Cave Research Foundation
Annual Report 2022

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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 2022 Annual Report

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Front cover photo: Plaque presented to CRF for the 2021 George and Helen Hartzog Regional Group Award for Outstanding Volunteer Service from the National Park Service's (NPS) Volunteers-In-Parks program. Back cover photos: *top*, On a survey trip in Berome Moore Cave, Missouri. Photo by Chad McCain. *Bottom*, Michael Raymond sketching in Craters of the Moon National Monument and Preserve, Idaho. Photo by Paul McMullen.

For information contact
Ed Klausner
1132 Hotz Avenue
Iowa City, IA 52245

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Contents

Operations Areas and Projects

Science

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2022

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Kayla Sapkota

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Karen Willmes
Mammoth Cave National Park
Cumberland Gap National Historical Park
Cave Hollow–Arbogast Cave
Forestville / Mystery Cave State Park

Ozarks Operations Area

R. Scott House
Mark Twain National Forest
Ozark National Scenic Riverways
Missouri Department of Conservation
Missouri State Parks
Buffalo National River
Don R. Russell Preserve, Oklahoma

Sequoia / Kings Canyon Operations Area

Fofo Gonzalez and Jen Hopper
Sequoia / Kings Canyon National Park

Northwest Operations Area

John Tinsley
Lava Beds National Monument
Craters of the Moon National Monument
Klamath Mountains

Southwest Operations Area

Janice Tucker
Carlsbad Caverns National Park

Hamilton Valley Operation

Patricia Kambesis
Hamilton Valley Field Station

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 2022:

Fellows

Meghan Gallo

Meghan has been a contributor to Arkansas projects for several years, having helped with mapping and monitoring projects since around 2010. She has been active in Buffalo National River and Arkansas State Parks trips, along with some private projects, such as the mapping of Onyx Cave in Carroll County, Arkansas. She is reliable and dedicated, as well as a valuable sketcher.

Aaron Thompson

Aaron has been a regular contributor to both Arkansas and Missouri projects for several years now. He has helped locate, map, and monitor many caves and has also been involved in some cave gating projects. Aaron is discerning, dedicated, and hardworking. He has participated in mapping and biomonitoring activities on Buffalo National River, Arkansas Natural Heritage Commission, and Arkansas State Parks projects.

Claty Barnet

Claty's support of both expedition activities and the administration side of Ozarks Operations has situated her as a valuable player in our work in Arkansas. She is likeable, detail-oriented, and hardworking, having taken on the role of Ozarks Personnel Officer just this year. She has participated in mapping and biomonitoring activities on Buffalo National River, Arkansas Natural Heritage Commission, and Arkansas State Parks projects.

Michael Raymond

Michael has been caving at Mammoth Cave since 2018. He recently volunteered to be the Safety Officer. His credentials are excellent, because he is one of the Small Party Assisted Rescue instructors for National Cave Rescue Commission. He has also attended expeditions in other locations, such as Craters of the Moon. Michael has been very active with the new Eastern Operations project to resurvey Minnesota's Mystery Cave. Behind his quiet demeanor is an intelligent, dedicated, and exceptionally competent caver, vertical caver, and cave diver.

Certificates of Merit

Jessie Bridges

Jessie has been a contributor to Arkansas projects for several years, having helped with mapping and monitoring projects, along with squeezing into some tight and uncomfortable places in the name of mapping. She's moved into trip leading and sketching and continues to be a valuable asset on any team.

Ben Damgaard

Ben joined his first CRF trip in early 2019 and has helped map over 6,700 feet of cave. He has begun leading trips, as well as sketching. He has participated on Buffalo National River, Arkansas Natural Heritage Commission, Moore Cave, and Tumbling Creek Cave trips.

Isaac Smith

Isaac has played a vital role in various projects in CRF Ozarks. Since 2019 Isaac has been on at least 29 trips within CRF Ozarks and has been on several trips to Mammoth Cave. Isaac is a tough, reliable caver who has assisted in many different survey projects. As such he is always willing to carry more than his fair share of any load. Isaac also contributes an exceptional working knowledge of cave life. Maintaining reliable accounts of faunal observations in caves is a mainstay of CRF Ozarks and is key to our program. According to the Missouri Cave Database, Isaac can be attributed to 693 unique accounts of cave life observed in Missouri caves since 2019. These are records of single species occurrences on a given date at a given site. Isaac's expertise is reliable enough that Mick Sutton has deferred to him at times and has relied upon his work in helping to clean up faunal records for the Missouri Cave Database. Given the priority that our cooperating agencies give to documenting cave life, Isaac brings a much-valued presence to CRF Ozarks.

Kelly Koch

Kelly has been involved with the Roaring River Recharge Area Delineation project from the start. Kelly was the lead naturalist at Roaring River State Park throughout much of the duration of the project. Kelly changed 99% of the charcoal packets which involved changing charcoal packets at a wide variety of locations, multiple times for each round for the last nine rounds. This means that Kelly has changed literally hundreds, if not thousands of charcoal packets throughout the past six years. Kelly has also involved the Cave Research Foundation in events that she has led for the park including a cave mapping workshop for the Missouri Interpreters Association in 2019. Due to her gigantic commitment to the project and the inability of the project to have succeeded without her involvement, she is deserving of a Certificate of Merit.

Mark Jones, Kirsten Alvey-Mudd, and Dennis Novicky

Mark, Kirsten, and Dennis are awarded specifically for investigating, planning, and executing necessary gate repairs on the Sodalis Nature Preserve, home to the bulk of the world's Indiana bat population. This effort took numerous days and is not completed yet. They analyzed the problem, came up with solutions, and then did the bulk of the work, all in cooperation with the Iowa Natural Heritage Foundation, City of Hannibal, and US Fish and Wildlife Service. The same three were also totally responsible for doing the same for the Lost Boys Cave, also in the city of Hannibal, in cooperation with the Missouri Department of Transportation. (This effort has preserved the cave, which some in the agency wished to have filled.)

Chris Shulse

Chris Shulse (not a CRF member) of Missouri Department of Transportation for his efforts in saving the Lost Boys Cave.

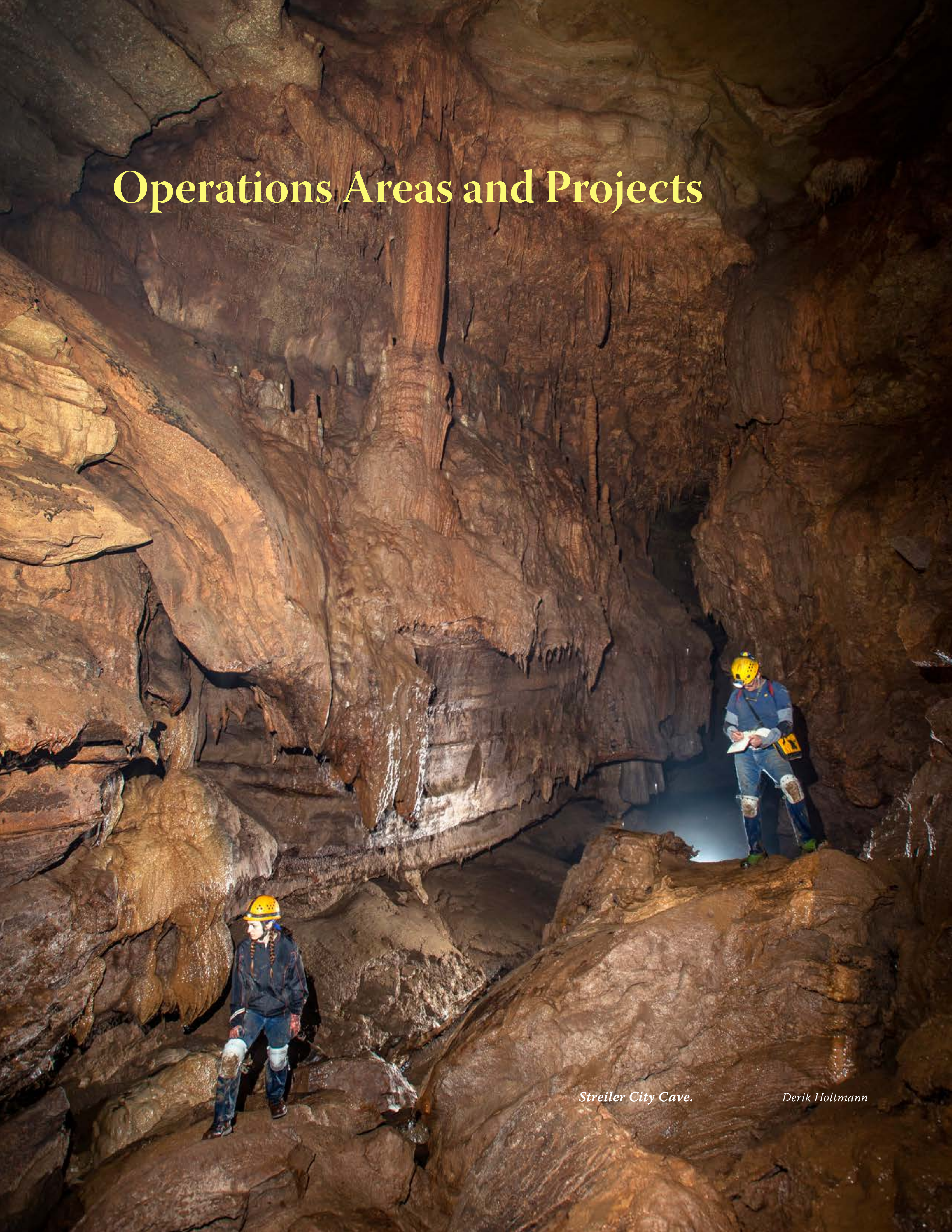
Chad McCain and Mark Brooks

Chad and Mark for their efforts in protecting the important Pot of Gold Entrance to the Moore Cave System. This demonstrated, to a variety of agencies, that cavers are willing to put their money where their mouths are, literally. Many entities have talked about saving important water inputs to an endangered species site, but these two pulled it off.

Elizabeth Winkler

Elizabeth was nominated for a Certificate of Merit for the work she coordinated with Mammoth Cave National Park for the celebration of the fiftieth anniversary of the connection between Flint Ridge and Mammoth. She spent a lot of time meeting with park officials. She organized many activities, both underground and above ground, in conjunction with the celebration. She communicated with people who were involved in the connection and made arrangements for them to participate.

Operations Areas and Projects



Streiler City Cave. *Derik Holtmann*

Eastern Operations 2021–22

Karen Willmes

Eastern Operations Manager

Mammoth Cave National Park

Overview and Highlights

We were awarded the 2021 George and Helen Hartzog Regional Group Award for Outstanding Volunteer Service from the National Park Service's (NPS) Volunteers-In-Parks program. The Park nominated CRF for the award in recognition of our exemplary long-term partnership.

September 9, 2022, was the fiftieth anniversary of the connection between Flint Ridge and Mammoth. The park planned a public celebration of the event and gave it a lot of attention. There was a display of cave maps at the Visitor Center, and the gymnasium-size floor map was laid out in a local gym. Elizabeth Winkler helped coordinate many of the activities, including participation by four of the cavers who made the connection happen (Richard Zopf, Pat Wilcox, Gary Eller, and Steve Wells). CRF spearheaded a Mammoth Cave National Park event by leading four groups of tourists on cave trips to the connection route which included the cavers who made the connection. The story was picked up by local and national news. As part of the celebration, we announced a new length for Mammoth Cave: 426 miles.

Map of the Mammoth Cave System on the floor of the gym. *Elizabeth Winkler*

Richard Zopf, Steve Wells, and Pat Wilcox.
Elizabeth Winkler

Commemorative cake. *Elizabeth Winkler*

In March Christian DeCelle found a route between East Salts and Stan's Well, on Stan Sides' property adjacent to Hamilton Valley. Members of EO contributed to the effort to open a new entrance to Stan's Well on Hamilton Valley property. It reduces travel time to a remote and difficult part of the cave by hours.

