nearly 30 feet long and 20 feet tall. Sliding sideways along muddy slabs, the previously named passage earned its name. Another 100 feet was traversed before we came to an obstacle. Arrows pointed to a 1 foot high by 1.5 foot wide hole that Mark was not able to squeeze through. We ended survey at this point and headed back to the main room.

Mark noticed an upper level of "The Slides." Climbing up the tall, ledgy canyon, I was faced with an interesting passage that intermittently started and stopped. It was really just a mess of massive boulders that required some technical climbing, but footprints showed the way. Sitting atop a 20-foot tall boulder, 30 feet above the floor, I peered down an interesting 10-foot deep crevice, noticing a large shelf of trash and organic debris. I quickly climbed around to observe what appeared to be a nest. Woodrats! They had gathered a good deal of shiny candy wrappers and bits of trash left behind. There were no obvious signs of a current inhabitant, however, it's possible they had moved along to another place in the cave.

Next, we focused our attention to the opposite end of the cave that trends northeast. Venturing back to the Collapsed Colosseum room, we were able to tie into the R Survey that was started in September. Going forth to set a station,

Hannah Lieffring and Dennis Novicky.

I gave no details on what the passage entailed (other than its dimensions). Mark anticipated a long crawlway, when in fact, we stumbled upon several joint-controlled passages/rooms. Only visiting the area once before, I couldn't recall where all the holes lead. While Mark drew a large chamber, I took my time investigating loops and alternate routes.

When we began this section, I estimated over 300 feet of cave to be surveyed, maybe more, which could take multiple days to finish. The amount of trash and graffiti in this area was significantly less, which was good news. We also observed cave-adapted millipedes, cave-adapted springtails, and a few significant fossils. One of our best finds was a large shark tooth, roughly 1.5 inches wide. By the end of the day, the team surveyed roughly 430 feet of passage.

The following Saturday morning, Mark Jones and I were surprised to see three vehicles pull into the parking area behind us. The turnout for our graffiti removal event was larger than expected! Several determined cavers showed up to restore damaged areas of the cave. Not only were there members of the Chattanooga Grotto present, but word had gotten to the Dogwood City Grotto and our group included Brandon Balkcom, Norman Earl, Alex Lambie, and Andy Zellner. Luckily, we had plenty of tools (and personnel) to get the job done. Everyone spread out in the entrance area, tackling their own sections on the walls, ceilings, and formations.

Some areas, such as the one Andy was working on, were much more dry, and the paint simply chipped away. He found great success using only a wire brush and water. Meanwhile, Brandon and Alex tag-teamed an alcove

splattered in acrylic paint. We found that both the combination of the surface the graffiti was on along with the type of paint would determine how difficult the removal process would be. After trying several different methods, the group consensus was that the wire brush tools were too aggressive on the rock and it was taking too long to remove just a small section. Mud would be our best option moving forward.

Once we were happy with the progress in the entrance room, we slowly made our way back to the Northeast area of the cave. Alex, Mark, and Andy took off ahead, using their new knowledge of "mudding" to restore the cave at a quicker pace. Brandon, Earl, and I lagged behind, looking for areas that were overlooked by the first group. Between every breakdown block, an arrow, signature, or tin can could be found. Doing our best to be thorough, we ventured down small cracks and crevices to reach the vandalized areas the first team missed.

We took a break at the Three Sisters formation, making sure to sign our names in the register book. Unannounced, a bright white light crested over a boulder, it was Jason Weyland! His muscles were not yet aching from hours of scrubbing, so we were happy to have him join us for the afternoon. A few moments later, two more lights appeared and our group was back together again. Jason joined Brandon, Earl, and I to work on a side passage near the Collapsed Coliseum room. The other team was down one person and decided to survey instead of removing graffiti.

The groups went their separate ways and continued finding new areas with abundant graffiti. Jason worked on some of the harder-to-reach spots that required a bit of climbing. He maneuvered up a rocky slope until nearly reaching the ceiling. Sitting on a rock ~15 feet off the floor, he carefully stationed himself in a spot where he could reach out and work on a large swath of obnoxious white spray paint. Feeling fatigued, we all sat back and watched as the graffiti slowly disappeared. Everyone was amazed with how the passage was transformed.

Finishing up survey in the northeast reach of the cave, an additional 60 feet was mapped.

We continued our cleanup on the following day. Dave Bechler, a renowned cave biologist, was able to join us. Touching up the entrance area, Dave noticed several cave crickets (*Euhadenoceus sp*) along with various salamanders. He then began looking over the worst of the graffiti and remarked "I can hardly tell there was spray paint at all!" Our team did some wonderful work that day erasing any trace of modern vandals.

Brandon crawled into an alcove to pick up hundreds of small, plastic airsoft pellets. The outside of the alcove was once spattered with yellow, blue, orange, and pink acrylic paint but the majority of the paint was successfully hidden with a layer of mud/clay.

Climbing down into the pit nearest the entrance, Brandon and I continued our cleanup while Dave stayed up top. Several small pools were found and after picking up a few shards of a beer bottle, I noticed something scurry. Our first cave adapted amphipod, wow! I often daydream about what other fascinating creatures are living throughout the cave.

Eight enthusiastic cavers participated in the effort to benefit a cave many of them never knew existed. As the original survey eluded, only 1,000 feet of passage was "supposedly" the entirety of the cave. Currently, 3,134 feet have been mapped and thoroughly managed. There are certainly more leads to check and passages to be mapped.

2021 Ozarks Operations Activities

Scott House

Ozarks Operations Manager

Ozark National Scenic Riverways

CRF Ozarks works with the Ozark National Scenic Riverways (NPS) under a funded cooperative cave management agreement that will expire in 2025. Despite the pandemic, a fair number of trips (46) were taken as volunteers went out in very small groups of 2–4 people; field monitoring hours exceeded 800. CRF monitored over 100 caves while adding over 400 faunal records to the data. Housing became an issue as NPS standards are one person to a room (we have ten beds but only three rooms). Scott House is project director.

Looking out at the Jacks Fork River. *Kirsten Alvey*

Buffalo National River

CRF work at Buffalo National River (NPS) is facilitated through a funded cooperative cave management, cave survey, and bat monitoring agreement that is good through early 2025. Fewer trips (34) were taken to Buffalo NR as the Arkansas Fish and Wildlife Office felt that it was important to constrain visits to caves with bats; still, volunteered field hours exceeded 700. There were also considerable housing difficulties for the same reason as OZAR. Kayla Sapkota is project director.

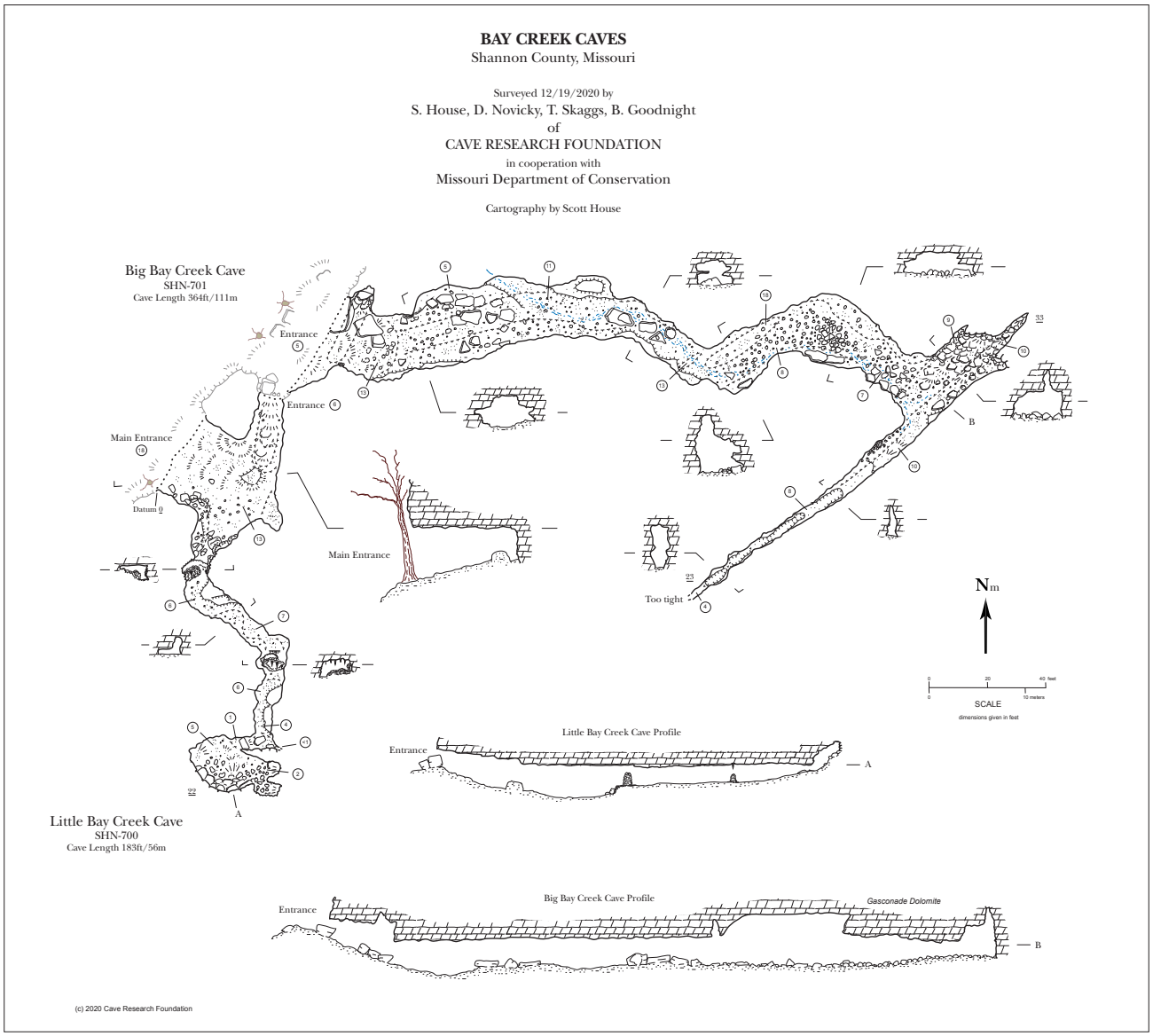
Mark Twain National Forest

CRF work on Mark Twain National Forest (U.S. Forest Service) is performed through a pair of funded cooperative agreements covering inventory, survey, monitoring, hydrology, and gating. A new funded agreement is now good through 2025. Forty-four trips were taken over the past year; volunteered field hours exceeded 800. Over 140 faunal records were added. Project directors include several people as the projects are widespread geographically.

U.S. Fish and Wildlife Service

We initiated a new, funded cooperative agreement with FWS. The Service supported several trips to known gray bat caves to assess the need for cave gates. Money has been provided to produce one gate, scheduled for early 2022. Additional funds are being provided for monitoring bat caves.

A Salem Cave Crayfish. *Shawn Williams*



The entrance zone of an Ozark cave. *Mark Jones*

Scott House in a well-decorated stream cave. *Kirsten Alvey*

Safe in the hands of an NPS archaeologist is this worked piece from an Ozark cave. *Scott House*

Missouri Department Of Transportation

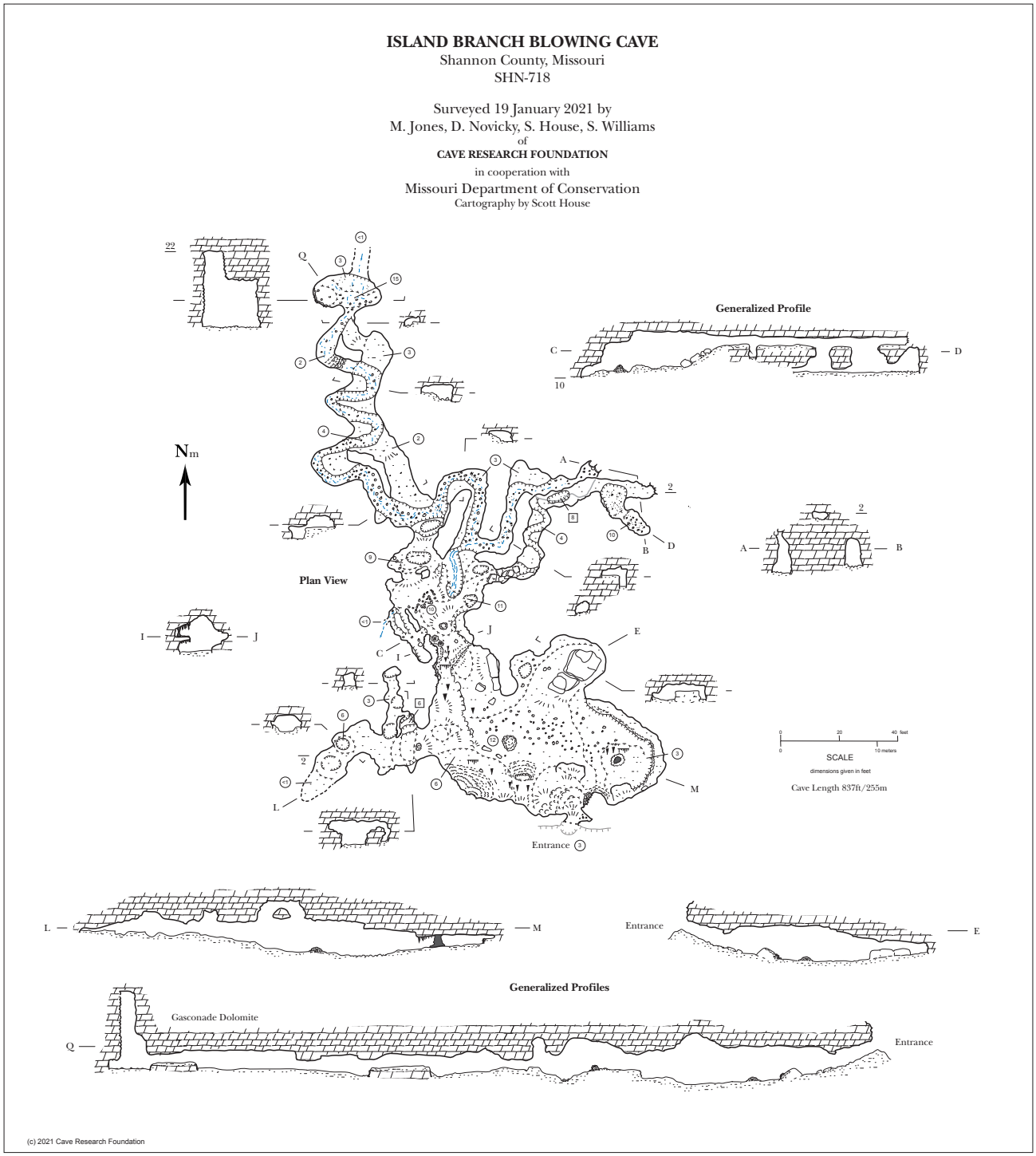
The MODoT transferred two bat mitigation payments to CRF this year; the funds originated from federal highway funds and will be used for bat protection, planned in conjunction with the U.S. Fish and Wildlife Service. One gate on a private cave is already being planned. Additionally, CRF is working with MODoT on the protection and survey of a historic cave within their right of way at Hannibal, Missouri. This is a cave associated with the unsuccessful 1967 search for three lost boys. The likelihood is that the boys were trapped in a cave exposed by highway construction. The cave we are surveying was explored during the search but only incompletely surveyed.