An accident occurred during the February expedition, resulting in an assisted self-rescue. This was a good test of coordination between CRF and the park during a rescue. There were things that could be improved, but overall, it went very well.

Our volunteer numbers are improving post-pandemic. We held 11 expeditions. No expeditions had to be cancelled on account of weather. Participants traveled 147,046 miles to attend. CRF volunteers spent 9,537.19 hours on work that benefitted Mammoth Cave National Park. They spent an additional 1,304.06 for work indirectly applicable to the park, for a total of 10,841.25 volunteer hours. (Not all of the hours spent on the new entrance were recorded.)

Richard Zopf, Superintendent Barclay Trimble, Tom Brucker, Elizabeth Winkler, Gary Eller. *Elizabeth Winkler*

Between October 1, 2021, and September 30, 2022, 142 trips took place, supporting a variety of projects (some trips supported multiple projects):

- MCNP cartography—87
- Archaeology—4
- Biology—6
- Biomonitoring—4
- Caves outside park (Biosphere Reserve)—35
- Education—3
- Geology—2
- Hydrology—1
- Paleontology—1
- Park requested support—11
- Roppel cartography—7
- Small cave inventory—15
- Technology—1
- Trails—2

Archaeology

Four teams assisted Master's degree candidate Kailey Alessi, NPS staff, and other volunteers with an archaeological excavation and inventory that took place just inside the

Meeting at Hamilton Valley facility. *Ed Klausner*

Historic Entrance. Volunteers helped with carrying tools, setting up the grid, taking photographs, excavating, screening the dirt, and identifying artifacts.

Park Support

The park asked for our assistance with several different projects in addition to the archaeology dig.

Several teams helped with setting up a microbiology study by preparing the sampling site in Long Cave and carrying ladders to Colossal. Both caves are important hibernation sites for endangered bats.

One party helped retrieve the lock from Long Cave, and another serviced a bad data logger there.

The party that cleaned the lock at Salts Cave also cleared some fallen trees.

A team scouted a filled pit near the Historic entrance in order to design a geophysical survey to determine depth of pit, areal extent, and to characterize fill.

Science Support

Two parties assisted Maggie Osburn with her geomicrobiology objectives.

Some fossil shark's teeth were collected.

The dye bugs in Great Onyx were replaced as part of a study of the hydrology of the Great Onyx basin

Small cave teams often support biomonitoring objectives, and several made biological and geological observations.

Education

Aaron Bird and Rachel Bosch led another Kids Caving expedition. One preliminary trip provided an orientation for one of the potential kid trip leaders. During the expedition the group of adults and kids paddled down the Green River collecting water samples at known springs and other karst features and looking for anything undocumented. They also went to Crystal Cave to practice sketching.

Cartography

Inside Mammoth Cave National Park, 87 trips supported cartography.

In Colossal Cave, one party surveyed leads in the complex Helictite area. Two parties added details and additional survey near Chalybeate Spring. Six parties surveyed cutarounds along Grand Avenue. Another party surveying cutarounds near New Year's Junction found an unexpected lead off of one of them. Most of these surveys counted as new survey.

One focus was to try to reconnect the Hazen entrance to Colossal Cave. Several parties tried various methods to open the lock at the Hazen entrance, without success until an angle grinder was brought to the cave. The team that was able to enter the cave found a route that may not have been used before. It led to a pit with leads at the bottom. The teams that weren't able to get into Hazen worked on objectives in Colossal instead. They also looked at the potential connection area from the Colossal side and observed shattered rock and pieces of lumber.

A team regained access to the Bedquilt entrance of Colossal Cave that had been blocked by flood debris, and another evaluated the potential for putting ladders in the Woodson-Adair entrance.

In Crystal Cave, five teams continued the resurvey of Lost Paradise, Waterfall Trail, Five Passages, and Floyd's Jump Off. A new route to Bottomless Pit was found and surveyed.

In Salts Cave, one party finished up some loose ends on the sketch along Salts Trunk. Four teams worked in East Salts, where they connected to Stan's Well. Another team did a radiolocation of the connection area from the surface.

Six parties entered the Doyle Valley entrance. One mapped a network of crawls near the X Loop, a long and cold trip. One team rigged a permanent rope near the French Connection. One party checked leads near the Hawkins Formation. Three parties continued the climb up Big Rift Dome. The dome topped out at 139 feet. Unfortunately, there were no leads at the top.

The owners of the Turley entrance generously donated the property to the park. Eight teams worked on the resurvey of the route from the Turley entrance to Logsdon River. One of the parties rescued a large black rat snake and carried it up the pit. One survey party did a through trip, entering the Turley entrance and exiting the Doyle Valley entrance.

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

Three parties continued the resurvey of Hanson's Lost River, a key part of the connection route between Flint Ridge and Mammoth Ridge. On earlier resurvey trips in the summer of 2007, when the weather had been dry, the water was "earwash" level. This time it was an easy

Michael Raymond in Mammoth Cave. *Rick Olson*

hands-and-knees crawl with over a foot of airspace. Two teams tried to resurvey the connection portion on the fiftieth anniversary of the connection, including connection participant Tom Brucker, but they didn't quite get to the Tight Spot. The other team, including Tom Brucker's son Nathan, found and surveyed 700 feet of virgin cave.

For the Cathedral Domes map, two parties surveyed Markolf's Pit and one worked on Edna's Dome. A party investigated a passage off Pilgrim Avenue, but the ladder they had wasn't long enough. The resurvey of the tricky Cox entrance route was finished. A party tied in a survey that closed a very long loop. Three parties resketched Bransford Avenue.

To improve the survey data, two parties worked on correcting foresight/backsight errors along El Ghor and the Historic tour trail.

One of the Historic teams carried in a ladder to check leads in the River Hall area. Another team worked on rigging and surveying in the Labyrinth and Lee's Cistern.

Two parties garnered some new survey footage in the Bransford/Cocklebur area.

Six teams went to New Discovery. One team surveyed in the western end of the cave. Near the China Wall, one team did some mop-up survey, and another took a ladder in to resurvey passage. Three teams continued sketch enhancement of Big Avenue and Noah's Way.

In Frozen Niagara, one party surveyed from near the Aero Bridge and also added some of the new infrastructure to the map.

Two teams worked on rigging and surveying using the Ferguson entrance.

Fifteen parties worked on small cave objectives. One cave was relocated. Eight caves were surveyed, including a pit found by a Woodson-Adair party. A Disto shot was taken at the entrance drop of one cave. A cave diving team dove the entrance pool of a spring and said there was good potential for another dive. Two teams looked at a spring resurgence and another small potential cave in Cedar Sink. One cave was reached by taking a raft down the river. The party continued the survey before they got too cold to continue. In another small cave, a party surveyed in the Piney Creek section, mostly crawls, but they closed an enormous and unexpected loop.

Miscellaneous Projects

Aaron Bird led two trips as part of his new project to conduct a detailed study of modifications made in cave passages in the Mammoth Cave System for business or lifestyle reasons.

Cartography Outside of Mammoth Cave National Park

Three teams went to Hidden River Cave. One party surveyed a side lead off Wheet River until it became too tight. Another party pushed leads up the West Branch. The third party removed dye trace packets and data loggers and tried to locate several leads.

Seven teams went to Roppel Cave. One team pushed a lead, Eros Trail. Another dug and worked on a climb in Trifecta Dome. Two teams surveyed in the Barnyard Maze. A team did replacement survey in Black River. A team removed a ladder from Pirate's Pot and installed a replacement.

More than 22 teams worked on Stan's Well, surveying, rigging, climbing, and digging as part of the effort to establish a new route to East Salts.

Trips were also taken to Church Pit, Dogwood Cave, and Vinegar Ridge Cave.

Technology

A party went to Adwell Cave to test and calibrate some BRIC4 survey devices.

Cave Hollow–Arbogast Cave Survey Project

Has not restarted due to the pandemic.

Ozarks Operation Activities

2022

Scott House

Ozarks Operations Manager

Primary Funded Projects

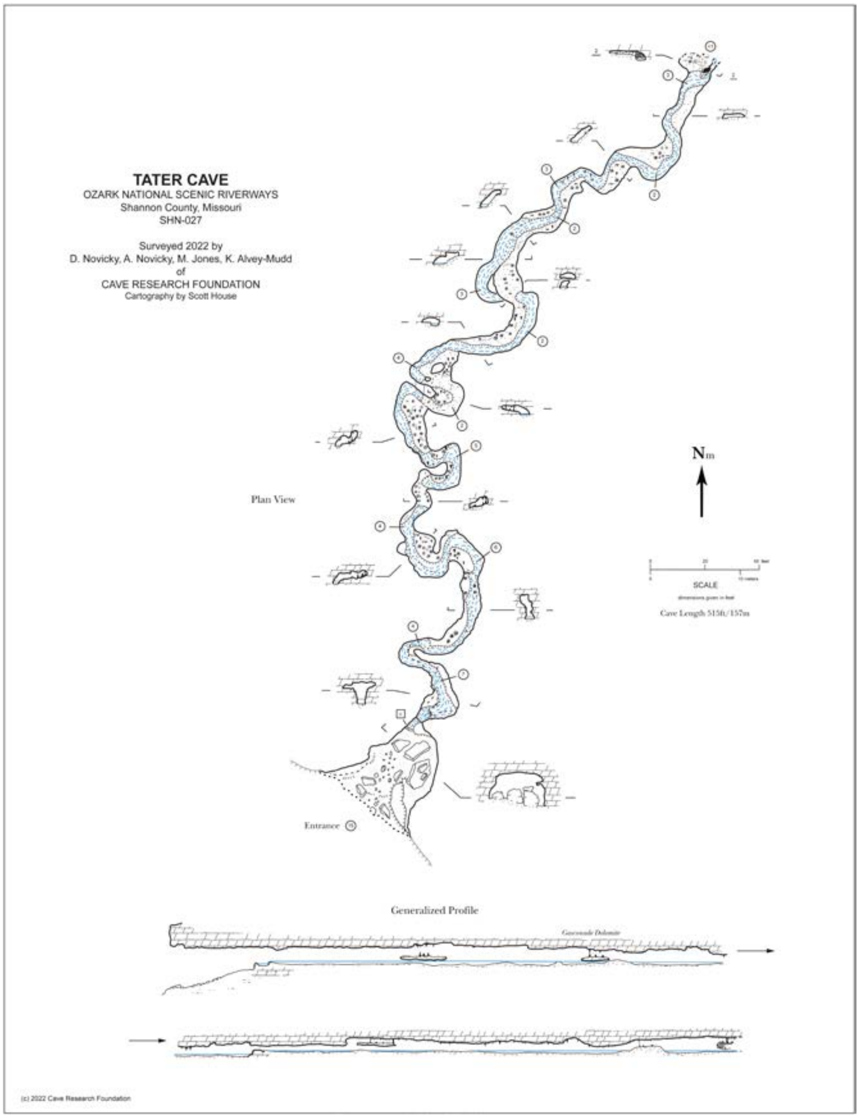
Ozarks Operation has fielded at least 280 trips over the past 12 months. Many trips are interagency in nature so some overlap in recording will be present.

Alex Litsch on rope at an Ozark Riverways shaft. *Scott House*

Discovering a new pit in Ozark Riverways. *Scott House*

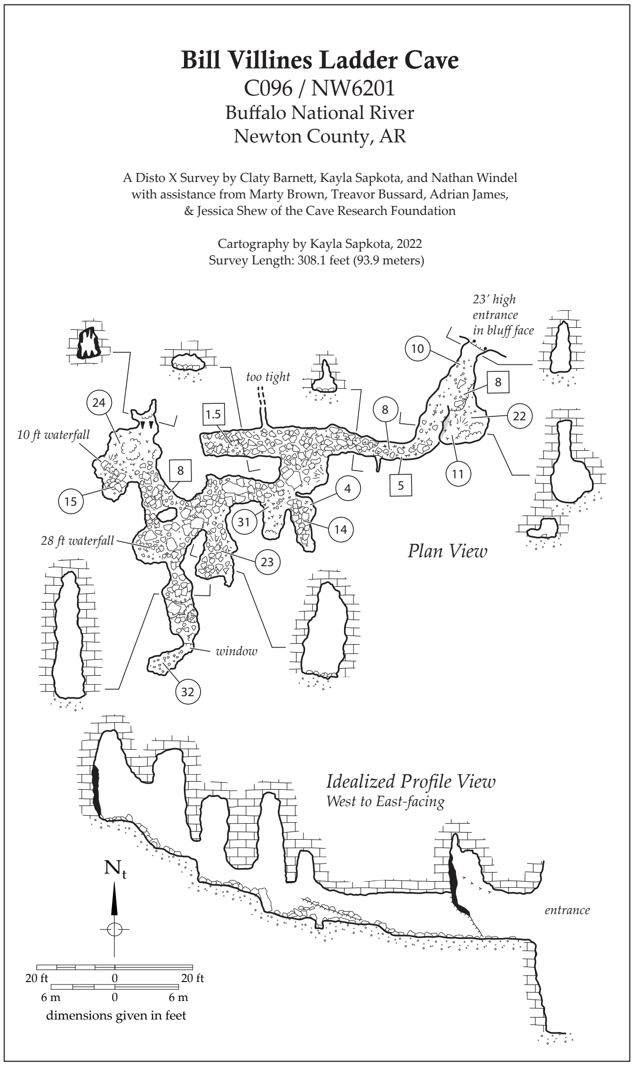
Ozark National Scenic Riverways

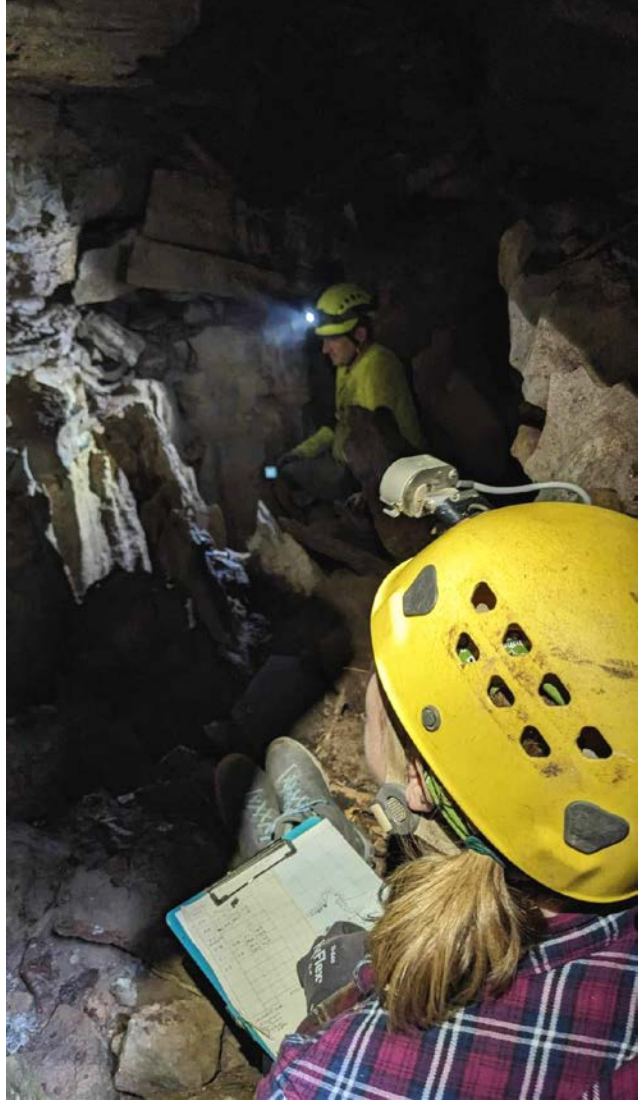
CRF Ozarks works with the Ozark National Scenic Riverways (NPS) under a legal cooperative cave management agreement that will expire in 2025. Despite the pandemic, a fair number of trips (46) were taken as volunteers went out in relatively small groups (2–4). Housing during COVID-19 was an issue as NPS standards are one person to a room (we have ten beds but only three rooms). Several maps were completed, 95 cave monitoring visits were taken, and signs and gates were maintained. New cave faunal records totaled 449. Scott House is project director with Mark Jones and Dan Lamping being active schedulers.



Treavor Bussard hikes to map caves at Devil's Eyebrow Natural Area. *Rhett Finley*

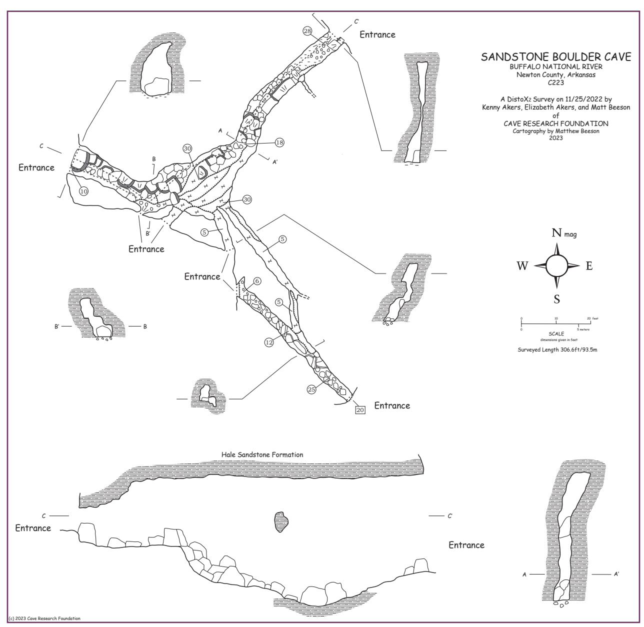
Laura Baumann sketches at Tall Bluff Hollow Cave. *Maya Robles*

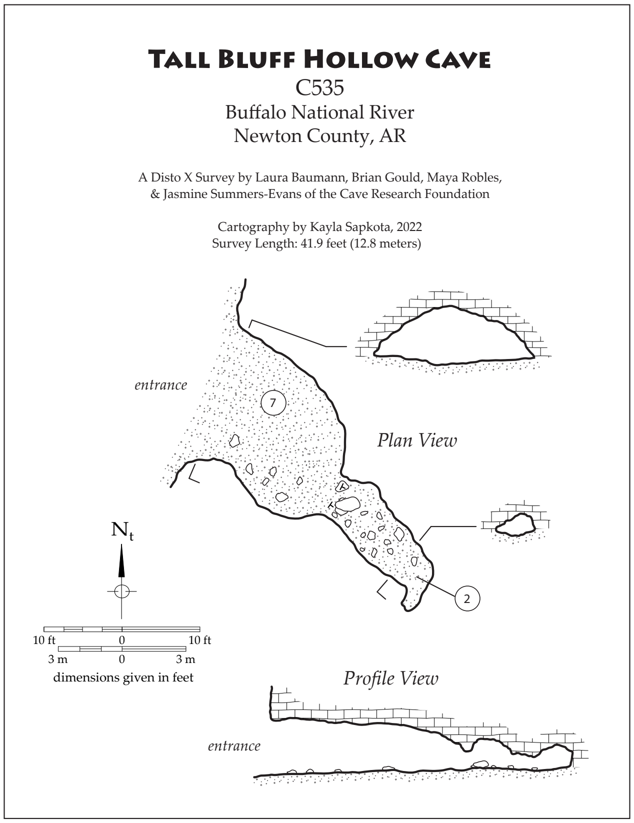


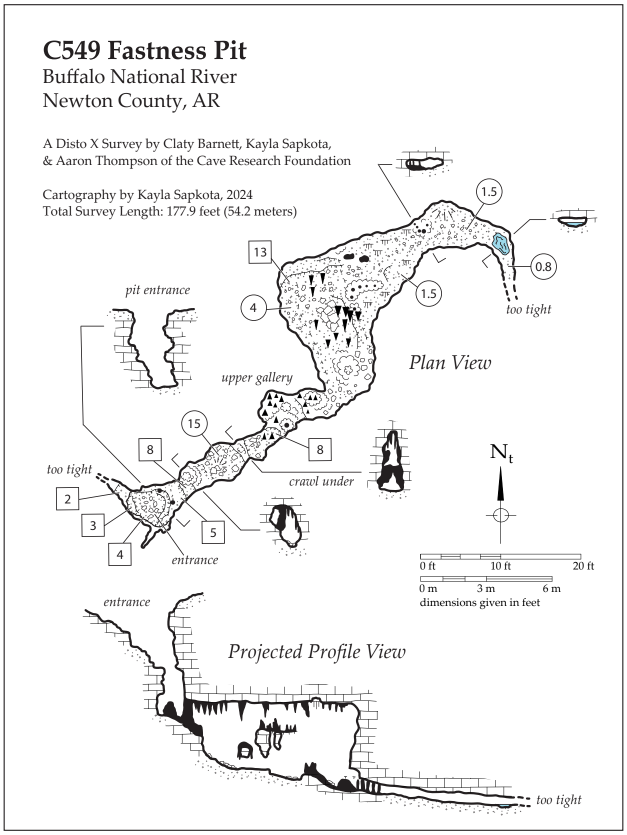


Kayla Sapkota sketches in Fastness Pit. Claty Barnett

The ladder crew—Nathan Windel, Jessica Shew, Kayla Sapkota, Claty Barnett, Adrian James, Treavor Bussard, and Marty Brown by a kind hiker.







Buffalo National River

CRF work at Buffalo National River (NPS) is facilitated through a cooperative cave management, survey, and bat monitoring agreement that is good through early 2025. Many more trips (58) were taken to Buffalo NR as the issues of access and housing were worked through. Numerous maps were completed and new surveys initiated. Kayla Sapkota is project director.

Mark Twain National Forest

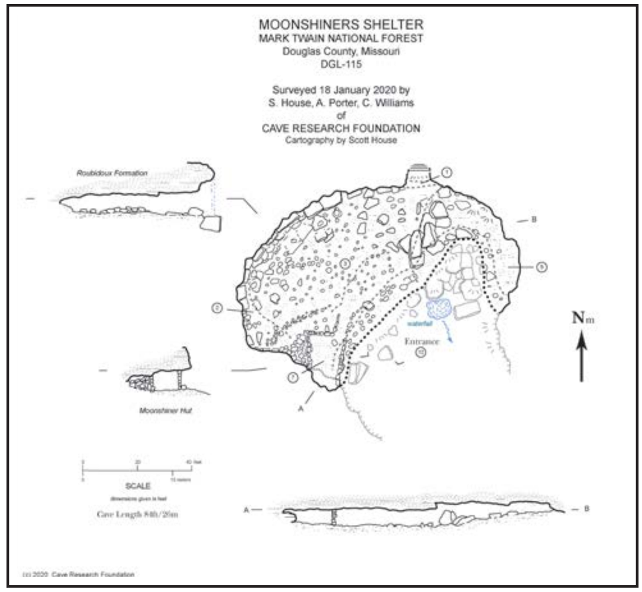
CRF work on Mark Twain National Forest (U.S. Forest Service) is performed through a cooperative agreement covering inventory, survey, monitoring, hydrology, and

Field operations center at USFS Winona facility.