Pioneer Forest (L-A-D Foundation)

This project is being done as part of our mission with a friendly landowner; this year L-A-D provided some funding through a new agreement with CRF. The Meramec Valley Grotto is an active partner in this work with cartography and inventory as the main goals. Six trips were taken during the past year with an aggregate of 150 volunteered field hours. Sixteen caves were monitored with 70 faunal records added. Dan Lamping is the nominal head of this project.

Ozark Underground Laboratory

Three trips have been taken to continue the mapping and restoration of Tumbling Creek Cave, Taney County, Missouri. This project is being supported by the OUL in the form of free housing and other support. Dan Lamping is doing the data entry and cartography.



Three Forks Cave Project

Mark Jones leads this project to map caves in a defined area in Oklahoma. Ed Klausner is doing primary cartography. Unfortunately, all expeditions this year got cancelled.

Missouri State Parks

Work on Missouri State Parks (Missouri Department of Natural Resources) is done through a series of letters of authorization or volunteer basis. Trips continue on a mostly informal basis, responding to agency requests. A

Looking out of a large Ozark stream cave. *Scott House*

proposed funded agreement was found to have too much bureaucracy involved, so we declined the offer. One large cave (Ozark Caverns) on Lake of the Ozarks State Park was surveyed; Matt Beeson led that effort.

Missouri Department Of Conservation

CRF work on lands administered by the Missouri Department of Conservation is done through a series of unfunded special use permits. Thirty-five trips have been taken for inventory, and survey purposes; 32 caves were monitored with several hundred faunal records added to the database. Dan Lamping serves as the primary contact.

City Of Perryville

Work in and around the City of Perryville, Missouri, is facilitated through a cooperative agreement between the city and the Missouri Speleological Survey. Seed funding is provided by CRF. Survey is ongoing in Crevice Cave, the longest cave in the state, headed by Alex Litsch. A new series of karst interpretive signs are ready to be installed. These were written by Scott House and designed by Dan Lamping.

Arkansas Natural Heritage Commission and Arkansas State Parks

Twelve trips were taken to support cave work on lands owned by the Heritage Commission. Three other trips were taken to a cave on state park lands. Kayla Sapkota is the lead.

Missouri Caves and Karst Conservancy

We continue to support the mapping of the Moore Cave System in Perry County, Missouri, under the leadership of Chad McCain. Current surveyed length exceeds 23 miles. Several trips were taken, including one large expedition of 30 people.

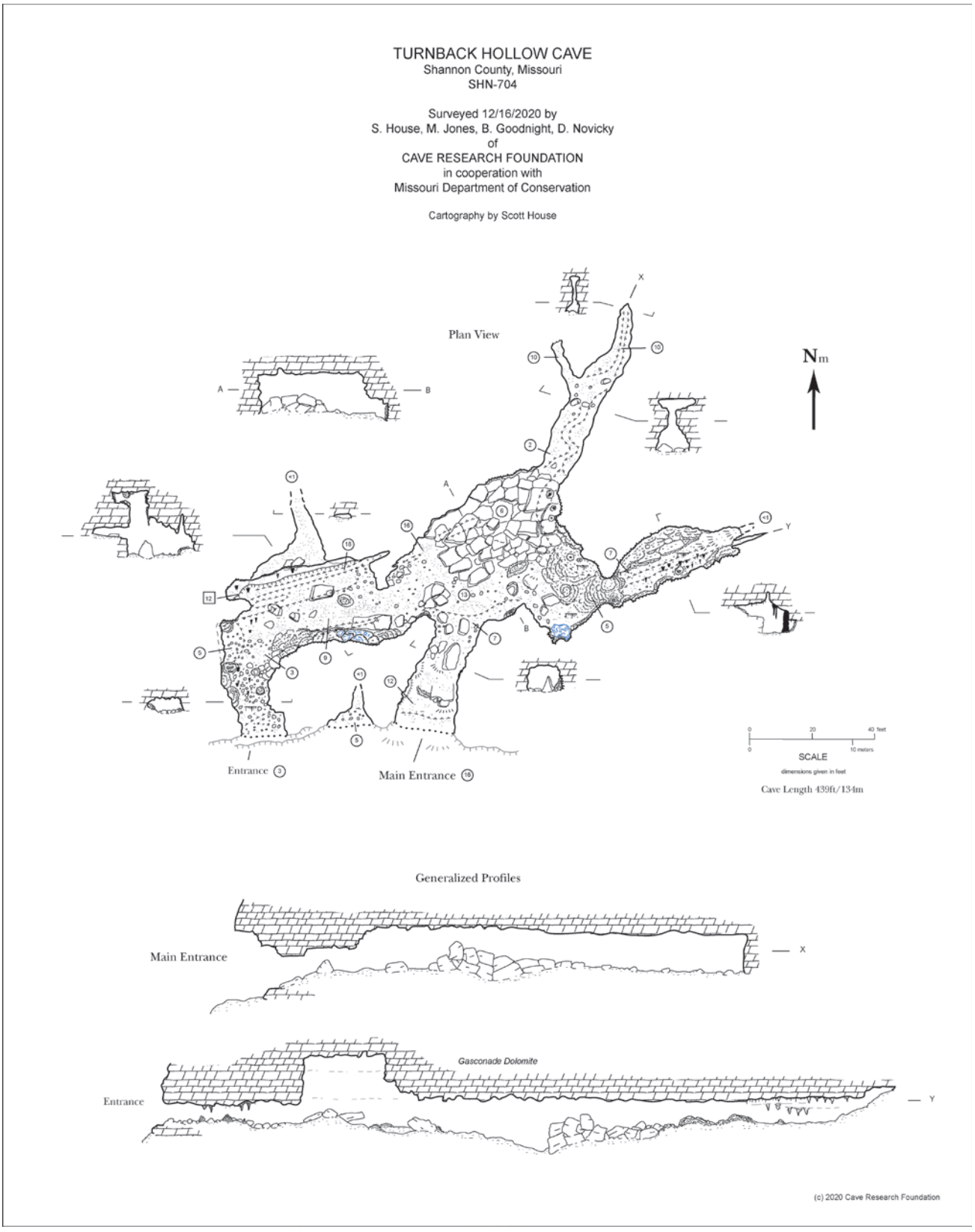
Missouri Speleological Survey

We continue to guide the development of the Missouri Cave Database and share all information gained with the MSS. The five members of the cave files committee are all CRF members. Three CRF members serve as president, vice-president, and treasurer.

Other Private Lands

Numerous trips were taken to non-agency lands, including a private cave in Arkansas; small Perry County, Missouri, holdings; private lands bordering Forest Service properties; gray bat caves; and others.

Surveying in Moore Cave System. *Derik Holtmann*


TURNBACK HOLLOW CAVE
Shannon County, Missouri
SHN-704
Surveyed 12/16/2020 by
S. House, M. Jones, B. Goodnight, D. Novicky
of
CAVE RESEARCH FOUNDATION
in cooperation with
Missouri Department of Conservation
Cartography by Scott House
Plan View
N m
Entrance 3
Main Entrance 16
SCALE
dimensions given in feet
Cave Length 439ft/134m
Generalized Profiles
Main Entrance
Gasconade Dolomite
Entrance
(c) 2020 Cave Research Foundation

Low Water Bridge Cave Gating Project

(How Things Get Done)

Scott House

Sometimes folks read about some project that we, in the Ozarks, have finished, and they ask how we manage to get so much done. The quick answer is that we don't try to do it by ourselves. Obviously, the necessary ingredient is that we have people who are interested in taking on and completing a project, but there is absolutely no way we could get these projects completed without a lot of help from our friends. So, to dissect one project a little bit, here is what happened to get a bat-friendly gate installed on a privately owned cave, in this case, Low Water Bridge Cave in Greene County, Missouri.

It started like this: **Drew Albert** from the **National Weather Service** in Springfield, Missouri, noticed strange radar signatures in the immediate area that were not storms. He apparently considered birds, but these oddities only occurred in the evening and only showed up because much of the terrain (Springfield Plateau transitioning to the Osage Plains). So he wondered about bats. Some of the signatures were quickly related to known summer colonies of gray bats but some were not. Maybe unknown colonies were the answer? Folks from the **Missouri Department of Conservation (MDC)** looked at potential bat sites and consulted the **Missouri Speleological Survey** cave database. Among the caves considered was Low Water Bridge Cave which had some bat records. A visit or two was made and the cave was identified as at least a major transient gray bat cave. After hibernating in caves all winter and depleting their body fat reserves, gray bats emerge in early spring and embark on long and sometimes treacherous migrations at a time when insects are not yet plentiful. They need safe caves to rest and replenish energy along the way to their final destinations. Low Water Bridge Cave serves as one of the major migratory stopovers for gray bats in southern Missouri, but the site receives high levels of visitation from humans which may disturb the resting bats. The new owner of the property, **Zach Carter**, was interested in protecting the cave and was unhappy with the high level of human visitation the cave was receiving. **Rhonda Rimer,** regional natural history biologist for MDC, wanted to help Mr. Carter get some protection for his caves and the bats. She was a strong advocate of a cave gate which would not only help a private landowner but also help the bats.

Meanwhile a bridge rehabilitation project at Bagnell Dam, 80 miles to the northeast, was being planned. The dam and accompanying bridge provide habitat for a colony of gray bats. The necessary bridge project was going to cause summer disruption to the colony utilizing the area. **Ameren Missouri** (the owners of the dam), the **Federal Highway Administration (FHA)**, the **Missouri Department of Transportation (MODoT),** and the **U.S. Fish and Wildlife Service (USF&WS)** initiated funding for mitigation of the disturbance to a viable colony. **Vona Kuczynska** of USF&WS worked the funding issue with **Chris Shulse** of MODoT and, in early 2021 through a cooperative agreement, federal funds were transferred from MODoT to **Cave Research Foundation** for the purpose of physically protecting other privately-owned gray bat sites.

A match was found! In early March of 2021, **Mark Jones** and **Jon Beard** made a trip to Low Water Bridge Cave, met with the landowner and made brief measurements of a site for a gate. A chute gate was deemed inadvisable because of a) aesthetics of the property; b) a large chute would draw attention to the cave; and c) possibility of the river in front damaging the gate during floods.

After much discussion a decision was made to gate this cave. **Craig Williams** of CRF and fellow cave archaeologists of the group **CAIRN** visited the cave for a needed cultural evaluation. Jones returned to the cave in late fall

with experienced CRF cave-gater **Krista Bartel** in order to obtain exact measurements and cross section of the proposed gate. **Scott House** then used a model of **Jim Cooley's** template for design and materials to create a draft cave design which Jones then modified to get a materials list. **Wheeler Metals** of Springfield quickly provided estimates of steel costs. CRF treasurer **Bob Hoke** worked with the metal company to get prompt payment for the steel. Rhonda Rimer offered for the local MDC work shop to pick up the steel, cut pieces to approximate size, cut the hangars, pins, and "fish plates" at no cost to the project and finally, to deliver the steel to the work site. This was done by an MDC expert craftsman and experienced gater **Chez Kleeman.** MDC also provided the necessary gases and other materials. The landowner bulldozed an ATV route down the hill to the cave and offered up his property for a work camp. Other preps were done at the Winona Ranger Station where the **National Park Service** and **U.S. Forest Service** provide workspace and housing. **Dennis Novicky** and **Brenda Goodnight** hitched up their camping trailer to serve as a mobile food vehicle while Mark towed the CRF covered gating trailer to the site. The trailers arrived at the site, followed by the MDC truck and trailer with the steel and gases, and work began.

As detailed elsewhere, things could not have gone better. Mark, Dennis, and Krista plus three or four MDC staff worked long hours on the gate, finishing it in good time, while enjoying Brenda's good food. The CRF caravan had left Shannon County on Tuesday, and all arrived safely back on Friday afternoon. Mark and **Andrew Porter** worked on Saturday, cleaning gear and putting it away. Since MDC had picked up the steel, the metal company refunded the delivery charge. The total cost of the project (time, steel, travel, and incidental costs) was less than $10,000—cheap for a cave gate. Mark made one last trip back to the MDC workshop to pick up the leftover steel, which will be used on some future project.

And that's how things get done: with a lot of help from our friends.

2021 Arkansas Annual Report Contributions

Kayla Sapkota

Buffalo National River

Field work resumed in April 2021. At this time, facilities use was allowed at the Steel Creek Research Center on the Upper District with limited occupancy for the remainder of the year. Use of the Toney Bend Research Center on the Lower District remained suspended due to structural issues.

Teams focused on monitoring sites in higher traffic areas, along with some small caves mapping, as well. Putting our fully stocked energy to use, we did 34 trips (largely day trips due to facilities restrictions), which included visiting 85 caves and mapping 2,093 feet in total. Caves were monitored in the following areas: Steel Creek, Kyle's Landing, Broadwater Hollow, Big Hollow, Erbie, and Boxley for the most part. Teams also picked up trash in a cave located near a popular trail in the Lower District.

Kyle Moore and Treavor Bussard at the Devil's Eyebrow Natural Area. *Kayla Sapkota*

Matt Bumgardner emerges from the horizontal entrance of Forest Trail Pit. *Bethany Bruman*

Arkansas Natural Heritage Commission

Five trips were made to ANHC Natural Areas in 2021 with small teams to observe COVID-19 precautions.

Devil's Eyebrow Natural Area

A team mapped three caves at the Devil's Eyebrow Natural Area in the early winter. Later in the year, a fall team mapped five additional caves in the same area, with one cave being new to the files.

Devil's Knob Natural Area

An early winter trip to Devil's Knob Natural Area mapped one additional cave for the area. It was a short pit.

Foushee Cave Natural Area

A team visited Foushee Cave Natural Area to check on a reported cave lead but found that it was only a small sink.