Craig Williams examines cultural materials in a national forest cave. *Scott House*

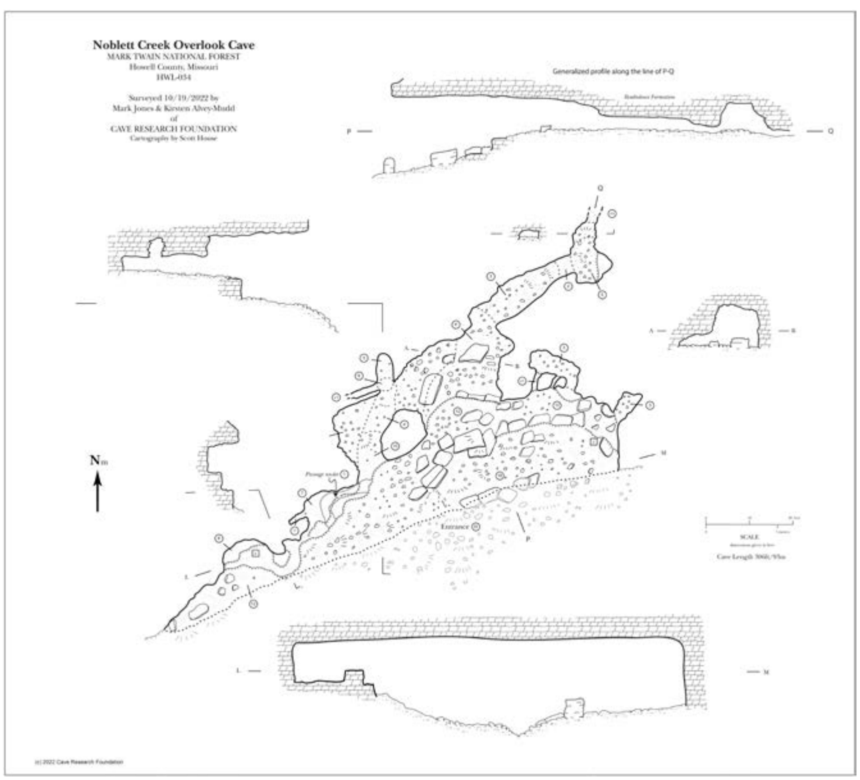
A waterfall over a cave entrance in Mark Twain National Forest. Scott House

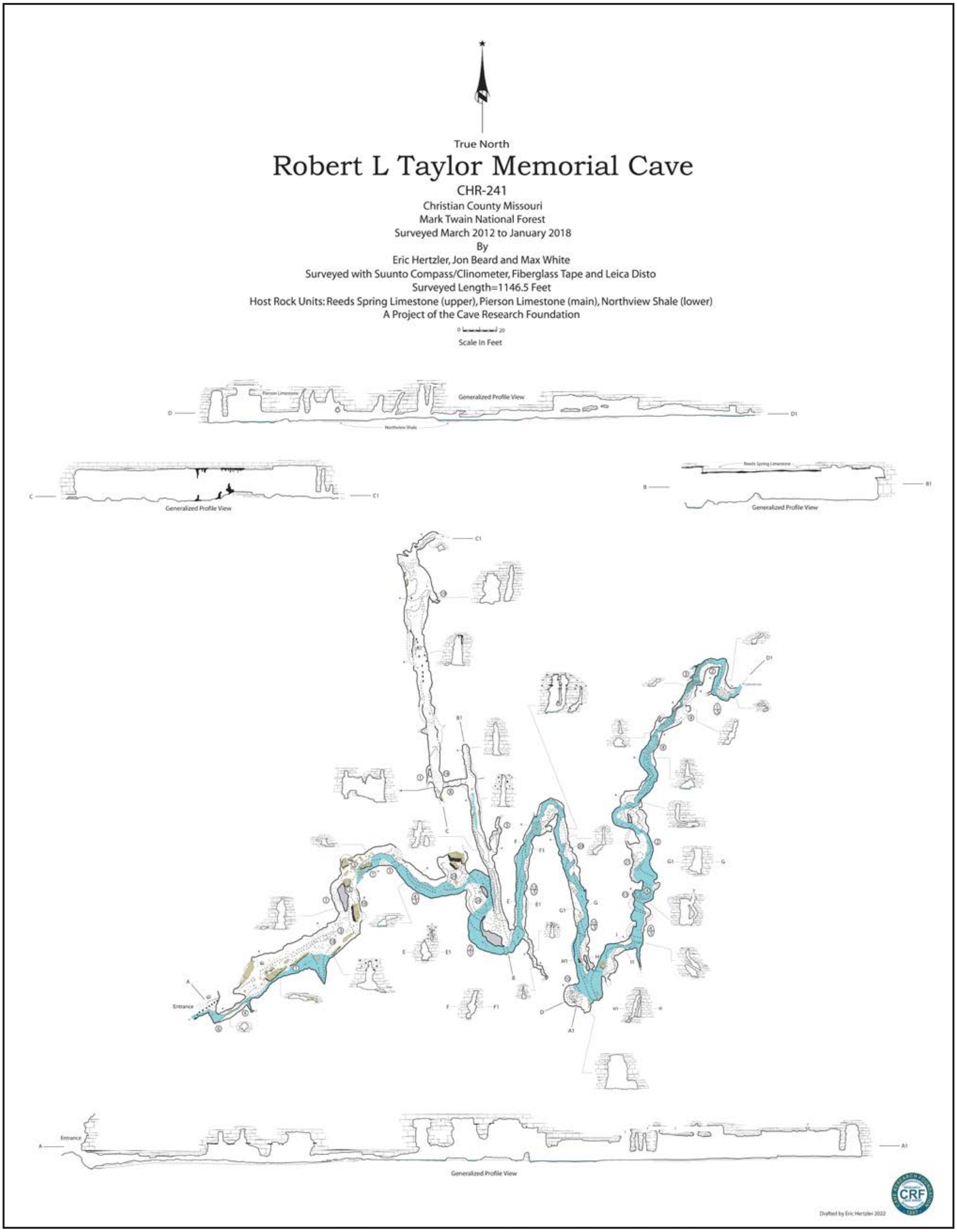
gating. A new agreement is good through 2025. Forty-two trips were taken in 2022. 101 cave monitoring visits were accomplished with 567 new faunal records added. Project directors include several people for differing purposes. Several cave gates are in the design process.



U.S. Fish and Wildlife Service

We initiated a new, funded agreement with F&WS in 2021. The U.S. Forest Service supported several trips to known gray bat caves to assess the need for cave gates. Money had been provided to produce one gate on a major gray bat maternity colony, completed by Jim Cooley and team in spring 2022. Additional funds are being provided for unspecified monitoring but include grotto sculpin. More than ten trips




True North
Robert L Taylor Memorial Cave
CHR-241
Christian County Missouri
Mark Twain National Forest
Surveyed March 2012 to January 2018
By
Eric Hertzler, Jon Beard and Max White
Surveyed with Suunto Compass/Clinometer, Fiberglass Tape and Leica Disto
Surveyed Length=1146.5 Feet
Host Rock Units: Reeds Spring Limestone (upper), Pierson Limestone (main), Northview Shale (lower)
A Project of the Cave Research Foundation
0 20
Scale In Feet
Pierson Limestone
Generalized Profile View
Northview Shale
D
D1
C
C1
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Reeds Spring Limestone
B
B1
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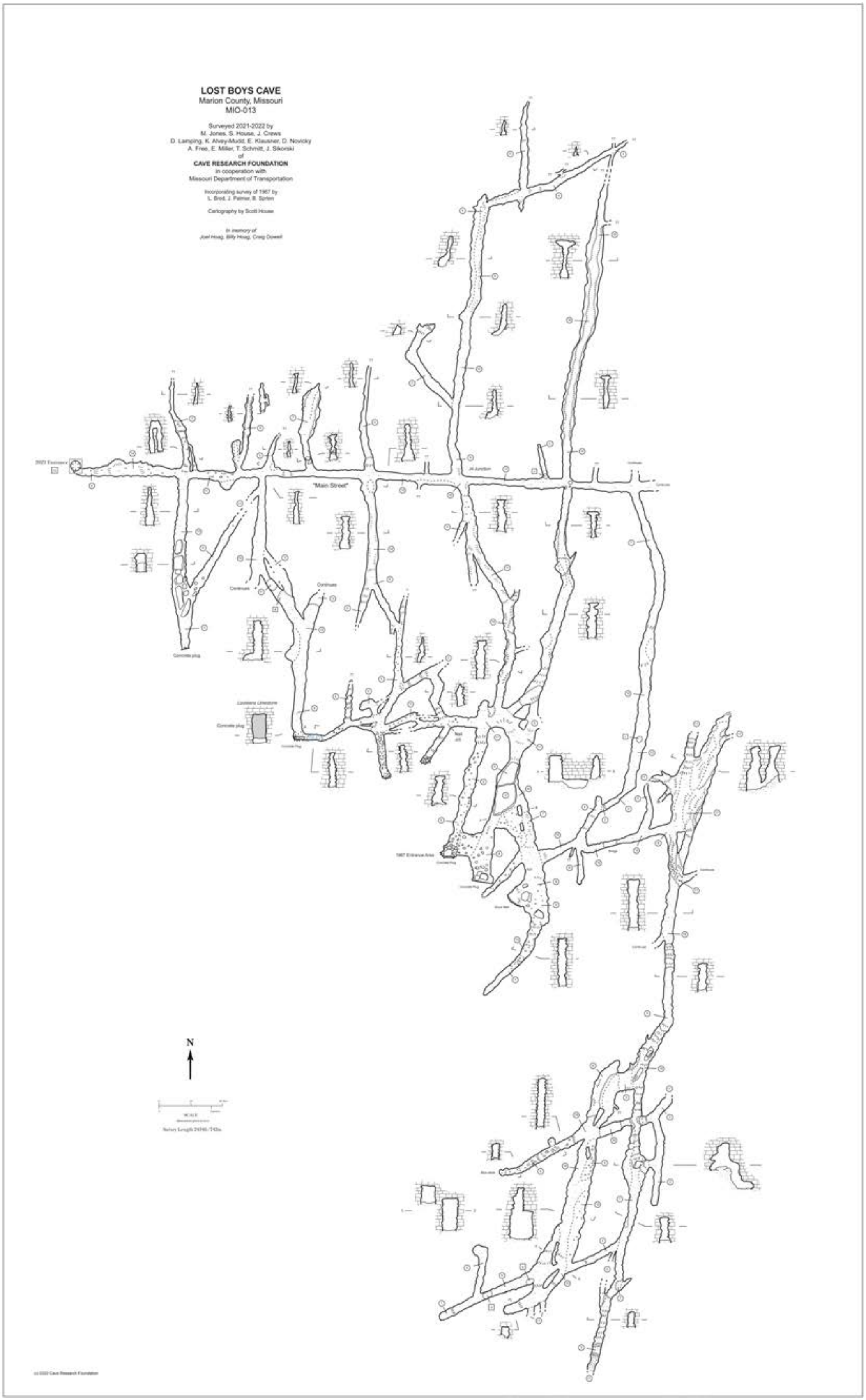
Entrance
A
A1
Generalized Profile View
CRF
Drafted by Eric Hertzler 2022


LOST BOYS CAVE
Marion County, Missouri
MIO-013
Surveyed 2021-2022 by
M. Jones, S. House, J. Crews
D. Lamping, K. Alvey-Mudd, E. Klausner, D. Novicky
A. Free, E. Miller, T. Schmitt, J. Sikorski
of
CAVE RESEARCH FOUNDATION
in cooperation with
Missouri Department of Transportation
Incorporating survey of 1967 by
L. Brod, J. Palmer, B. Sprien
Cartography by Scott House
In memory of
Joel Hoag, Billy Hoag, Craig Dowell
"Main Street"
1967 Entrance Area
Concrete plug
N
SCALE

Jim Cooley at Toby Cave gate.

CRF crew enters Lost Boys Cave.

were dedicated to F&WS work. Further, trips were taken to evaluate and stabilize (fix) gates on Lime Kiln Mine within the Sodalis Nature Preserve in Hannibal, Missouri. Several of the breached or unsecured gates were fixed. Discussions are under way for a funded maintenance program. In conjunction with the Arkansas field office of USF&WS, a series of gates are planned in one Arkansas state park.

Missouri Department Of Transportation

MODoT transferred two mitigation payments to CRF; the funds originated from federal highway funds. The payments are to be used for bat protection, planned in conjunction with F&WS. One gate on a private cave (gray bat transient colony) was completed by Mark Jones and team. Additionally, CRF is working with MODoT on the protection and survey of Lost Boys Cave within their right of way at Hannibal, Missouri. A half-mile of the cave has been surveyed, and a team secured and improved the entrance.