Hell Creek Natural Area

A team accompanied ANHC personnel to check out a few

Waterfall Shelter at the Devil's Eyebrow Natural Area. *Kayla Sapkota*

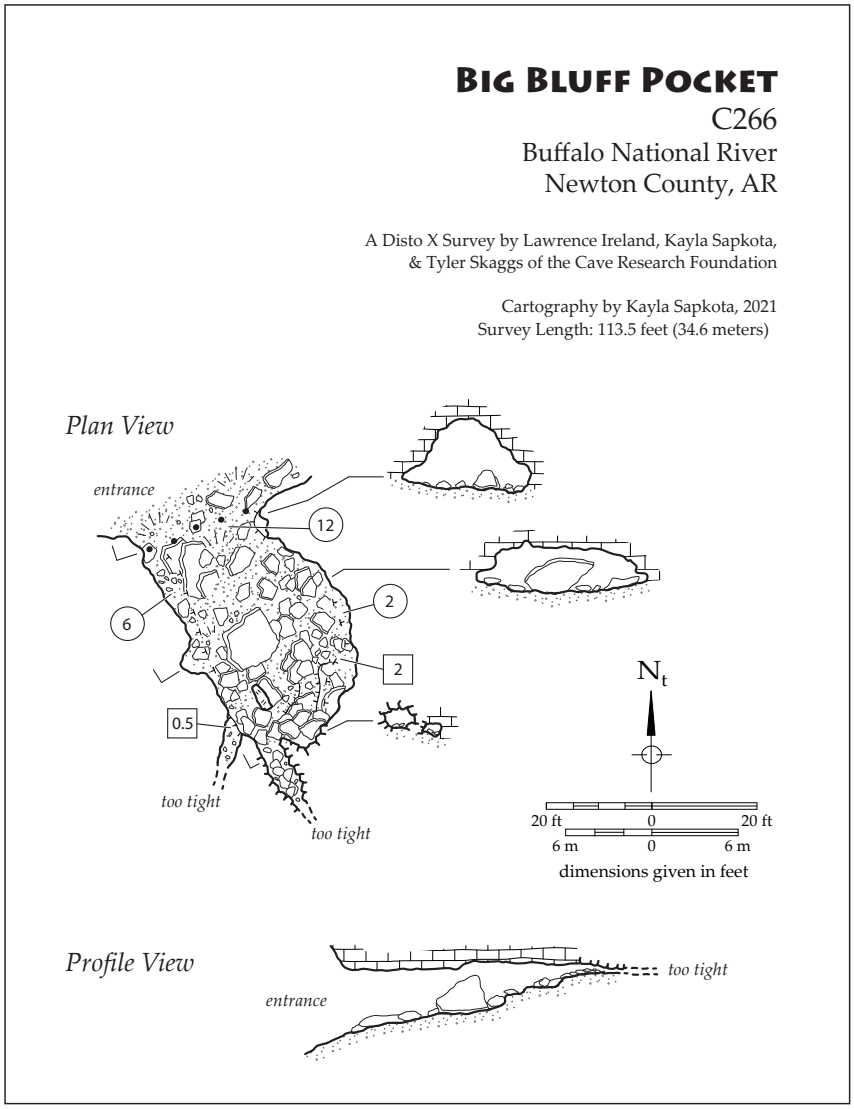
Kayla Sapkota sketches as Rhett Finley and Katie Gromlovitz search for cave life. *Mariana Perez*

LIDAR leads on the Hell Creek Natural Area, though they did not turn out to be caves. A team took a trip to the same area later in the year and ridgewalked a remaining part of the natural area but didn't find any additional caves.

Slippery Hollow Natural Area

A spring mapping trip to the Slippery Hollow Natural Area yielded 226 feet of survey on a longer cave there. A fall mapping trip to the same area with a group of Arkansas Master Naturalists as new JVs yielded a new lead and a new cave mapped at 80 feet in length.

In total, CRF mapped 900 feet for the Arkansas Natural Heritage Commission across the five natural areas visited.



Sequoia / Kings Canyon National Parks 2021 Annual Report

Jennifer Hopper and Fofo Gonzalez

Operations Managers

General Observations

- 2020 and 2021 were very challenging years for cave exploration in Sequoia / Kings Canyon National Parks (SEKI) due to the pandemic, low water, and an aggressive fire season. Most of the scheduled expeditions were cancelled.
- Due to COVID-19, caves within SEKI were closed to research and visitation starting in March 2020, a closure that lasted through the rest of the year and was finally lifted on June 3, 2021, only to be shut down again in October, due to fire activity in the area.
- Barbara Wortham, principal investigator (PI) for the paleoclimate study at Lilburn cave, has finished her PhD. The study used stalagmites to determine likely precipitation and temperature variation over the last 20,000 years. The research will continue under a new PI.
- The cave inventory project (Carol Vesely, PI), developed in Lilburn Cave, will carry over to multiple caves in the SEKI area to give access and provide data for many years. The app to capture data is under new tutelage and more features will be added.

Greg Roemer

- Even in a shortened season, we had six new joint venturers join the project. We understand that groups need to attract new people in order to remain viable, and have continued this goal.
- Due to COVID-19 and fire impacts, the volunteer hours donated to the park decreased from an average of about 4000 hours per year to 488 volunteer hours (20 person-days) in 2020 and 1200 (50 person-days) in 2021.
- The cartography project in Lilburn Cave is active, with exploration teams preparing climbs into passages that may extend into blank zones on the map.
- In early October 2021, fire blazed through the canyon in which Lilburn Cave and the fieldhouse are located, and the area is not yet safe for ground reconnaissance to determine the status of the cabin and other infrastructure.

Cave Management

- We continue to abide by strict qualification guidelines for cavers entering Lilburn. In the past, some people with no caving experience or who had not been vetted by other Lilburn regulars went on Lilburn trips. This qualification procedure has the ultimate goal of preventing any major incidents due to the possibility of an inexperienced caver being injured. The expedition leader is responsible for choosing whether or not to test JVs in vertical skills on site before entering the cave.
- We maintain online platforms including an email distribution group, social media, and Google Drive for expeditious data-sharing with key park personnel and JVs. Investigators' and trip reports, as well as other data collected, are uploaded after expeditions. This assures continuity and data preservation with leadership changes.
- In order to promote a welcoming, safe, and inclusive environment for everyone involved with the CRF, we adopted and continue to abide by the Geological Society of America Code of Ethics to set expectations in a way that is easy to understand and well-defined. This code includes language about alcohol use, prohibits sexual harassment of any form, and

encourages discussions with trip leaders about any concerns that may violate the code of ethics. We have the code available online and at the cabin so everyone can take time to become familiar with it.

Cave Data Management

- The Chief Cartographer, Dr. Jed Mosenfelder, continues to work on cleaning up older data (in the past, multiple cave data management programs were used, and sometimes data migration created issues that require attention). He reviews older cave drafts that are not up to standard with a systematic approach in order to prioritize areas with the most issues, or zones that could be tackled by survey and exploration teams.
- We maintain a laptop at the fieldhouse which enables trip report preparation, sharing, and storage.

Hydrology and Geochemistry: Paleoclimate Project (Barbara Wortham, PhD)

- Understanding the future of our climate depends on building records of how our climate has changed in the past. Records of paleoclimate can be built from stalagmite archives found in cave environments.
- A stalagmite sample was analyzed for U-Th to date its formation. In addition, thin sections of the stalagmite pieces have been analyzed for trace elements. This analysis may show how El Niño Southern Oscillation impacts the southern Sierra Nevada. In addition, the stalagmite was tested as a possible record of past fire activity. Thin sections were used for oxygen and carbon isotope analysis, to determine variability in precipitation and vegetation.
- Monitoring of the cave environment has included cave water pH, and stable isotopes, pCO_2, temperature, and humidity. This data was collected during trips to Lilburn. The goal of this monitoring work was to understand how 1) the surface water that is likely primarily derived from snowmelt is influencing the dripwater in Lilburn, and 2) how temperature and precipitation variability impact dripwater, physically and chemically. From this, we can better interpret our results from the Lilburn stalagmite.
- In 2020 only a few water samples were collected, due to the issues with access to the park.
- The research permit for this project has been extended through 2022 (normally permits are given on a yearly basis). The permit will be valid based on no changes in methodology or research location(s), submission of spatial information on study sites, and annual submission of the Investigators Annual Report (IAR).
- The PI for this project finished her PhD. However, university colleagues plan to continue paleoclimate research in the cave.

Fofo Gonzalez

Greg Roemer

Cartography Project (Jed Mosenfelder, PhD)

- There was no cave survey in 2020, and in 2021 there was a single survey trip, with 88.9 feet of surveyed length. Total cave length stands at 22.25 miles, putting Lilburn at number 28 in the list of long caves in the US.
- The permit issued is valid 2019–2021 and will be renewed thereafter.

Cave Inventory (Carol Vesely and Roger Mortimer)

- ◊ Working under the cartography permit, we continue to develop a cave inventory collection system using an app based on an Android operating system for portability and ease of deployment. Ongoing beta testing and data collection are in process. The focus is making the software nimble, self-explanatory, and as logical as possible.

Jennifer Hopper

- ◊ A new software engineer will build on top of the current platform, in order to modernize the app and correct a few bugs in the software.
- ◊ Carol developed a slideshow and in-person lessons to train new users of the app. As of 2021, 21 JVs have been trained in cave inventory. As more JVs become familiar with the system, we expect the rate of inventory to increase.
- ◊ We have assembled three full sets of cave inventory kits, which consist of a tablet in a rugged, shockproof and waterproof protective case, a pencil and paper cave inventory backup system, and a custom zippered carrying bag.
- ◊ In the future, we would like Carol and Roger to expand the cave inventory to other areas of the national park. Given that cave inventory is a topic that has attracted the attention of multiple national parks, we could even help other parks set up their own cave inventory initiatives, thanks to the ease of implementation of the Android-based app.

Other Projects

Structural Geology and Lilburn Cave (Marek Cichanski, PhD)

- ◊ This project evaluates the role of structural deformation on the karst and its surrounding non-carbonate rocks. In 2017, Dr. Cichanski performed geologic mapping in the cave and created six geology quads, which are stored on a shared online platform. In 2018 Marek was not able to attend any trips due to a combination of work and health issues. Marek has requested a merge of his Structural Geology project into the Cartography project. He plans to add photos to the digital inventory Help section of the app to assist JVs in the recognition of geologic features. He also would like JVs to be able to measure strike and dip using a tablet.

Passage Restoration at Lilburn Cave

- ◊ Once we can return to the cave we will assess the status of areas with high travel, and to determine if the presence of smoke and debris from the fire have affected any areas that may require restoration.

Mineral King Caves (Marcia Rasmussen)

- ◊ The higher elevation areas in the Mineral King section of Sequoia National Park are home to several small caves and karst features. They are accessible only for a few months every year, and this project requires strong hikers, doing ridge walking at elevation.
- ◊ Maps of White Chief Cave and the Area of Thousand Entrances: Multiple marble pockets are yet to be explored in the vicinity of White Chief Cave and Area of Thousand Entrances; therefore, this project will likely extend for multiple years.
- ◊ The focus of this project area will likely shift to cave inventory of the existing caves and mapping of new caves in the vicinity of White Chief Cave and the Area of Thousand Entrances for the near future.

Ursa Minor (Joel Despain)

- ◊ This project focuses on geomorphology research in the cave (sediments, bedrock features, and water samples), as well as on continuing the cartographic study of the cave by pushing leads in the upper levels.

Fofo Gonzalez

Fofo Gonzalez

◊ A climbing lead is still pending, and although there were no trips during 2020 or 2021, this is still considered an ongoing active project, with alternating work trips and restoration trips to preserve the pristine nature of the cave.

Hurricane Crawl Survey (Carol Vesely)

◊ Hurricane Crawl, a pristine and delicate marble cave, was first explored about 30 years ago. Sections of the survey are not up to standard, and there are still promising leads to be surveyed.

◊ The permit for this project has been approved, but access to the cave will depend on when the park can safely reopen this area due to fire damage.

Slide Creek / Eleven Range Overlook (David Angel)

◊ Joel Despain proposed this area for a CRF project several years ago. The access is difficult, and requires ropes to descend into the canyon. Once there, the terrain is difficult to move through with poison oak and uneven ground without trails. Although some caves have been located in the area in past years, the few recent attempts to relocate the caves were not successful and GPS data for the known caves and karst features was determined to be inaccurate. David was able to recruit a person familiar with the terrain and the cave locations, but due to COVID-19 and fires they were not able to go. Once the base data of the known features has been established, further trips will be planned.

Other Possible Projects

Unsurveyed Caves

◊ The park notified us of approximately four caves in a road construction area. One to two may be significant, and we have discussed possible future survey trips.

Monitoring of Stage at Big Spring (Jennifer Hopper).

◊ We are continuing field tests of the data loggers and Bluetooth data collection systems (after a few issues), since we are using equipment designed and created specifically for this project. This proposal has undergone a park-mandated tribal/historic review, and has not yet been approved. This project would support the Hydrology and Geochemistry project. The data loggers will be retrieved at the next opportunity, and we will be able to download the first batch of data.

Educational and Cooperative Efforts

- Due to COVID-19, in-person educational sessions and events are on hold at the park.
- Future projects may include educational posters regarding karst areas and the importance of caves and the surrounding flora and fauna.

Plans for the Future

- We continue to work with park representatives, inviting park employees to participate as JVs on the project.
- We have expanded our scope to other areas in SEKI besides Lilburn Cave and Mineral King. There are several areas in the park that have not been a focus of research, and a number of caves other than Lilburn have potential for projects, including possible unexplored leads. The expansion of the cave inventory project will allow for one avenue of research outside the traditional areas of focus.
- The single largest unknown at this moment is the status of the fieldhouse in Redwood Canyon after the KNP Complex fire (currently 75% contained). The area has not yet been deemed safe for a reconnaissance trip. The cabin status will likely shape the next years of the Lilburn Cave project and will effectively influence the main focus and activities of the CRF SEKI project. Other areas like Mineral King and Hurricane Crawl may receive more of our attention.

2021 Lava Beds Operations Report

John Tinsley

Manager, CRF Northwest Operations

The CRF operations at Lava Beds mustered one full-scale multi-week expedition in 2021. It was quite productive as has been the norm, with Principal Investigators Klausner, West, Tinsley, and Broeckel on site from time to time. The expedition commenced on March 27 with the arrival of Mark Jones who arrived early to assist the Monument with assorted tasks such as ice monitoring at a time when there generally are no interns on the NPS staff. Mark was joined by David Donner and his son, Sasja Donner. In three days, they surveyed 5 caves.

Ed Klausner, Elizabeth Miller, and crew arrived around April 15, and for the next 11 days, Elizabeth Miller, Mark Jones, Karen Willmes, Paul McMullen, and Dave and Sasja Donner accompanied Ed to survey additional caves in the Elmer's Trench lobe of the Mammoth Crater flow.

The principal research projects serviced included West's survey of the Balcony Boulevard lobe, Klausner's survey of Elmer's Trench lobe, Tinsley's survey of (a) the caves of the basalt of Valentine Cave and research on (b) the eruptive history of the Mammoth Crater flow were the principal activities. The crew also addressed by request the NPS-articulated needs for surveys of the caves of the Heppe Ice Caves group, which was also staffed by all available hands.

John Tinsley and Mike Spiess surveyed 3 caves in the Valentine Cave basalt flow, with about 600 feet of surface and subsurface survey. Some 85 known caves remain to be tackled. Tinsley is structuring this project so as to be able to deal off small caves to interested prospective surveyors, mainly as a means to develop new surveyors and especially bookkeepers.

Paul McMullen. *Mark Jones*

Issues Facing the Project in 2021

1. A new Superintendent, Chris Mengel, entered onto duty in late summer following Larry Whalon's retirement in January of 2021. It is important to inform the new administrative personnel of CRF and our capabilities. We also expect to have a meeting with management during our expeditions in 2022 in March and April to include any on-site principal investigators.
2. This winter, Tinsley plans to present to management of the CRF project and will likely present the eruptive model of the Mammoth Crater flow developed by Julie Donnelly-Nolan and presented by Tinsley at the 18th International Vulcanospeleological Seminar.
3. The local CRF-LABE MOU expired the last week of July 2021. There has been no traction towards renewing it or merely extending it. Tinsley started advocating for this in spring of 2020. We are operating under our RPs and the CRF-NPS National MOU. I am comfortable with that mode of operation, as it worked fine at SEKI from 1991-present. If Dave Hays wants a local MOU, Tinsley will work with him to write something the CRF President can sign.
4. After meeting with the new Superintendent we'll see if Dave Hays' reorganization of the management structure sticks or gets modified by the new superintendent.
5. Dave Hays and I agree that a proposal-based approach to CRF activities at Lava Beds is likely best going forward, rather than a volunteer-based operation in which our activities are in fact directly controlled by NPS.
6. As our PIs finish up their initial investigations, they need to be thinking about what/if they might like to do next. Liz Wolff states that she is not likely to undertake a major new project once she finished up the Cave Loop studies, for example. Tinsley is actively seeking other prospective PIs. There are

After the fire. *Mark Jones*

many lobes of the Mammoth Crater flow that have yet to be carefully examined, both inside and outside the Monument.

Results in 2021

1. The Balcony Boulevard sphere of the 2021 expedition logged about 200 field hours, 16 administrative hours, surveyed 21 caves and environs totaling 10,597 feet of surface and subsurface survey: 2029 feet of cave survey and the balance as surface survey distributed among upper Cave Loop (Heppe group), the Balcony Flow *sensu strictu*, and South Trench detail. Future work includes finishing the survey of South Trench towards Genesis Cave, including nearby collapse areas and those near Bitty Pit. As the Monument now defines a cave as 25 feet long rather than 40 feet long, there is more work going forward.
2. The Elmer's Trench sphere of activity logged 252 person-hours of fieldwork surveying 29 caves, ten of which received newly assigned E numbers. Surveys totaled 2645.5 feet. Remaining work addressing Elmer's Trench includes several leads west of the Monument (Hill) Road; and the east side of Monument Road needs ridge-walking, as it was recently burned and new finds are thus likely to pop up.
3. The Valentine Cave Basalt project saw 4 caves mapped totaling 600 feet of survey in 48 hours of field time.
4. Larry Welch and his radon crew decided to postpone further fieldwork until 2022. Tinsley will be working with Dr Welch to make sure his fieldwork gets done if at all possible.
5. The Monument has pretty much taken over the ice monitoring work originally done by Mike Sims and Bill Devereaux, following Bill Devereaux's retirement. CRF personnel such as John Tinsley, Dave Donner, and Mark Jones assist as they are able.

Acknowledgements

We thank Dave Hays for his steadfast support of the CRF work at Lava Beds, and we look ahead to a productive spring expedition.

Balcony Flow Expedition, Spring 2021

Lava Beds National Monument

Dave West

Two hundred sixteen and a half hours were expended mapping 2,028.49 feet in eighteen caves and grottoes with another 8,568.4 feet of surface survey accomplished as well.

Mark Jones arrived early in order to assist the Monument with ice monitoring and other duties for which the Monument was lacking interns. Having some extra time available, he asked if I had anything he could square away, and on March 26, he and Dave Donner (Cal Dave) went first to Honeycomb Hollow to obtain a surface profile I needed for Cave #B043, allowing me to finish up that map. They also went to Cave #B049 and completed that survey. I had given Mark a couple of leads in the trench nearby to survey as well, and he and Cal Dave finished them up as well as finding a new one. Then on April 1 and 2, he and Cal Dave began the survey of Cave #B175 in the burned area of the Balcony Flow.

Karen Willmes and I arrived on Saturday, April 17, and joined the assembled group of Mark Jones, Paul McMullen, Ed Klausner, and Elizabeth Miller at the Research Center (RC). Ed would focus on his project in Elmer's Trench, for which he will provide a separate report. The following day Karen and I went off to obtain surface profiles over Cave #L030, Cave #L040, and Cave #L050 in the Upper Cave Loop Flow, an effort requested by the Monument and begun in October 2020. Mark and Paul surveyed Cave #L035and after completing that went into Cave #L040 to obtain a cross section I needed for the map.

Monday morning David Hays (Chief of Integrated Resource Management, Park Dave) and John Cannon (LABE GIS coordinator) arrived for a welcoming meeting. After that, Cal Dave and I went out to the southern trench of the Balcony Flow to continue mapping. The trench is so wide in this area that we are running three survey lines up it, one on the west edge, one on the east edge, and one in the middle. We mapped until we were opposite Cave #B020, and after a short lunch, took a shot down to a grotto in a side branch of the trench. Things didn't line up properly, and I concluded I had made an error in the orientation of the printed prior work to magnetic north, and we abandoned the trench survey until I could fix it. We then proceeded to Cave #B020 to get a shot into the last remaining lead in the lowest point in the cave. Meanwhile, Mark and Paul went to Cave #B175 to complete the survey there (939 feet total), and finding they had more time, surveyed nearby Cave #B112 (43 feet) and Cave #B320 (87 feet).

On Tuesday, with Mark and Cal Dave off to get their second COVID vaccination shots, Paul McMullen and I first returned to the Heppe Caves and obtained surface profiles over Heppe Grotto and Heppe Chimney. Then after lunch at the RC we went out to the Balcony Flow to get surface profiles over Cave #B320 and Cave Cave #B112, while getting GPS locations for what are likely smaller caves that were once considered too insignificant to meet the Monument prior guidelines they had provided. The old guideline was that to be considered a cave, it had to be at least forty feet long. Anything less didn't justify reporting. During our meeting with Park Dave, he said they would be interested in any cave, no matter how small. This meant

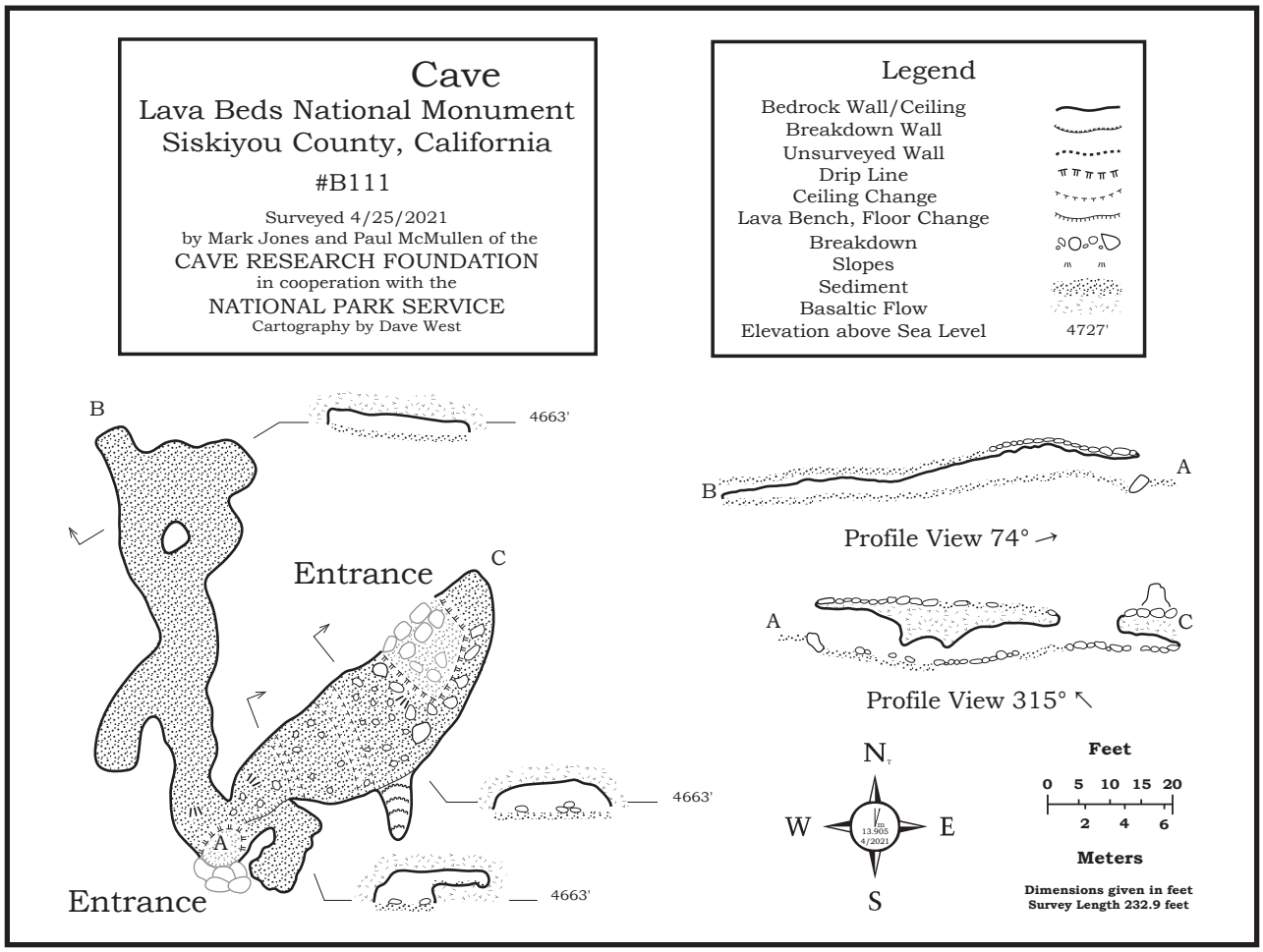
Dave West sketching more trench. *Paul McMullen*

Karen sets station at Cave #B010. *Paul McMullen*

that many former "grottos," that went undocumented could, and should, now be documented.

On Wednesday Mark and Paul surveyed Cave #B010 (193 feet), the vent where the flow originated. Cal Dave and I went to Cave #B050 to get a cross section and then shared GPS information on various undocumented caves/grottos between Cave #B050 and the Whitney Butte Trail so that he could report them as undocumented caves. Cal Dave needed a short day to keep an appointment, so I came back to the RC to have lunch and get caught up on paperwork.

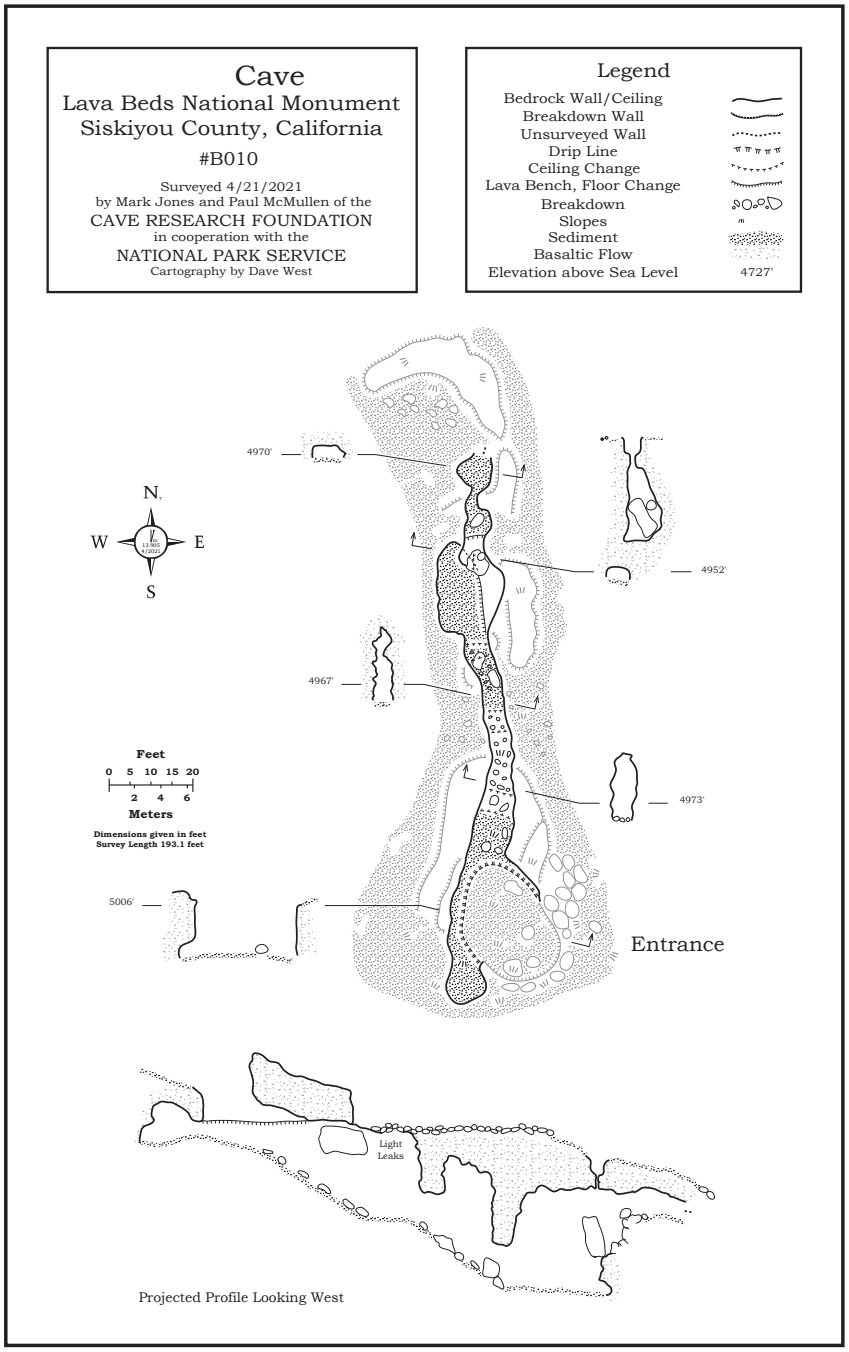
Thursday morning Karen and I went up the Whitney Butte Trail and retrieved the clipboard I had left at one of the leads between Cave #B050 and the trail before returning to the trench survey. We got the trench survey caught up to Cave #B020 on the west side of the trench and then shot down into the trench and surveyed back to the point where Cal Dave and I had started a couple of days previously. We took a shot to the entrance of a grotto that had an entrance about 29 feet wide and five feet high that was about 12 feet deep. I took two shots into it; the collapse in front of it may contain a cave entrance. Many holes going into the breakdown, but nothing documented. We repositioned the shot Cal Dave and I had taken but not drawn and after getting that caught up proceeded to where Cal Dave and I had stopped on the east edge. We took a single shot, but the wind came up and was gusting



so hard it nearly knocked Karen off her feet. Doing surface work in high wind is simply impossible, with the fiberglass tape whipping about and just trying to keep your feet while sketching. We called it a day and returned to the RC early.

On Friday I finally got a three-person team. We claimed two of the 100-foot survey tapes and set up a routine of Cal Dave on point and backsight, Paul on foresight and book, and me on sketch. This allowed me to concentrate solely on the sketch and let them stay a step ahead of me with data collection. This worked well, and we got almost 1300 feet of survey. Having filled up an 8-1/2 by 11 sheet of grid at forty feet to the inch, we stopped the three legs of survey at the edge of the paper for beginning on another day.

Saturday morning we were joined by Cal Dave's son, Sasja Donner. The two of them went with Mark out to the northeast section of the flow and surveyed the collapses at Cave #B320 and Cave #B175. They went on to survey Cave #B125, establishing a surveyed length of 86 feet. Paul and I returned to the south trench and first took a shot off of each the previous day's survey to move it off of one page and onto another and then went down the west edge until it ran off the page. We then had lunch before starting down the east edge. Our first shot was to a shallow pit that appears to have passage in two directions paralleling the main trench. We carried on surveying partway around a dogleg in the trench. Next trip we can tie to Cave #B015 on the first shot. Finally we did a bit of ridgewalking, finding a couple more things for later survey.