Pioneer Forest (L-A-D Foundation)

This project is being done as part of our mission with a friendly landowner; L-A-D provides some funding through

Rebecca Landewe of L-A-D Foundation and a salamander.

Mark Jones

Lost Boys Cave passage.

Looking out a L-A-D Foundation cave in Shannon County.

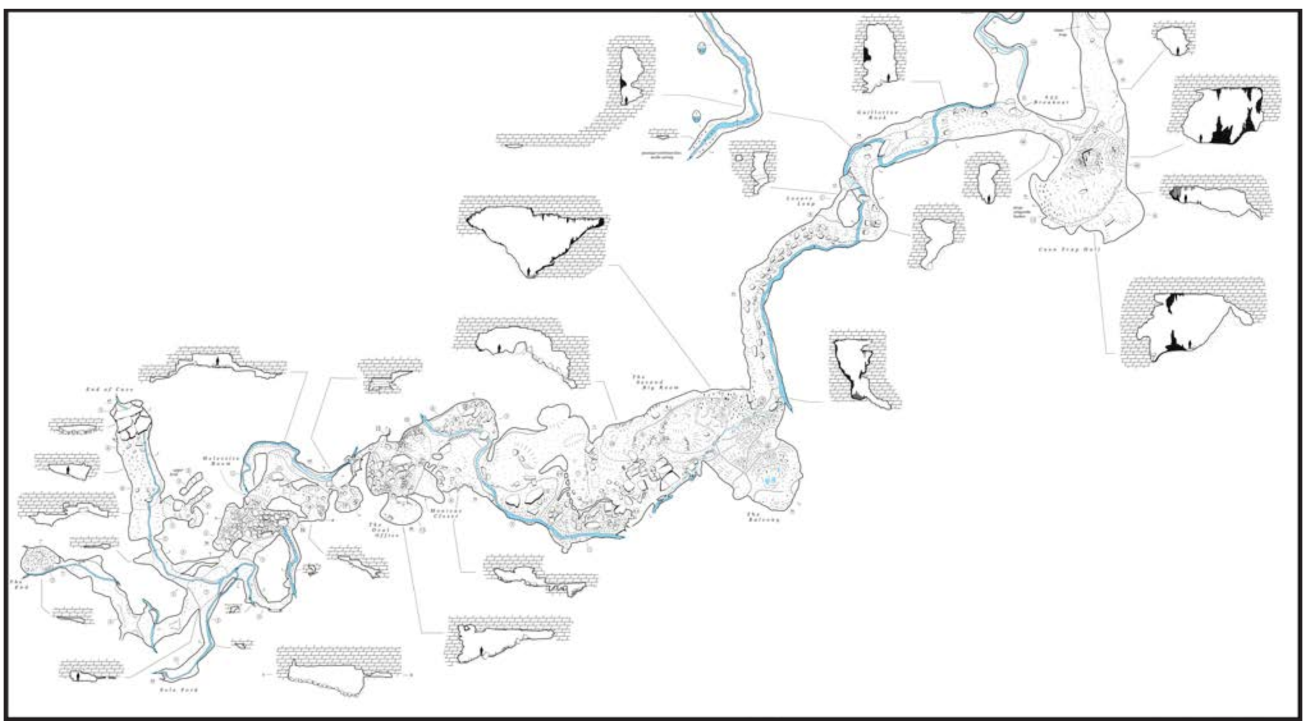
a new agreement with CRF. Some trips are taken in cooperation with Meramec Valley Grotto; others are taken in conjunction with the Ozark Riverways project. Cartography and inventory are the main goals. Four trips were taken during 2022. Dan Lamping is the nominal head of this project.

Gray bat cluster in an MDC cave. *Jim Ruedin*

Unfunded Projects

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 (evening reminisces by Tom Aley count for a lot). Dan Lamping did the cartography and organized the trips.



Detail of The Love Cave. Cartography by Dan Lamping and Tom Panian.

Joe Sikorski in a large MDC cave in Shannon County. *Dan Lamping*

Three Forks Cave Project

Mark Jones leads this project to map caves in a defined area in Oklahoma. Ed Klausner is doing primary cartography.

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.

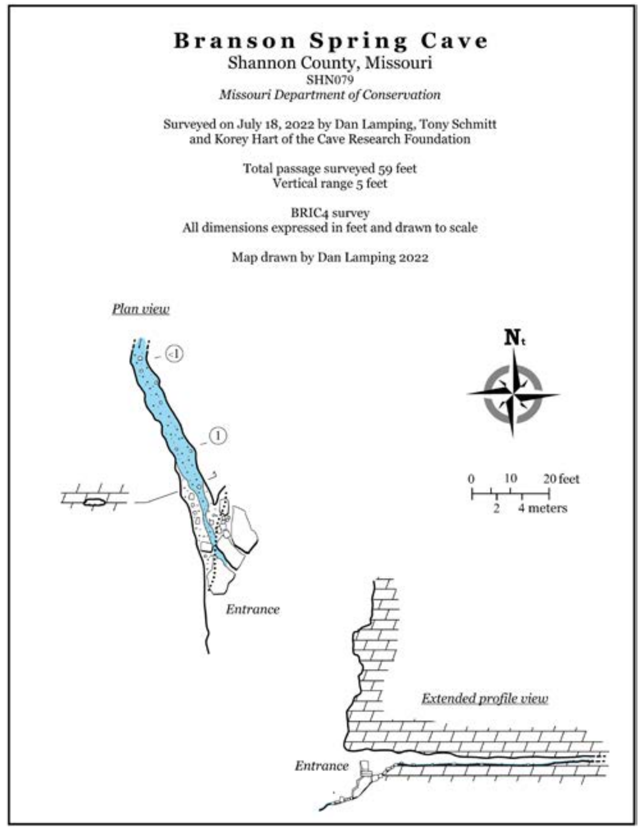
Missouri Department of Conservation

CRF work on lands administered by the Missouri Department of Conservation is done through a volunteer MOU. At least 34 trips were taken on lands administered by MDC or on projects supported by the agency for inventory and survey purposes. A publication on the caves within a new MDC Natural Area, Island Branch, is in the works. Dan Lamping serves as the primary contact.

Mick Sutton looks at unusual formations in a MDC cave.
Scott House

Whiskey Cave on MDC land in Shannon County.

Dan Lamping



City of Perryville

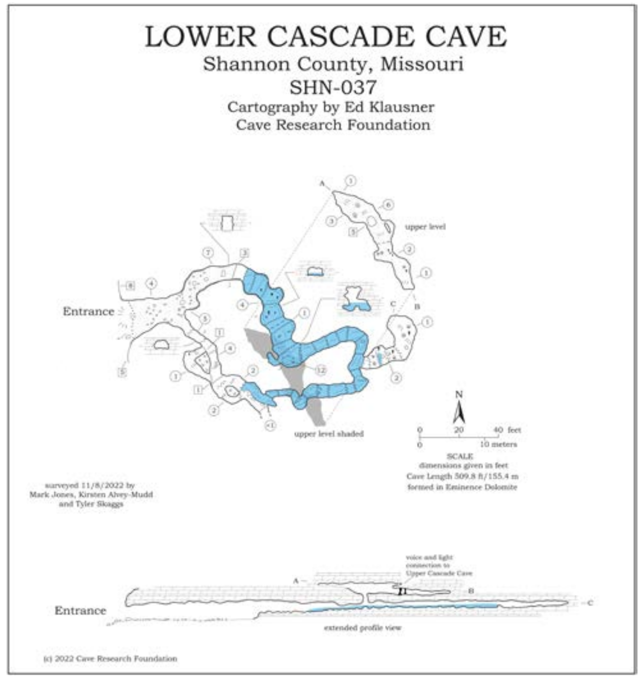
Work in and around the City of Perryville, Missouri, is facilitated through a cooperative agreement between the city and the Missouri Speleological Survey. Seed funding was provided by CRF. Survey is ongoing in Crevice Cave, the longest cave in the state. The first series of karst interpretive signs for the city have been installed. Major remapping of Streiler City Cave was initiated in the spring, in conjunction with the Missouri Speleological Survey meeting. Over 3,000 feet of passages have been surveyed.

Arkansas Natural Heritage Commission and Arkansas State Parks

Seven trips were taken to support cave work on lands owned by the Heritage Commission. Five other trips were taken to caves on state park lands. Kayla Sapkota is the lead.

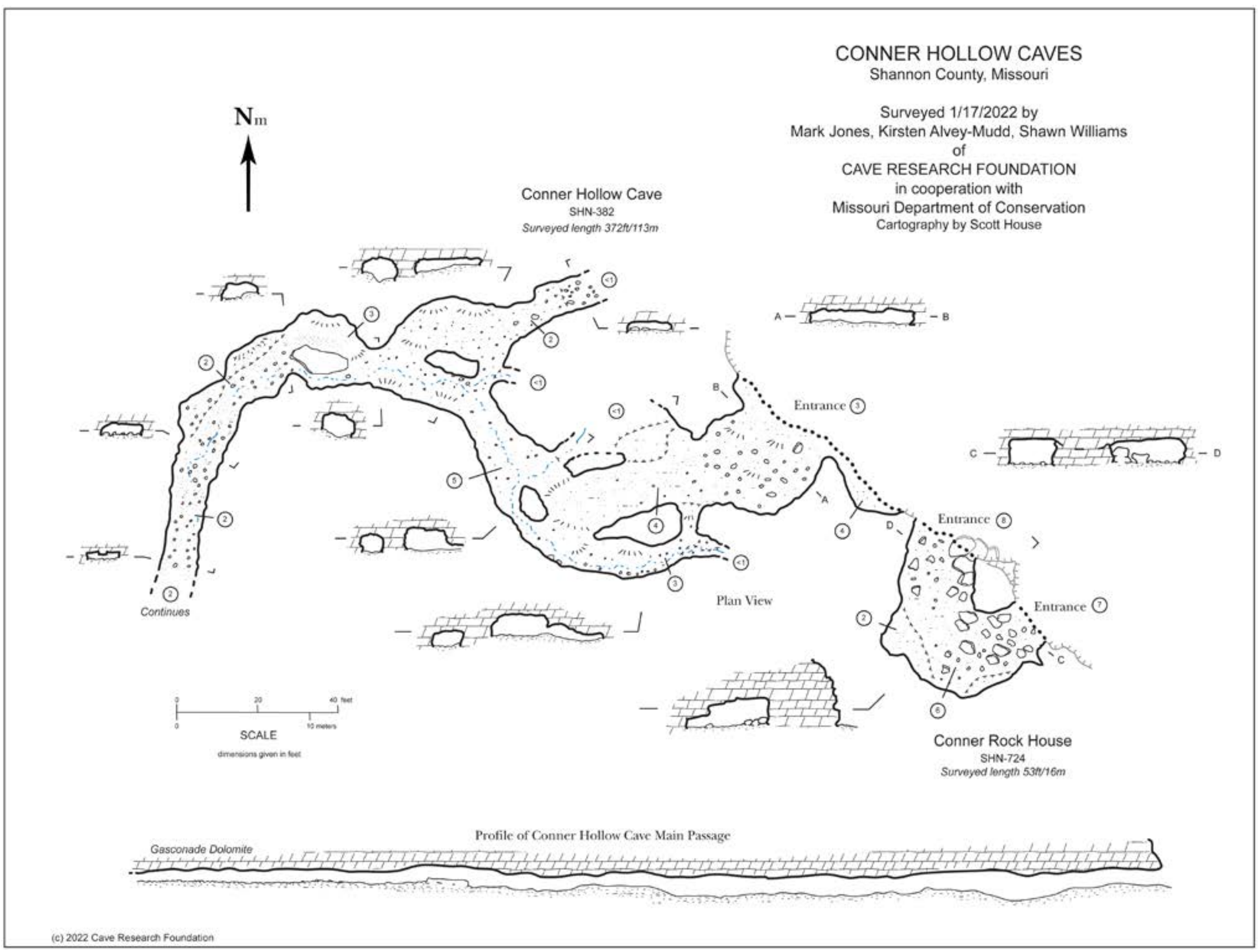
Large MDC cave in Shannon County. *Derik Holtmann*

Perryville cave cleanup. *Derik Holtmann*



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 is 24.8 miles. Several trips were taken, including one large expedition of



Streiler City Cave. *Derik Holtmann*

Jeff Crews at Kaintuck Natural Bridge.