The weather forecast for our second Sunday was much less than pleasant with freezing temperatures and snow showers and rain. Mark and Paul went out to the northeast portion of the flow and surveyed Cave #B125 (104 feet) and Cave #B111 (233 feet). Others went to town for supplies, and I waited until after lunch before doing a bit of ridgewalking on the southern portion of the flow. Found one collapse that looks promising. Overall, a good day despite the weather.

Monday's weather was only slightly improved over Sunday's. Paul, Mark, and I persevered and surveyed over 1,500 feet, but had to stop sketching because of loop error problems. Our last five shots were additional loops to pull things together. We had good backsights all the way, but there is evidently so much magnetic interference in random patterns that back sights alone are not sufficient. Having annotated what parts of the sketch are associated with which stations, I will be able to remedy the issue to some extent when I get home. Paul identified a ~32-foot-long

cave for later survey, and I sketched in a few small grottos along the way.

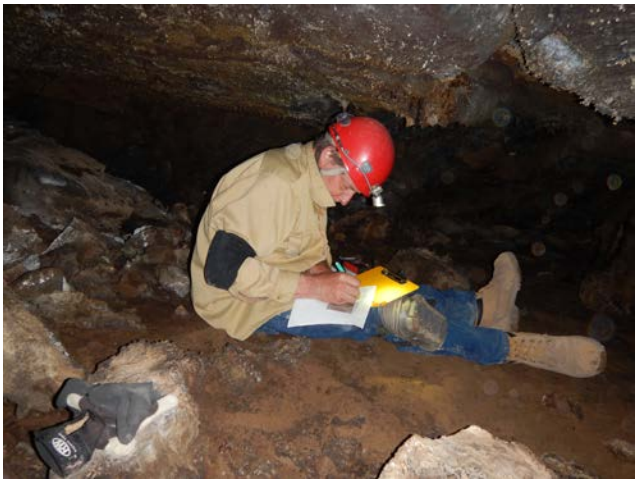
Tuesday I found myself alone again. I waited until the afternoon to see if one of my compatriots would be able to join me, but finally went out alone again. I obtained GPS readings for every other survey shot in the previous day's survey, and then sketched on a separate sheet the last shot of the previous day so it could be included in the morphed composite. By the time we return, I should have a reasonable representation of the area and can fill in any blanks that come about at that time.

Karen joined me on Wednesday and the two of us returned to the trench survey while Mark and Cal Dave continued work on the caves in the northeast portion of the flow. Karen and I first ran a survey line along the west edge to close two more loops with Monday's work. We then followed the southwest edge of the dogleg, crossing the trench to transfer the sketch to the new sketch page. We then took another shot along the west edge of the trench. Sketcher burnout set in, and we returned to the RC. Mark and Cal Dave surveyed Cave #B195 (92 feet), Cave #B165 (40 feet), Cave #B118 (31 feet), and Cave #B145 (45 feet).

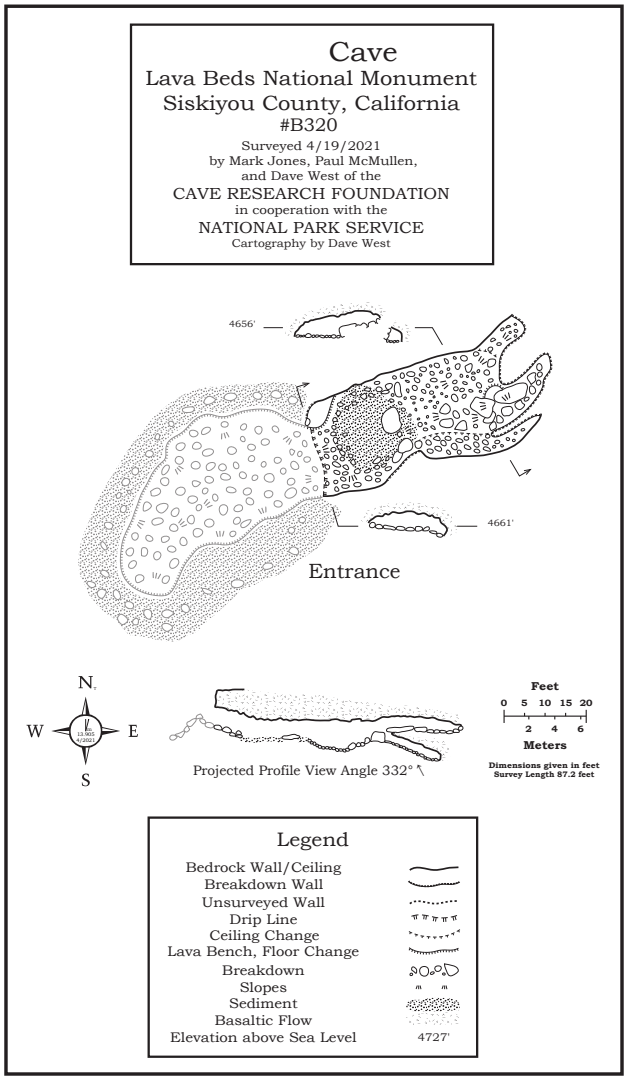
Thursday was our last day of field work at the monument. Mark, Karen, and I returned to the trench survey and filled the page Karen and I had started the previous day. We reached the south end of the main trench. A couple branches to the east remain, and a survey to tie to the Cave #B010surface will be useful. A small bit remains in the northeast part of the flow as well, primarily a single large collapse with no apparent associated cave. In addition, we have over 100 leads to investigate.

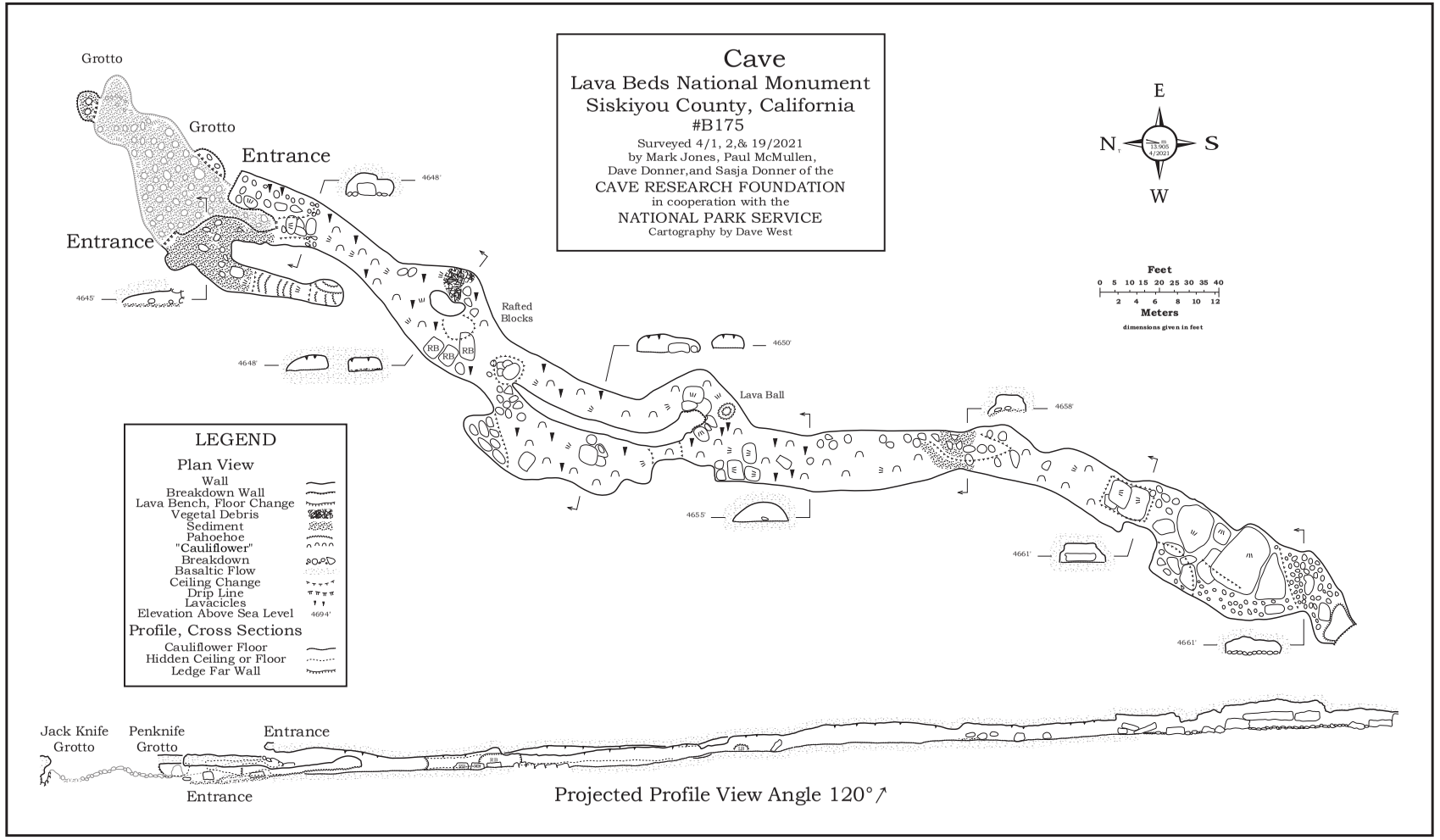
Drafting of all individual cave maps and updated versions of the Heppe Group and Balcony Flow maps were completed by the end of the year and provided to the Monument.

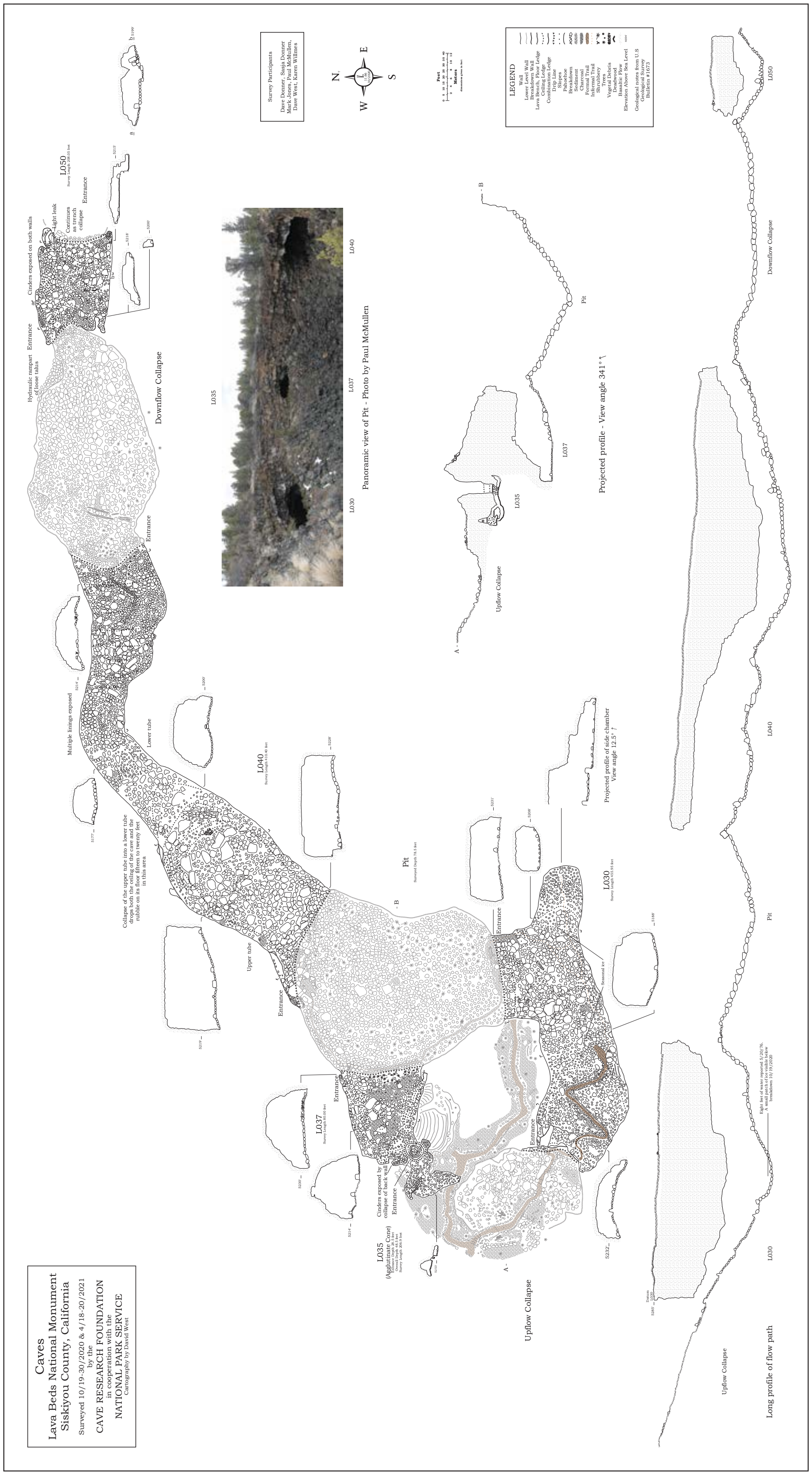
Schonchin Butte seen from a burned Balcony Flow.
Paul McMullen



Mark Jones sketching in Cave #B175. *Paul McMullen*




Cave
Lava Beds National Monument
Siskiyou County, California
#B175
Surveyed 4/1, 2,& 19/2021
by Mark Jones, Paul McMullen,
Dave Donner,and Sasja Donner of the
CAVE RESEARCH FOUNDATION
in cooperation with the
NATIONAL PARK SERVICE
Cartography by Dave West
E
N
S
W
Feet
0 5 10 15 20 25 30 35 40
2 4 6 8 10 12
Meters
dimensions given in feet
Grotto
Grotto
Entrance
Entrance
4648'
4645'
4648'
Rafted
Blocks
RB
RB
RB
4650'
Lava Ball
4658'
4655'
4661'
4661'
LEGEND
Plan View
Wall
Breakdown Wall
Lava Bench, Floor Change
Vegetal Debris
Sediment
Pahoehoe
"Cauliflower"
Breakdown
Basaltic Flow
Ceiling Change
Drip Line
Lavacicles
Elevation Above Sea Level
4694'
Profile, Cross Sections
Cauliflower Floor
Hidden Ceiling or Floor
Ledge Far Wall
Jack Knife
Grotto
Penknife
Grotto
Entrance
RB
Entrance
Projected Profile View Angle 120°↗


Caves
Lava Beds National Monument
Siskiyou County, California
Surveyed 10/19-30/2020 & 4/18-20/2021
by the
CAVE RESEARCH FOUNDATION
in cooperation with the
NATIONAL PARK SERVICE
Cartography by David West
Panoramic view of Pit - Photo by Paul McMullen
Projected profile - View angle 341°
Long profile of flow path
Downflow Collapse
Upflow Collapse
Pit
L030
L035
L037
L040
L050
Entrance
LEGEND

Elmer's Trench

Lava Beds National Monument

Ed Klausner

April 16-26, 2021

The April expedition actually started March 27 when Mark Jones, David Donner, and Sasja Donner surveyed E130, E155T, E145, E150, and E170 Caves over a three-day period.

Elizabeth Miller and I began surveying in Elmer's Trench on April 16th. During the next 11 days, Elizabeth Miller, Mark Jones, Karen Willmes, Paul McMullen, Dave Donner, and Sasja Donner accompanied me into Elmer's Trench to map caves. We completed the survey of seventeen additional known caves, found and surveyed ten new caves, and eliminated many leads because they were too tight to enter, or too short to count as a cave. The original definition of a cave when the project started was 40 feet, but recently changed to 25 feet. This seems like a reasonable length with the exception of an unusual or interesting feature that is shorter than 25 feet. By the end of the expedition, all of the caves on the list of caves in Elmer's Trench that was given to me at the start of the project have been mapped with the exception of E196 which we couldn't find.

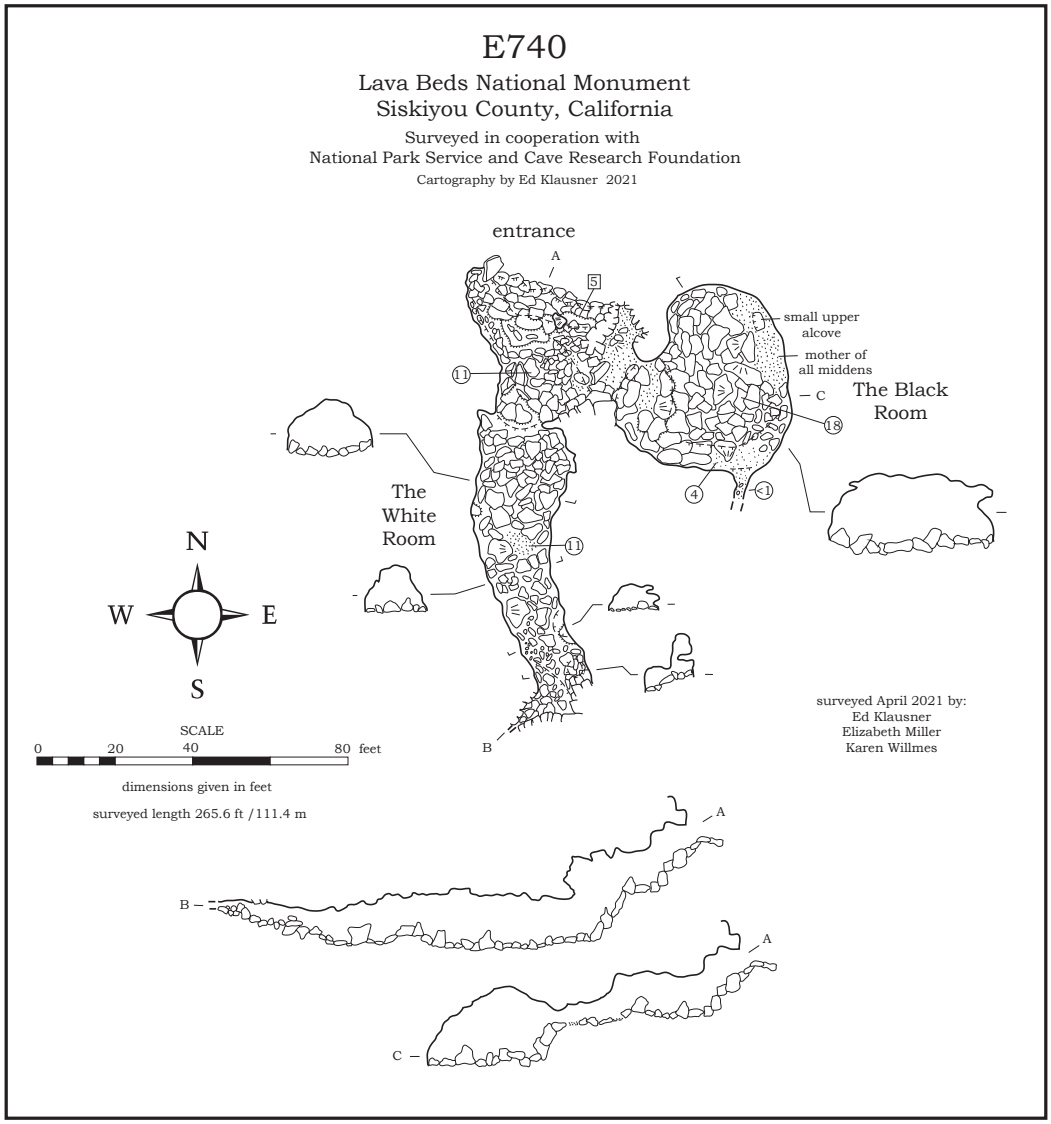
Mark Jones. *Paul McMullen*

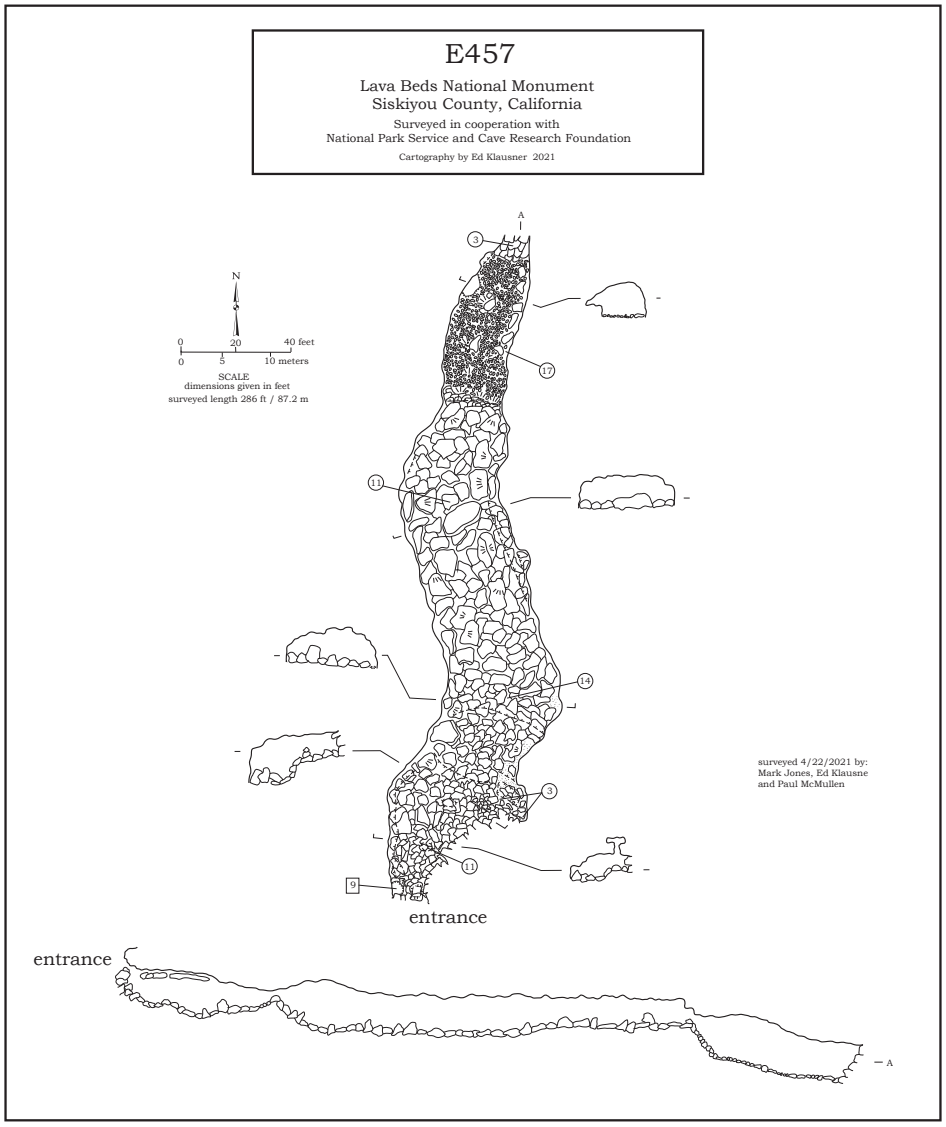
Elmer's Trench cave survey:

E130	212.7'
E155	92.2'
E145	65.1'
E150	68.6'
E170	36.7'
E101	33.2'
E100	432.9'
E452	72.8'
E459	69.0'
E010	68.5'
E030	50.9'
E040	102.7'
E205	77.1'
E740	265.6'
E725	37.4'
E020	112.3'
E050	28.8'
E451	37.7'
E457	286.0'
E125	66.8'
E135	53.7'
E131	47.2'
E121	28.6'
E122	37.3'
E123	40.0'
E179	56.6'
E152	53.8'
E153	25.3'
E154	84.0'
Total survey Elmer's Trench	2643.4'