On a survey trip in Berome Moore. *Chad McCain*

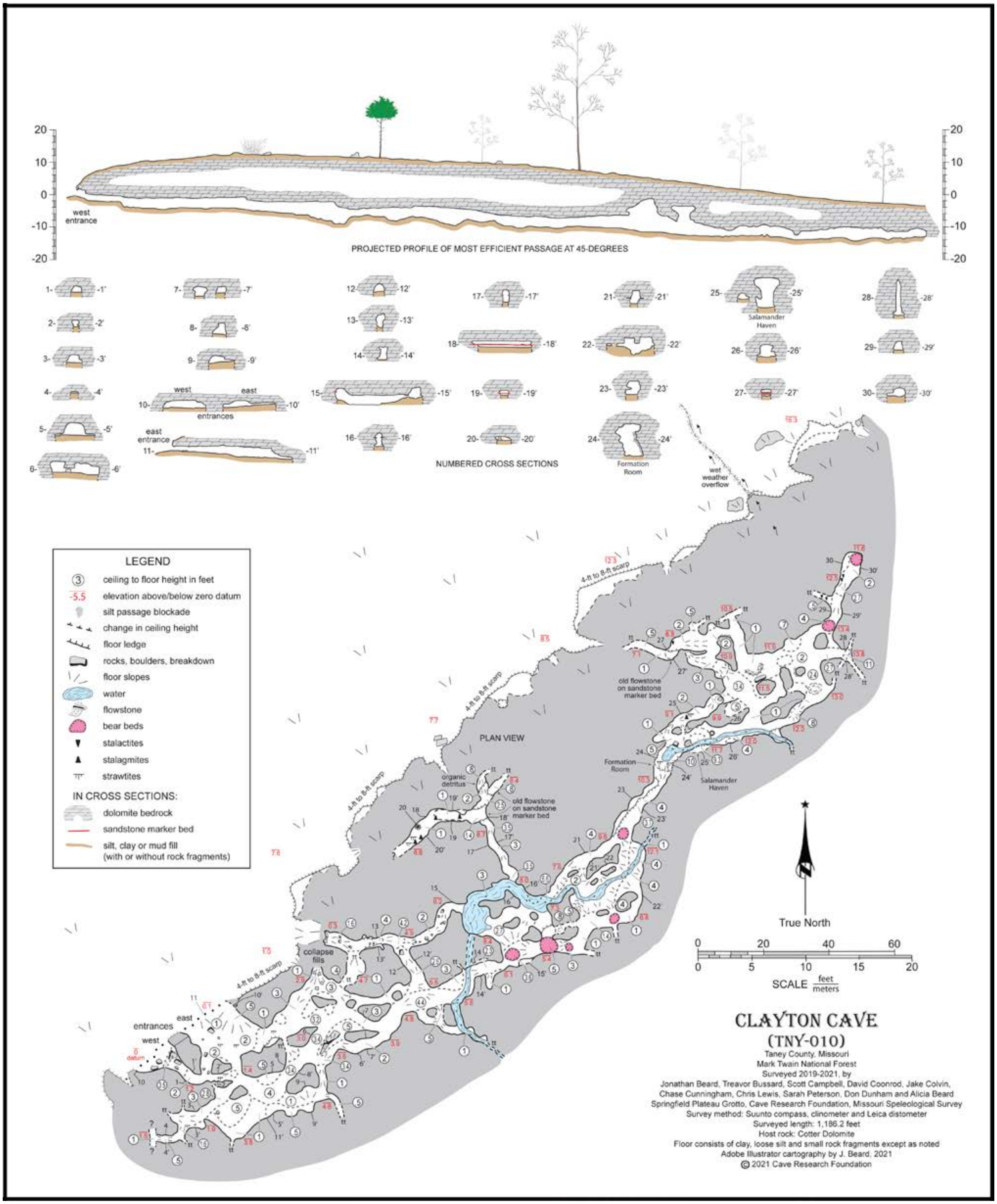
30 people. A discreet entrance of the system was purchased by MCKC; CRF Ozarks contributed funds to this effort. CRF member Alex Litsch served as MCKC president.

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. CRF fellow Ken Grush serves as database manager, in charge of maintenance and updating. By the end of 2022, the database had nearly 8,000 records of cave entrances, over 42,000 faunal records, more than 6,000 map records, nearly 4,000 monitoring records, and nearly 6,000 description records.

Other Private Lands

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


PROJECTED PROFILE OF MOST EFFICIENT PASSAGE AT 45-DEGREES
west entrance
NUMBERED CROSS SECTIONS
Salamander Haven
Formation Room
west
east
entrances
east entrance
LEGEND
ceiling to floor height in feet
elevation above/below zero datum
silt passage blockade
change in ceiling height
floor ledge
rocks, boulders, breakdown
floor slopes
water
flowstone
bear beds
stalactites
stalagmites
strawtites
IN CROSS SECTIONS:
dolomite bedrock
sandstone marker bed
silt, clay or mud fill
(with or without rock fragments)
PLAN VIEW
wet weather overflow
4-ft to 8-ft scarp
old flowstone on sandstone marker bed
organic detritus
collapse fills
True North
SCALE feet/meters
CLAYTON CAVE
(TNY-010)
Taney County, Missouri
Mark Twain National Forest
Surveyed 2019-2021, by
Jonathan Beard, Treavor Bussard, Scott Campbell, David Coonrod, Jake Colvin,
Chase Cunningham, Chris Lewis, Sarah Peterson, Don Dunham and Alicia Beard
Springfield Plateau Grotto, Cave Research Foundation, Missouri Speleological Survey
Survey method: Suunto compass, clinometer and Leica distometer
Surveyed length: 1,186.2 feet
Host rock: Cotter Dolomite
Floor consists of clay, loose silt and small rock fragments except as noted
Adobe Illustrator cartography by J. Beard, 2021
© 2021 Cave Research Foundation

Sequoia / Kings Canyon National Parks 2022 Annual Report

Jennifer Hopper and Fofo Gonzalez

Operations Managers

General Observations

- 2021 brought the joy of the reinitiation of caving activities in the park after the long hiatus due to the global pandemic. But the year also brought extreme sadness because of the catastrophic loss of the project's fieldhouse in Redwood Canyon.
- 2022 marked the beginning of a new era in the exploration of Lilburn Cave, as we continue to find our footing on how to perform exploration and research activities without the supporting infrastructure to which we had become accustomed through the decades.
- The year will close with three full expeditions in Lilburn cave, with multiple new joint venturers (JVs) joining the project.
- We are initiating the process to request metal storage boxes for the Lilburn cave area, which will be of great help to have a cache of gear for exploration, research, and safety.

Cave Management

- We are in continuous contact with our liaison in the park, the Branch Chief of physical and wildlife sciences and park aquatic ecologist for Sequoia and Kings Canyon National Park (SEKI).
- We continue to maintain online platforms including an email distribution group, social media, and Google Drive for expeditious data-sharing with key park personnel and JVs. Investigator and trip reports, as well as other data collected, are uploaded after expeditions. This assures continuity and data preservation with leadership changes. In addition, the park is now requiring information on participants prior to each expedition. The online platforms we use to collect new JV information have been of great assistance in collecting and organizing this information to share with the park.
- 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 understandable and well-defined expectations. 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 so everyone can take time to become familiar with it.

Cave Data Management

- The Chief Cartographer, 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 required attention). Jed systematically reviews older cave drafts that are not up to standard to prioritize areas with the most issues, or zones that could be tackled by survey and exploration teams.

Hydrology and Geochemistry: Paleoclimate Project

- The previous principal investigator (PI) for the paleoclimate project has completed her PhD. We currently do not have an active project. Prior to approaching UC Davis to offer Lilburn as a research site, we wanted to make sure that we would be able to provide the support and logistics necessary for data collection in the cave after the burning of the research station. With a plan in progress to request work box installation, we believe that it is feasible to continue.

Cartography Project (Jed Mosenfelder)

- We received a multi-year approval on the cartography research permit. This year, we have not attained new footage in the cave, but we expect this to change with the upcoming expeditions.

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 logical as possible.

◊ We contacted a new software engineer to help us improve the existing app.
◊ We currently have 21 JVs that have been trained in cave inventory.
◊ 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.
◊ We would like Carol and Roger to expand the cave inventory to other areas of the national parks. 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

Passage Restoration at Lilburn Cave

- The fire introduced a significant quantity of organic debris into the cave, which promoted the proliferation of biofilms in areas with standing water. Also, charcoal and soot are prevalent in the trade route passages, but since this was due to a natural occurrence, no passage restoration has been planned.

Mineral King Caves (Marcia Rasmussen)

- There are some small caves pending to be mapped in the White Chief / Area of the Thousand Entrances zone, in addition to continuing the cave inventory of White Chief or possibly redoing it completely.

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.
- A climbing lead is still pending, and although there were no trips in the last couple of years, this is still considered an ongoing active project. We plan 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.
- We confirmed with the park that access to this cave is now permitted for our project although the area is still closed to the general public after the fire.

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 started a monthly email update to the group, in which we share with our members the news from the park, updates about Redwood Canyon, the Lilburn Cave project, and other SEKI projects, and announcements.
- JVs have been invited to join a committee to investigate possible field station options in the park for research support.
- We will reach out to UC Davis faculty to inform them of Redwood Canyon access for research and share our willingness and ability to support paleoclimate studies in Lilburn Cave.
- We continue to work with the park in determining the best way forward for safely conducting research in Redwood Canyon, and request two bear-proof metal boxes for storage of rigging gear, research equipment, and safety supplies.

Northwest Operations—Report to the Board of Directors, November 2022

John Tinsley

Manager, CRF Northwest Operations

The National Park Service has asked us not to include the names of caves at Lava Beds and Craters of the Moon in our reports or on our maps to protect the caves.

The Northwest (formerly Lava Beds) Operations Area of the Cave Research Foundation (CRF) has seen post-COVID activities ramp up significantly after a COVID-wrought two-year slowdown or hiatus. The big change is that there are now three so-called "tines" on the Northwest Ops "pitchfork," specifically the Craters of the Moon mapping and inventory project coordinated by Mark Jones (CRMO); the new Klamath mapping and inventory project coordinated by Joel Despain, Heather Veerkamp, and Niles Lathrop (KLAM); and the Lava Beds mapping and inventory project coordinated by John Tinsley (LABE). Administratively, Tinsley manages the NW Ops area, but fortunately each project functions independently, so it is a tractable administrative undertaking thus far.

Paul McMullen crawling out of a lava tube at Lava Beds National Monument. *Ed Klausner*

Craters of the Moon

The Craters of the Moon effort fielded two expeditions this year, one in May and one in September. The May expedition, despite challenging and obnoxious weather as winter refused to quit, saw ten participants survey and inventory 11 caves, one of these was new. Some 4,444 feet of survey was put in the books in ten days. There was an emphasis on faunal as well as cultural observations for each cave. The September expedition saw seven CRF cavers survey some 48 caves totaling 6,456 feet of survey in 15 days, ably assisted by several NPS folks.

The cooperative NPS management's contribution to the effort cannot be underestimated. CRF folks interested in helping with this project should contact Mark Jones for details of the field schedule, as these dates actively evolve as interest and opportunity permit.