Ed Klausner sketching. *Mark Jones*

Karen Willmes. *Mark Jones*

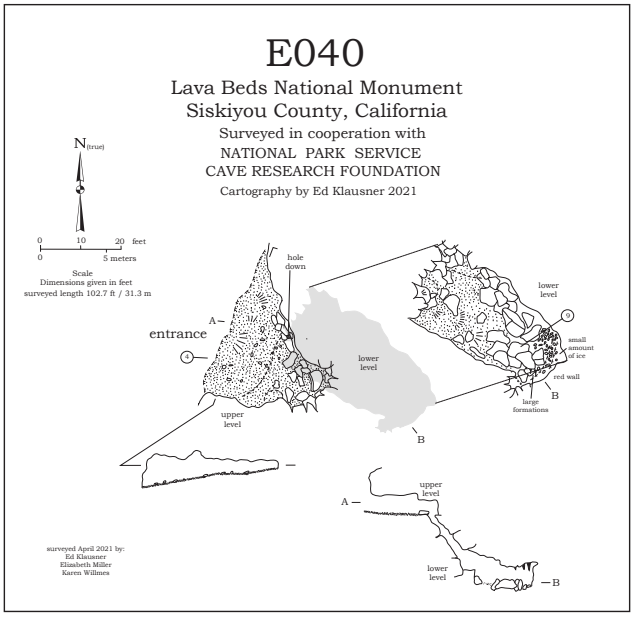


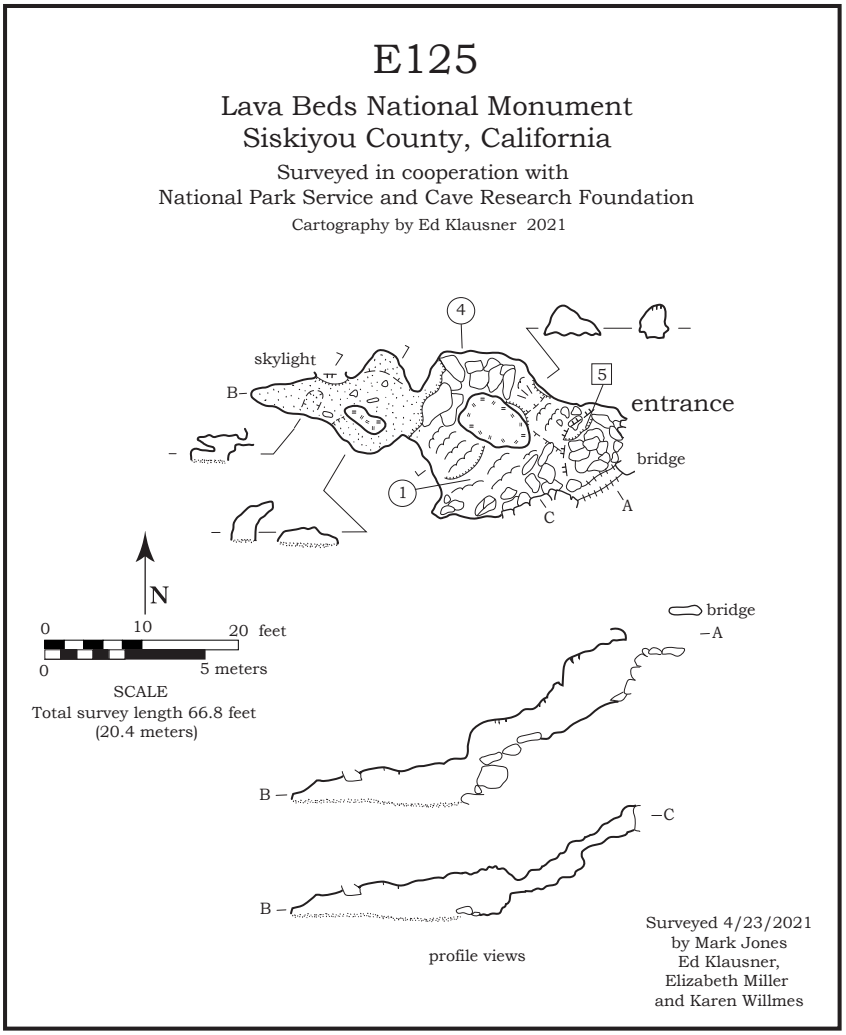


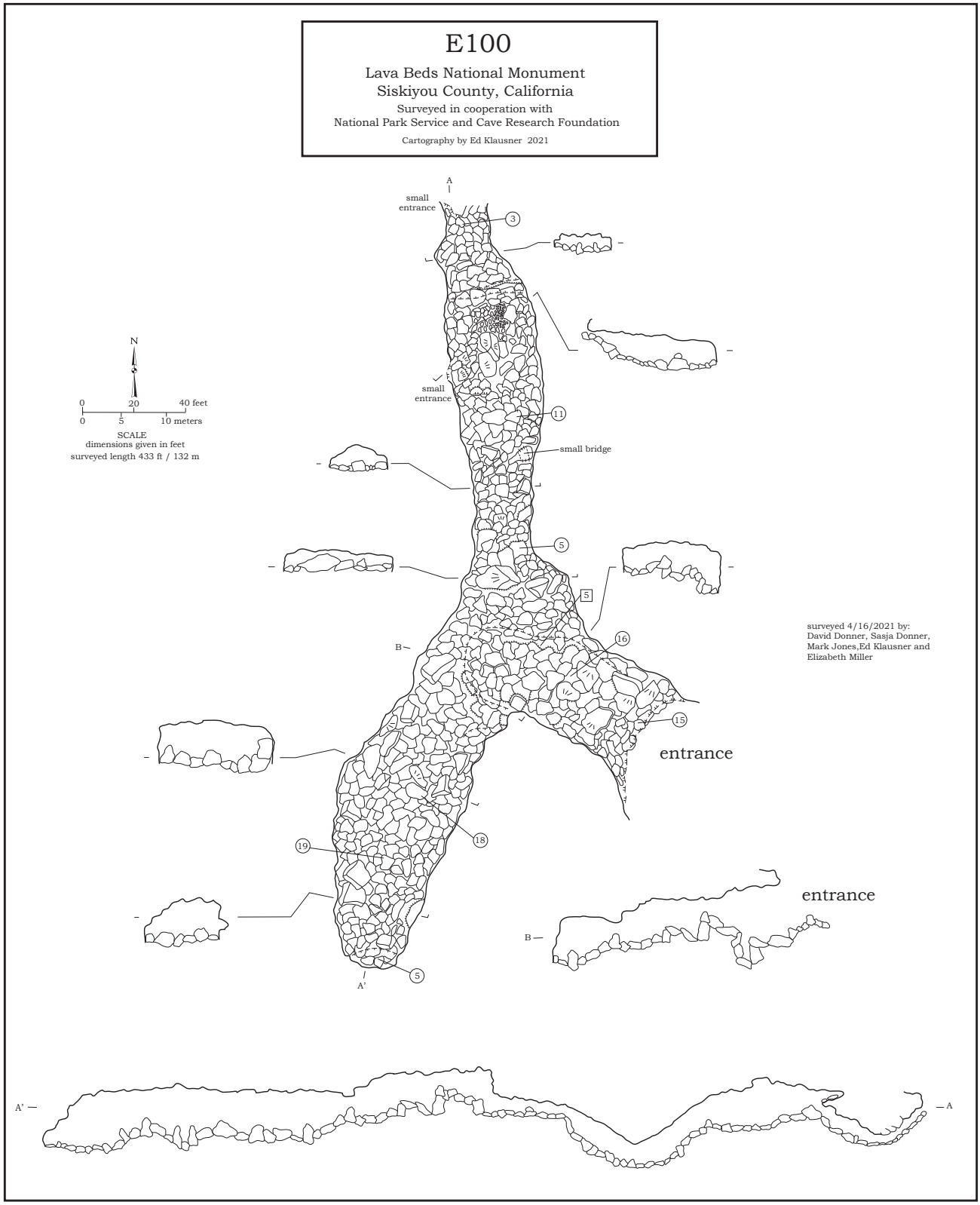
Karen Willmes. *Ed Klausner*

Mark Jones on the way to map a cave. *Ed Klausner*

Dave Donner. *Mark Jones*






E100
Lava Beds National Monument
Siskiyou County, California
Surveyed in cooperation with
National Park Service and Cave Research Foundation
Cartography by Ed Klausner 2021
A
small entrance
3
small entrance
11
small bridge
5
5
16
B
15
entrance
18
19
5
A'
N
0 20 40 feet
0 5 10 meters
SCALE
dimensions given in feet
surveyed length 433 ft / 132 m
surveyed 4/16/2021 by:
David Donner, Sasja Donner,
Mark Jones,Ed Klausner and
Elizabeth Miller
entrance
B
A'
A

Science

Bryce Belanger in Titan Cave, northern Wyoming. *Cameron de Wet*

2021 Philip M. Smith Graduate Research Grant for Cave and Karst Research

Proposals and Funding Recommendations

Master's Proposals

Matthew Terrell, M.S. Student

Department of Earth and Atmospheric Sciences, Indiana University
Advisor: Lee Florea
Landscape evolution in the karst region of Mitchell Plateau, South-Central Indiana
Funded for $3000

Doctoral Proposals

Andrew Oberhelman, Ph.D. Candidate

Department of Geological Sciences, University of Florida
Advisor: Jonathan Martin
Organic carbon and methane dynamics in a carbonate karst aquifer
Funded for $3000

Rachel Bosch, Ph.D. Student

Department of Geology, University of Cincinnati
Advisor: Dylan Ward
Speleothem and charcoal dating to constrain the pace of denudation of the Sinkhole Plain, Central Kentucky Karst
Funded for $1300

Bryce K. Belanger, Ph.D. Student

Department of Earth and Environmental Sciences, Vanderbilt University
Advisor: Jessica Oster
Reconstructing mid-Holocene hydroclimate conditions in the Rocky Mountains, USA: Implications for seasonality and monsoon influence during past warm periods
Funded for $2750

The total funding is $10,050.

Reconstructing Mid-Holocene Hydroclimate Conditions in the Rocky Mountains, USA

Implications for Seasonality and Monsoon Influence during Warm Periods

Bryce K. Belanger

The Cave Research Foundation Philip M. Smith Graduate Student Research Grant provided critical funding for laboratory analyses necessary for the completion of this project. Overall, this work focused on reconstructing past climate change in the northern Rocky Mountains using speleothem records from Titan Cave (TC) in northern Wyoming (Fig. 1). This project was motivated by the goal of better understanding precipitation changes during past warm periods in the western U.S. Speleothems, which are geologic formations in caves created by the deposition of calcium carbonate minerals over time, preserve a number of climatic signals in their geochemical make up, revealing aspects of past climate during the speleothem's growth (Lachniet et al., 2014; Oster and Kelley, 2016; Wong and Breeker, 2015). Speleothems provide the opportunity to reconstruct long-term terrestrial climate variability, extending records of past precipitation variability beyond the instrumental and tree ring record (Cheng et al., 2016; Wendt et al., 2018).

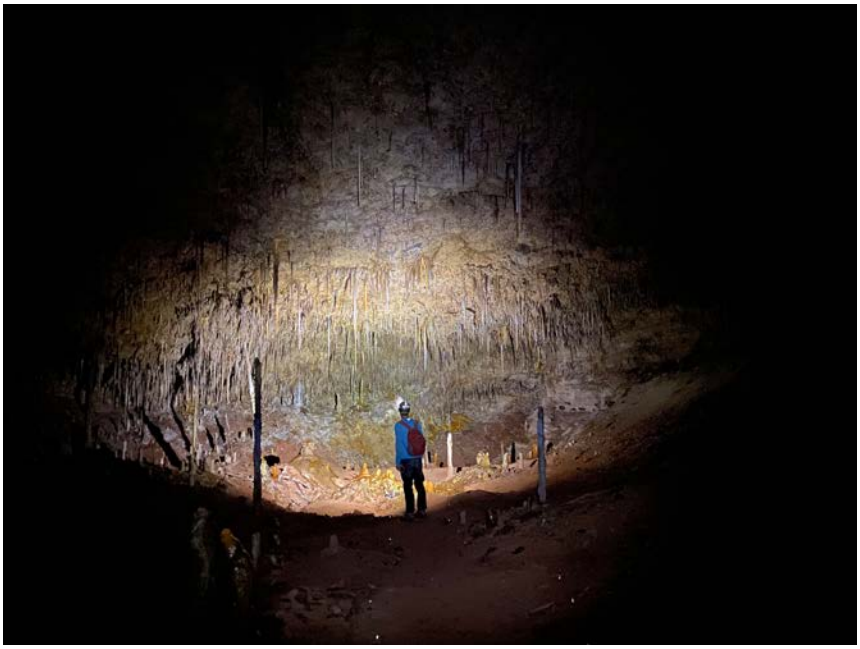


Figure 1. Bryce Belanger in Titan Cave, northern Wyoming. Photo by Cameron de Wet.

For this project, I was specifically interested in reconstructing past changes in precipitation during the mid- and late-Holocene (6000 years before present until modern day). A prominent climate trend observed in the Rocky Mountains during this time period is the emergence of three common drought patterns (Fig. 2), which alternate based on internal climate variability with secondary influence by sea surface temperatures (SSTs) (Wise et al., 2016). Shifts back and forth between the "wet north/dry south" and a "dry north/wet south" patterns are often referred to as the north/south, wet/dry precipitation dipole, a pattern which is centered around ~40°N latitude and persists to the present day (Pederson et al., 2011; Shuman et al., 2014; Wise, 2010). This pattern has been shown to persist on decadal to centennial timescales and is well-documented in the tree ring record of the past 500 years (Pederson et al., 2011; Wise, 2016). Recent evidence suggests that the north/south, wet/dry precipitation dipole of today may have emerged during the late-Holocene with the onset of modern tropical controls on Pacific climate. Shuman et al. (2014) observe that periods of high lake levels in central Colorado became synchronous with depressed lake levels in northwest Wyoming beginning ~3.5 ka (ka: thousand years ago) on ~500-year timescales. Work by Anderson et al. (2016) provides evidence for the emergence of a precipitation-$\delta^{18}O$ dipole around 4 ka between Jellybean Lake (Alaska) and Bison Lake (Colorado), indicative of dry conditions in the northern North America synchronous with wet conditions to the south, and vice versa. Anderson et al. (2016) also suggests that the appearance of the dipole pattern after 4 ka represents the onset of modern tropical controls on Pacific ocean-atmosphere dynamics, citing warmer North Pacific SSTs (Barron et al., 2003; Praetorius et al., 2015) and increased tropical storm activity in the northwest Pacific (Woodruff

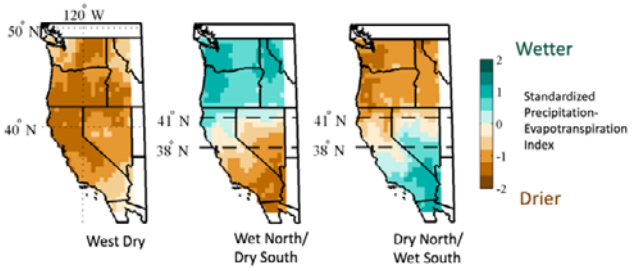


Figure 2. Three modes of cool-season western US drought as reconstructed from tree ring records over the past 500 years, from Wise (2016). From left to right: West-wide drought, Wet North/Dry South, Dry North/Wet south.

et al., 2009) between ~4 and 3 ka. Capturing the timing of dipole initiation will provide critical insights into the processes driving this drought pattern and help determine the influence of SSTs and internal climate variability on drought dynamics in the western U.S.

Today, understanding shifts and reversals in the western U.S. precipitation dipole is critical for anticipating future drought in the region. Growing evidence indicates anthropogenic climate change may increase the frequency and persistence of these drought patterns (Swain et al., 2014), possibly leading to more extreme wet and dry periods as the climate continues to warm. Therefore, it is critical to improve understanding of long-term internal climate variability and drivers of drought in the western US, and to determine the frequency, duration, and severity of droughts over the late-Holocene and Common Era in the region. Titan Cave, located in northern Wyoming on the northern side of the dipole, provides a unique opportunity to assess the timing of dipole initiation and the frequency of shifts in this pattern. In this project, I produce high-resolution, precisely-dated Holocene speleothem records from Titan Cave to compare with coeval climate archives, specifically from the opposing side of the dipole in the southern Rockies. Comparing climate proxies from Titan Cave with these regional records will allow for determination of the timing of dipole initiation and provide estimates of the frequency in which the dipole alternates between opposing states due to natural variability.

For this project, I produced a precise age model and high-resolution trace element and stable isotope records for stalagmite 'TC-7', which was collected from Titan Cave in 2019. TC-7 is ~4 cm in length and grew from ~3.1 ka to ~1930 CE (Fig. 3). Financial support from the CRF was critical for completing U-series dating and trace element and stable isotope analyses on the TC-7 stalagmite (Figs. 3, 4). My work focused on statistical comparisons between TC-7 proxy (trace element and stable isotope) data and other relevant coeval climate records, which demonstrate robust correlations between TC-7 proxies, Gulf of Alaska

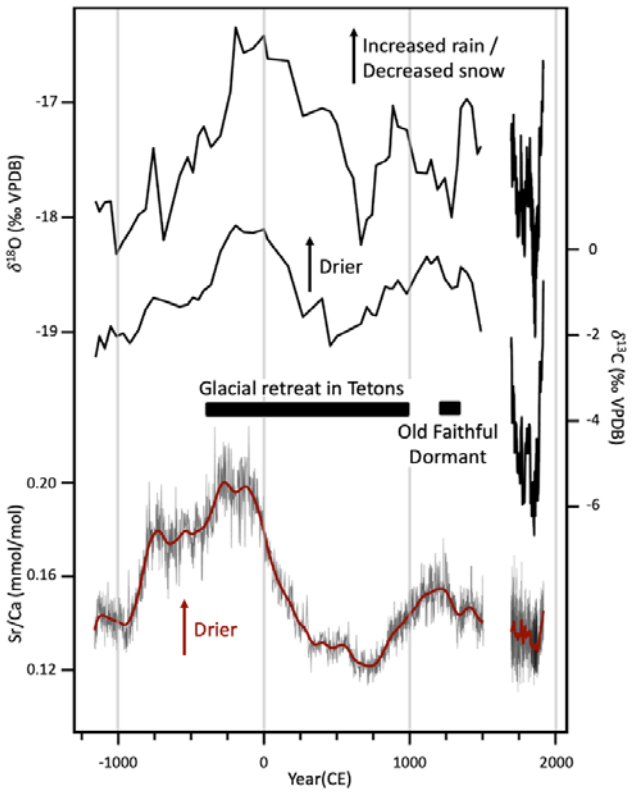


Figure 3. (Left) Stalagmite TC-7 with ^{230}Th/U ages and associated 2σ uncertainties presented in years before present (yr BP) with present = 1950. Sample measures 46 mm in length. (Right) TC-7 age-depth model. Potential growth hiatus is represented by the dashed red line. Notable ages are shown in years Common Era (CE).

(GoA) sea surface temperatures (SSTs) and Bighorn Basin tree ring-based reconstructions of regional snowpack. Furthermore, I observe dry intervals at Titan Cave consistent with other regional (northern Wyoming) drought events, specifically glacial retreat in the Tetons beginning ~2.4 ka (Larsen et al., 2020) and Old Faithful geyser dormancy from 1233–1362 CE (Hurwitz et al., 2020) (Fig. 4). TC-7 $\delta^{18}O$ variations are generally opposite to variations in the $\delta^{18}O$ of lake sediments from Bison Lake in central Colorado, suggesting the presence of the north/south wet/dry dipole since at least the beginning of TC-7 growth around 3 ka, however the temporal resolution of TC-7 $\delta^{18}O$ is low during this time. The TC-7 and Bison Lake $\delta^{18}O$ records also document periods of Rocky Mountain-wide aridity from 2.2-2.0 ka and 1.2-1.1 ka, consistent with the three modes of western US drought as proposed by Wise (2016).

Funding from the CRF was critical for this work and is greatly appreciated by all authors involved. Future work at Titan Cave will continue to improve our understanding of shifting western US drought dynamics in a warmer world.

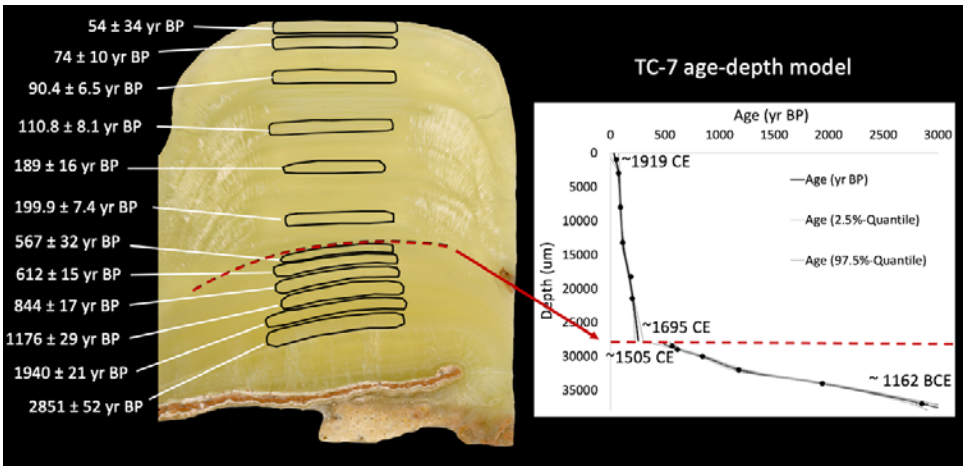


Figure 4. Select TC-7 proxies ($\delta^{18}O$, $\delta^{13}C$ and Sr/Ca) compared to significant climatic events in WY over the late-Holocene. Period of reduced snowpack and glacial retreat occurred in the Tetons from ~400 BCE to 1000 CE (Larsen et al., 2020). Dormancy of Old Faithful Geyser occurred from 1233–1362 CE (Hurwitz et al., 2020).