Klamath Operation

The Klamath Operation was initiated a couple of years ago by Joel Despain, Heather Veerkamp, and Niles Lathrop, after Joel and Heather retired from working life. They are taking a long hard look at long-known caves in the Hosselkaus Limestone, the McCloud Limestone, and the greater Klamath region, and they are finding significant extensions to many caves, all while doing lots of ridge walking and finding significant new caves and then surveying those. They have been productive at getting the results into print,

Date	Principal Investigator	Flow	Known	New	Total Mapped
7 May 2022	Ed Klausner	Elmer's Trench	84	59	135
7 May 2022	Ed Klausner	I & M Caves	6		6
7 May 2022	Ed Klausner	Lower Loop	13		13
7 May 2022	Dave West	Balcony Flow	50	74	124
Dec 2021	Scott House	Castle Flows	>80		>80
7 May 2022	John Tinsley	Valentine Flow	12	0	12
7 May 2022	Liz Wolff	Cave Loop	20?		20?
7 May 2022	Ed Klausner et al	Tichnor Complex	8		8

A table showing some gross numbers of caves mapped by CRF follows, as of May 2022. It is slated for updating, so don't presume this is carved in stone, so to speak. Some 286+ caves have been surveyed during the present Tinsley regime. Efforts to extend the numbers back in time continue. Updates and corrections sought and welcomed.

as witnessed by the maps and descriptive text for the Paul Gibson Cave Complex in Trinity County, California. Most exciting from a scientific standpoint are indications that some of the caves like Lake Shasta Caverns among others may be hypogene in origin, at least in some respects. Niles Lathrop is presently enrolled at Western Kentucky University studying for his MS degree under Dr. Pat Kambesis. John Tinsley and Joel Despain recently have agreed to serve on Niles' advisory committee. Tinsley brings to the table expertise in cave sedimentology and tephrachronology.

The 2022 Klamath report, likely to be released through the Karst Information Portal, describes some 22 caves ranging in length from 52 feet to exceeding 8,600 feet, with many more under study. They go afield nearly every other day, or so it seems, and the ridge walking is both arduous and productive. Prior to this effort, the prevailing opinion was that the bulk of the caves were already known and mapped. When the topography is as rugged as it is in the Klamath Mountains geologic terranes, this is a risky proposition to advance.

Much as he did when employed as cave specialist at Sequoia and Kings Canyon National Parks, Joel is doing an exemplary effort at drawing together cavers from across the Western Region of the NSS to aid in this effort.

Lava Beds

The Lava Beds operation fielded four expeditions in 2022. The lion's share of some 850+ caves are located in the basalt of Mammoth Crater, a ~35,000-year-old basalt flow on the north slope of Medicine Lake volcano. As originally conceived, there is a principal investigator working caves located in different flow lobes of this areally extensive eruption. Scott House continued his work in the North and South Castle flows in late March and early April. He has surveyed more than 80 caves to date in those flows. Dave West continued working the Balcony Boulevard flow complex, continuing to survey not only the caves but also the surrounding topography. There are some 12 major caves included in that effort to date. Ed Klausner continues to work on caves of Elmer's Trench and lower Cave Loop flow. He has nearly completed the Elmer's Trench effort, totaling 135 mapped caves, with some 59 of these being new finds. He has also generously surveyed six I & M caves at the request of NPS management. Ed is shifting his attention towards the lower Cave Loop flow, chiefly downslope from Post Office / Silver caves (13 caves surveyed to date), and is branching out into the Klamath National Forest with the Tichnor cave complex (four caves). He's also assisting Tinsley with mapping caves of the 12,000-year-old basalt of Valentine Cave flow as time and opportunity permit.

Ed Klausner under lavacicles. *Paul McMullen*

We look forward to a continued and productive field season at LABE in 2023 and beyond.

Craters of the Moon National Monument and Preserve, May and September 2022 Expeditions

Butte County, Idaho

Mark Jones

After a two-year hiatus, CRF returned to Craters of the Moon National Monument and Preserve in May to continue surveying and inventorying lava tubes. Todd Stefanic, the Wildlife Biologist and Mauro Hernandez, the Wildlife Biological Technician had developed a master list of important caves to be visited throughout the monument for us and provided all the necessary gear and equipment for the expedition. A total of nine CRF cavers participated during the ten-day event. Kailey Alessi, Dave Donner, Mark Jones, Ed Klausner, Paul McMullen, Elizabeth Miller, Theresa Schwartz, Fred Wilkinson, and Craig Williams were in the field fulfilling a variety of roles. A tenth member, Allen Palmer, the Seasonal Wildlife Biologist also participated.

A cave cricket investigates some ice crystals. *Ed Klausner*

To say that the weather was a challenge would be an understatement—rather than being pleasantly cool, it was unseasonably cold and wet throughout the expedition. In addition, rather than being a refuge from the elements, the lava tubes were often cold and damp. Despite these issues, eleven caves were surveyed with one being a new cave*, with only two remaining incomplete**.

Cave	Surveyed Length
#057	108.0
#347	219.7
#330	439.6
#030	361.6
#201	98.7
#415*	44.2
#361	349.1
#106	166.7
#054	266.5
#040**	1,928.7
#206**	461.2
Total	**4,444.0**

In addition to surveying, faunal observations were recorded for each site. Several of the lava tubes had indication of bat usage in the past which were confirmed during this expedition. With three qualified archeologists on the teams, in-depth cultural observations were also made, and a final assessment was submitted by that group.

In September, we continued by working from the master list developed by Todd Stefanic, the wildlife biologist at the monument. Seven CRF cavers participated during the fifteen-day event. Kailey Alessi, Andrew Erickson, Mark Jones, Paul McMullen, Rick Olson, Michael Raymond, and Fred Wilkinson were in the field fulfilling a variety of roles. Several National Park Service people also participated.

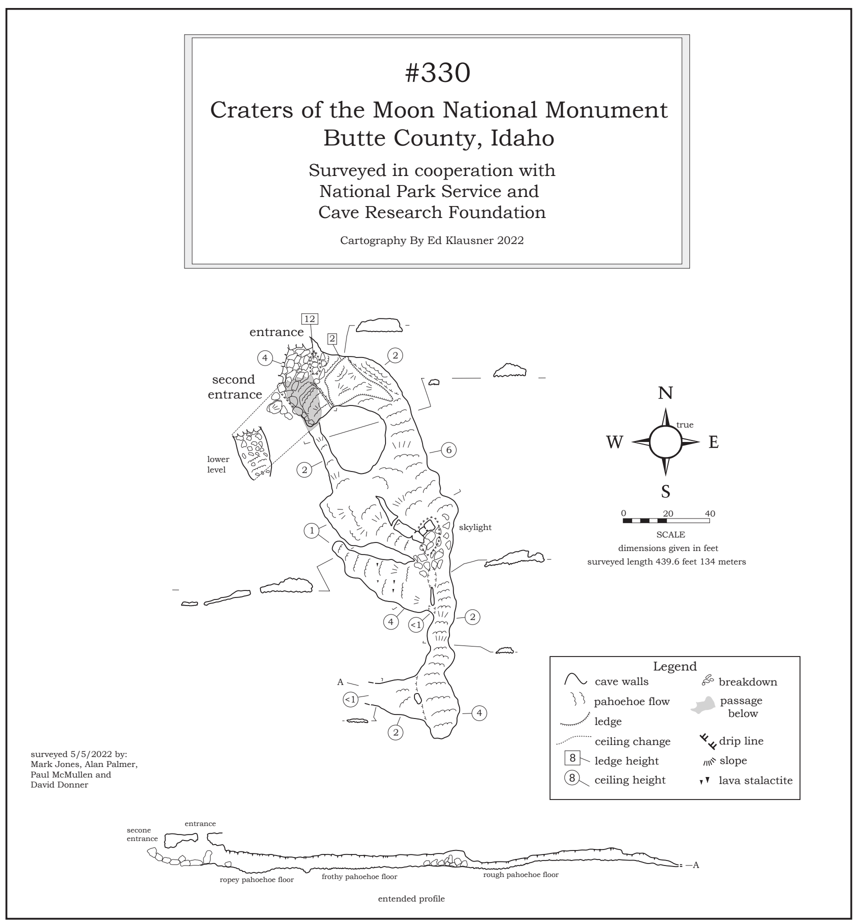
During the expedition, 48 lava tubes were surveyed for a total of 6,456.3 feet. In addition to surveying, faunal observations were recorded for each site. Several of the lava tubes had indication of bat usage in the past which

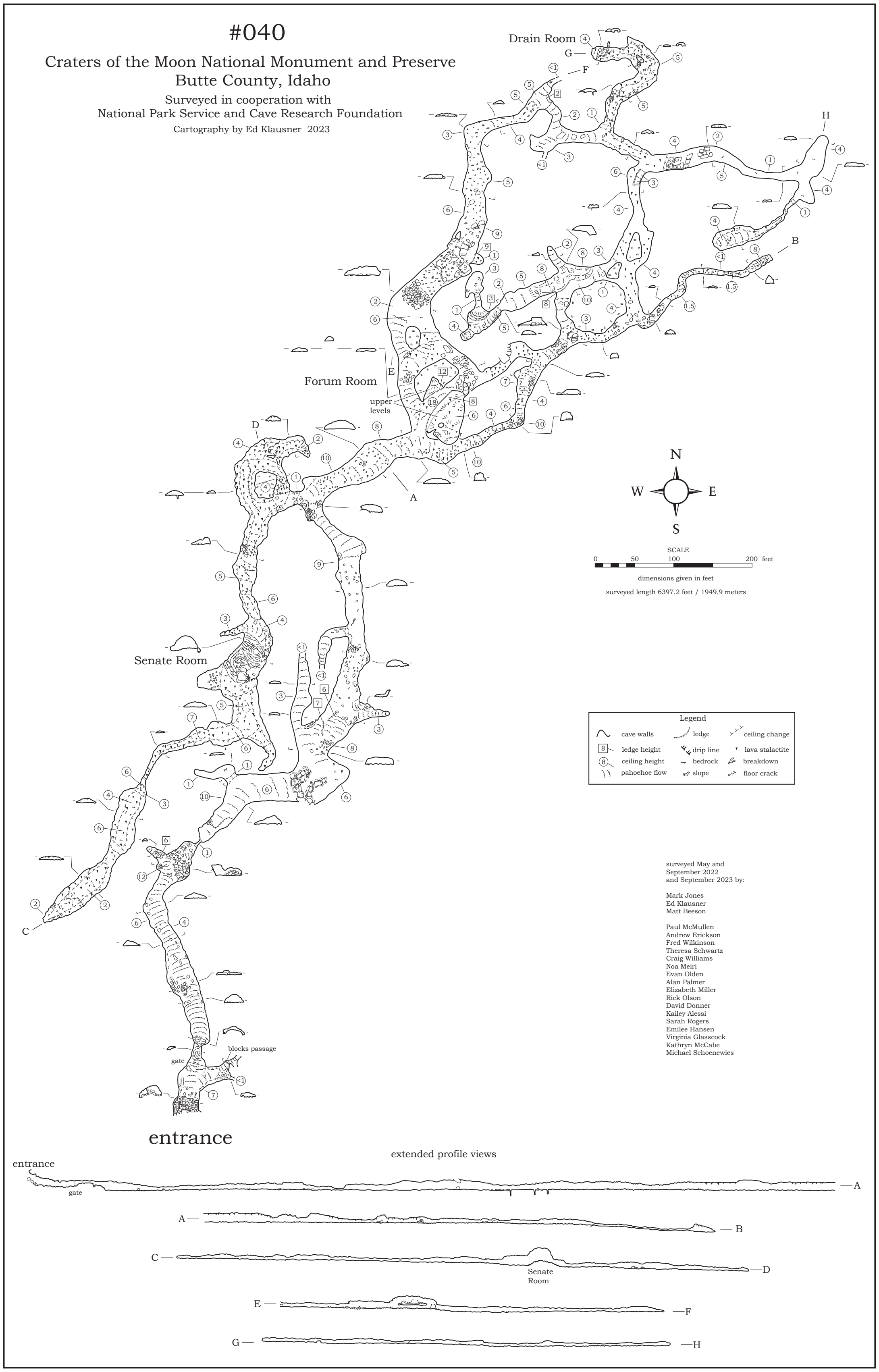
Mark Jones, Theresa Schwartz, and Kailey Alessi. *Paul McMullen*

Ice crystals on lava. *Paul McMullen*

were confirmed during this expedition. With a qualified archeologist on the team, in-depth cultural observations were also made, and a final assessment was submitted.