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Speleothem and Charcoal Dating to Constrain the Pace of Denudation of the Sinkhole Plain, Central Kentucky Karst

Rachel Bosch

Scientific Report

In our study area of central Kentucky, multiple tributaries to the Barren River were cut off from below by the development of sinkholes and cave passages in the Sinkhole Plain (Fig. 1) and diverted to flow to the Green River, migrating the drainage basin boundary between the Barren and Green watersheds westward over time. This is part of a larger pattern of erosional response to downcutting of the Green and Barren Rivers during the Quaternary, wherein sinkholes develop and deepen to reflect increased erosion potential of the subsurface network that drains to these rivers. In this study, we focused on Crystal Onyx Cave in Prewitts Knob, Cave City, KY, to investigate the landscape evolution and drainage history of the Sinkhole Plain in the context of the established chronology of the incision of the Green River using burial ages for the Mammoth Cave system (Granger et al., 2001).

Myself and Dylan Ward prepared a variety of samples for geochronological analysis, including radiocarbon dating of charcoal in surface stream deposits from the Sinkhole Plain; as well as U-series dating of flowstone and cosmogenic burial dating of allochthonous cave sediments, both from Crystal Onyx Cave, a cave set in Prewitts Knob, one of many remnant knobs, rising about 60 m above the modern Sinkhole Plain surface. The caves within these remnant knobs may act as just local drainage. However, we hypothesize that Crystal Onyx Cave may have been a part of an integrated karst drainage network including other knob caves, and perhaps connected with older levels of Mammoth Cave.

Crystal Onyx Cave, with its upper entrance at 268 m and lower entrance at 249 m ASL (above sea level) as shown in schematic profile in Fig. 2, is just one example of many knob caves. First, we considered the age of development of the passages that comprise Crystal Onyx Cave, with a focus

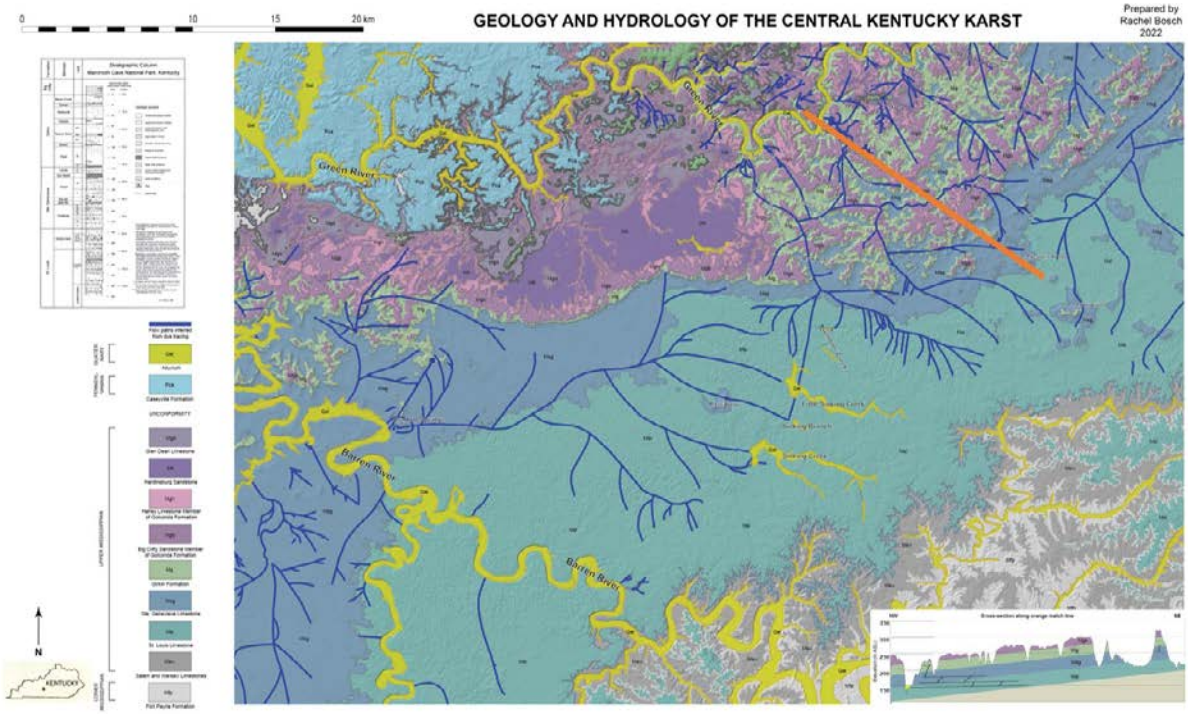
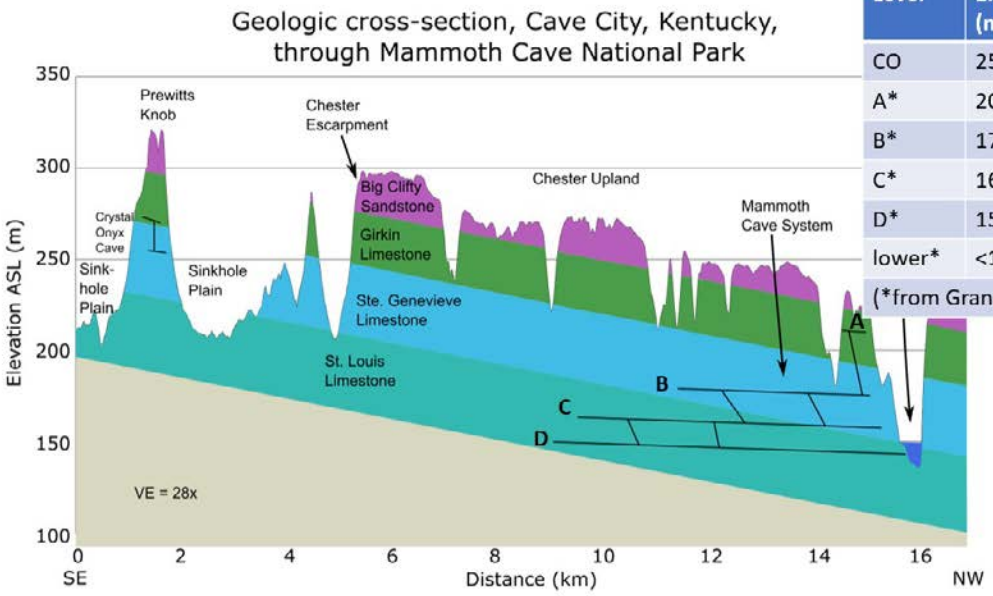


Figure 1. Map constructed by Dr. Bosch in QGIS and Adobe Illustrator using the following data: Kentucky DGI (2022), Kentucky Geological Survey (2022), Palmer (1998), and Toomey (2019). See Figure 2 for geologic cross-section along orange match line.



Level	Elevation (m)	Estimated burial age
CO	250	5.1 Ma
A*	200	3.6 Ma
B*	170-180	2.15 Ma
C*	167	1.55 Ma
D*	150	1.45 Ma
lower*	<150	0.85 Ma
(*from Granger et al., 2001)		

Figure 2. Geologic cross-section along orange match line in Figure 1. Table presents associated $^{26}Al/^{10}Be$ burial ages for Crystal Onyx Cave (this work) and the levels shown in Mammoth Cave system (Granger et al., 2001).

on the lower level, presumably the youngest passage. It could be similar in age to level B Mammoth Cave passages if it were to have been lithologically controlled. It may be consistent with or higher than level A because the elevation of Crystal Onyx is a bit higher than Collins Avenue in level A, or perhaps it was an isolated cave that never connected to the Mammoth Cave system.

Crystal Onyx Cave exhibits two consistent horizontal levels. In both levels we observe more clastic sediment than we would expect if these were isolated drainages that received sediment sourced from only the present-day knob. These deposits do not demonstrate any consistent sedimentary structures that would inform us as to the directions of the paleoflow. Additionally, scallops have been observed throughout the cave, but it has been concluded that these scallops do not yield sufficient information to reconstruct the paleohydrological setting of this cave (Palmer, personal communication, 2022-03-31).

Sand and sandstone from a breccia deposit were collected from a ledge in a lower-level passage of Crystal Onyx Cave for burial $^{26}Al/^{10}Be$ cosmogenic dating to determine where and when Crystal Onyx Cave fits within the geomorphic and hydrologic history of the Sinkhole Plain. Flowstone immediately overlying this breccia was collected to provide a minimum constraining age using U-series dating. Additionally, charcoal from a cut bank was collected from Little Sinking Creek for radiocarbon analysis to determine timing of sedimentation of the Sinkhole Plain.

Results from the $^{26}Al/^{10}Be$ burial dating revealed a burial age of 5.1 ± 0.7 Ma, consistent with the chronology established for Mammoth Cave by Granger et al. (2001). This sample from Crystal Onyx is quite a bit older and plots within the same range of erosional rates, verifying that it is within the same landscape (Fig. 3). It is therefore reasonable to presume that Crystal Onyx Cave could have been part

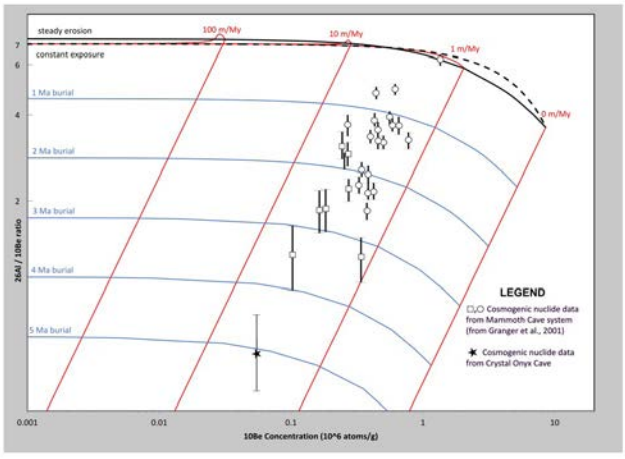


Figure 3. Cosmogenic nuclide data from sediments in Crystal Onyx Cave and the Mammoth Cave system, shown on a logarithmic graph of $^{26}Al/^{10}Be$ vs. $[^{10}Be]$. Burial isochrons are shown at million-year intervals. The star is the sand sample from this work, circles are gravel samples from Granger et al. (2001), and squares are sand samples from Granger et al. (2001).

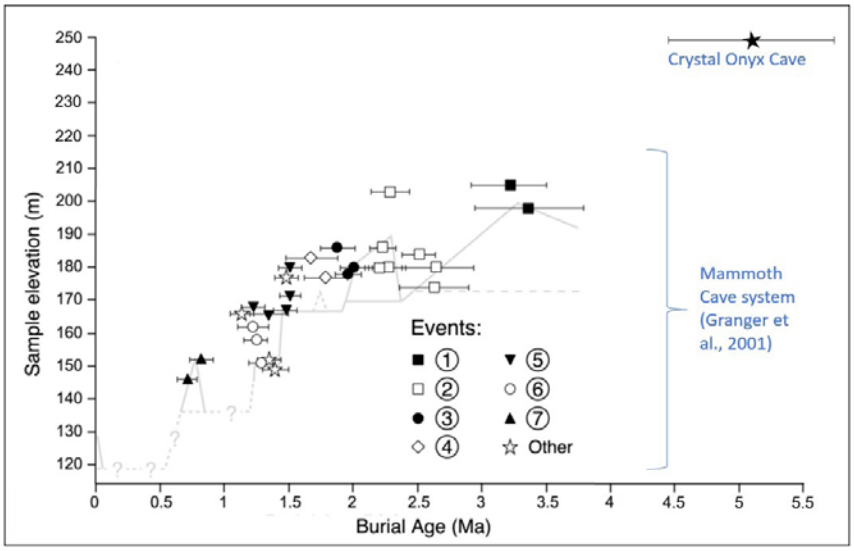


Figure 4. Burial age from Crystal Onyx Cave added to Green River history inferred from Mammoth Cave burial ages as presented in Figure 5A of Granger et al. (2001). Cave sediment burial ages plotted against elevation. Error bars represent one standard error analytical uncertainty.

of the Mammoth Cave system since a linear trend can be regressed through the Granger et al. (2001) data and the burial data from Crystal Onyx Cave (Fig. 4). The slope of that line yields an erosional rate of about 25 meters per million years for the Green River incision rate.

The charcoal sample was sent to the National Ocean Sciences AMS Facility at Woods Hole Oceanographic Institution, where they combusted the material and found that it did not contain sufficient organic carbon to provide a radiocarbon result. Samples of flowstone were sent to Bureau Veritas for whole rock lithogeochemical analysis prior to U-series dating. In communication with David McGee at MIT, it was determined that the calcite from our flowstone samples was not pure enough to be well-suited for U-series dating. Therefore, of the methods presented in the grant proposal, only the cosmogenic burial dating yielded results.

There are several possible explanations for the age of the lower level of Crystal Onyx Cave and how it fits in with the regional landscape. It is significantly older than level B of Mammoth Cave which tells us that its development was probably not lithologically controlled. It could have been formed contemporaneously with level A but was then abandoned by sedimentation earlier than level A, in which case level A may have experienced subsequent erosion and aggradation. Or it could be it could be that it's an older level of the same system and drained to the Green River and that there's nothing left further north and west from this level. A final possibility is that it was a hydrologically completely different than modern day Mammoth Cave; it may have drained to the west to the Barren River.

Considering the burial age of Crystal Onyx Cave in combination with the Mammoth Cave burial ages (Granger et al., 2001), the average estimated rate for the Green River incision is 25 meters per million years. Whereas, distributing the ~5 million-year age for Crystal Onyx Cave over the relief of Crystal Onyx Cave relative to the Sinkhole Plain, yields an average erosional rate of 15 meters per million years.

Questions for future research include whether knob caves at similar elevations to Crystal Onyx Cave throughout the Sinkhole Plain contain clastic sediments that we could interpret and date. Do they have other paleo flow indicators within them such as scallops that could inform reconstruction of the Pennyroyal Plateau prior to the denudation of today's Sinkhole Plain?

The results of this study were shared at the 2022 joint North-Central–Southeastern GSA meeting in Cincinnati, OH, and are in preparation for scientific publication.

Presentations

Bosch, Rachel and Ward, Dylan, 2022, Evolution of the surface and subsurface drainage of the Sinkhole Plain, Central Kentucky Karst, USA: Geological Society of America Abstracts with Programs, v. 54, no. 4, https://doi.org/10.1130/abs/2022NC-375448

Dissertations Completed

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