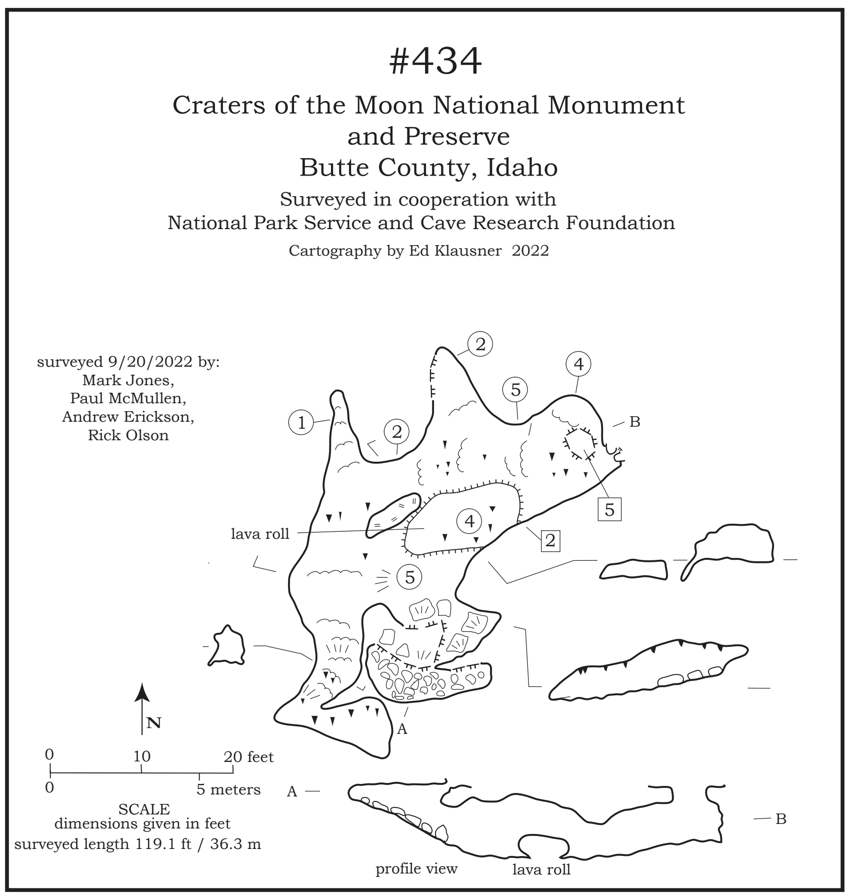
Cave	Surveyed Length
#440	207.5
#040	1,260.2
#152	16.6
#150	32.6
#448	20.0
#055	530.1
#366	257.7
#160	45.5
#153	102.4
#441	93.5
#464	87.0
#159*	165.6
*	40.3
#155	28.9
#157	18.2
#460	50.7
#410	155.0
#164	50.7
#364	160.5
#008	124.7
#353	330.0
#162	56.1
#434	119.1
#166	64.8
#436	512.7
#437	106.2
#161	62.5
#435	52.3
#165	165.1
#009	149.1
#452	23.9
#163	92.7
#388	65.0
#405	113.2
#450	27.3
#158	49.4
#167	84.8




#040
Craters of the Moon National Monument and Preserve
Butte County, Idaho
Surveyed in cooperation with
National Park Service and Cave Research Foundation
Cartography by Ed Klausner 2023
Drain Room
Forum Room
upper levels
Senate Room
blocks passage
gate
entrance
N
W
E
S
SCALE
0 50 100 200 feet
dimensions given in feet
surveyed length 6397.2 feet / 1949.9 meters
Legend
cave walls
ledge
ceiling change
ledge height
drip line
lava stalactite
ceiling height
bedrock
breakdown
pahoehoe flow
slope
floor crack
surveyed May and September 2022 and September 2023 by:
Mark Jones
Ed Klausner
Matt Beeson
Paul McMullen
Andrew Erickson
Fred Wilkinson
Theresa Schwartz
Craig Williams
Noa Meiri
Evan Olden
Alan Palmer
Elizabeth Miller
Rick Olson
David Donner
Kailey Alessi
Sarah Rogers
Emilee Hansen
Virginia Glasscock
Kathryn McCabe
Michael Schoenewies
extended profile views
entrance
gate
A
A
B
C
D
Senate Room
E
F
G
H

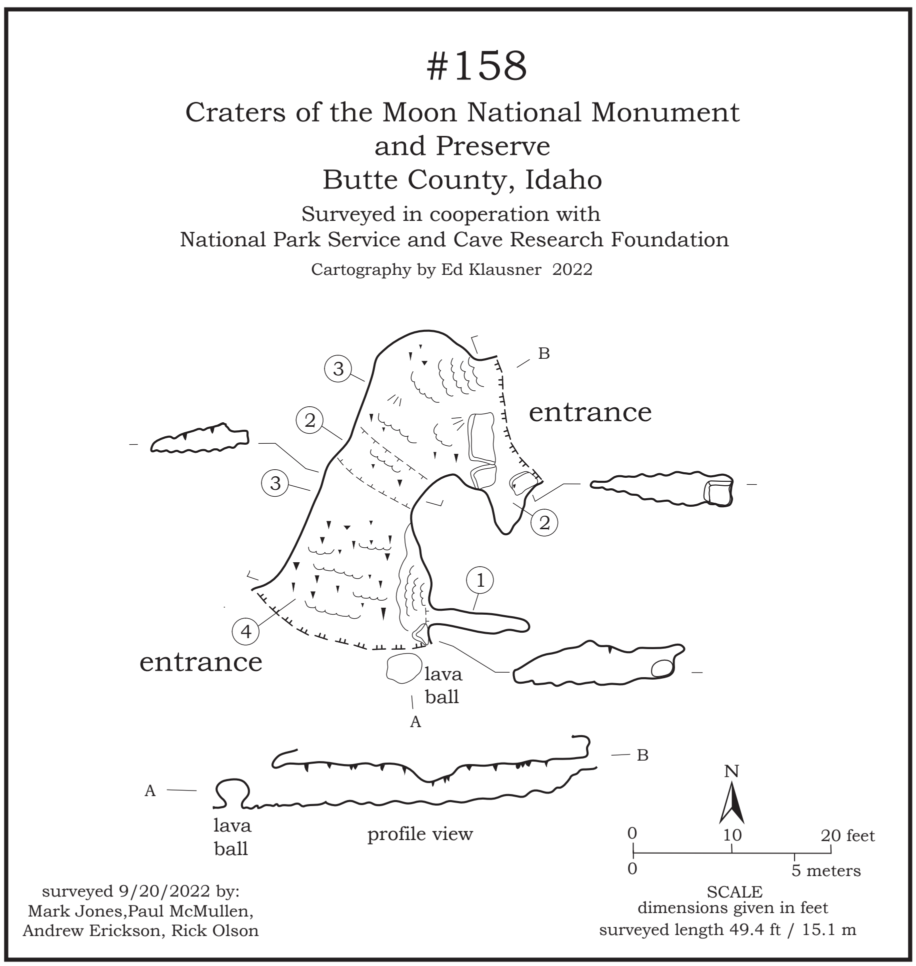
Michael Raymond. *Paul McMullen*

#143	16.9
#156	334.2
#445	69.1
#443	23.7
#444	23.0
#367	185.1
#442	19.1
#461	105.0
#151	112.9
#154	14.4



Ice formations. *Ed Klausner*

Mark Jones. *Paul McMullen*

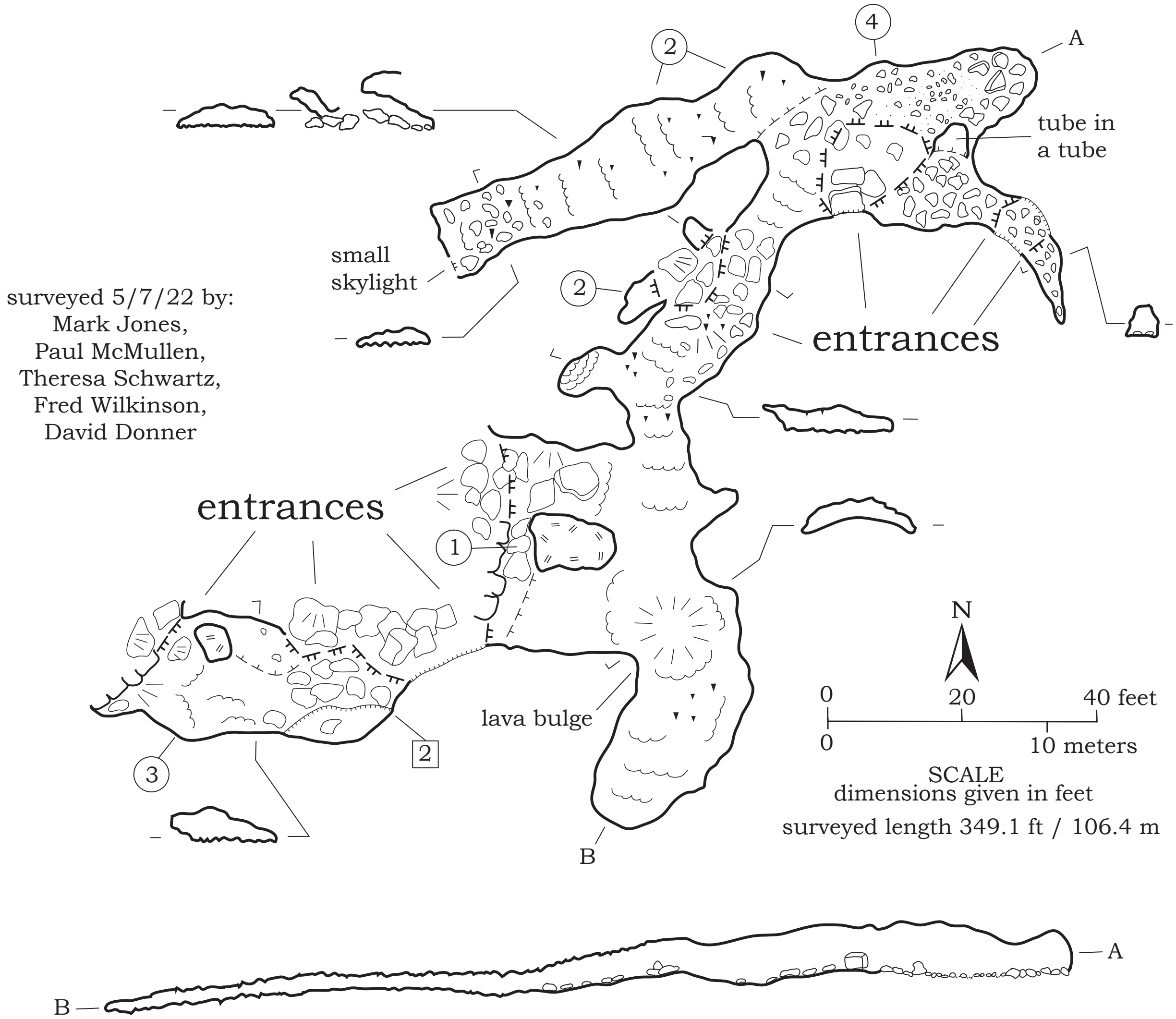


#361

Craters of the Moon National Monument and Preserve
Butte County, Idaho

Surveyed in cooperation with
National Park Service and Cave Research Foundation

Cartography by Ed Klausner 2022



Balcony Flow Expedition, Spring 2022

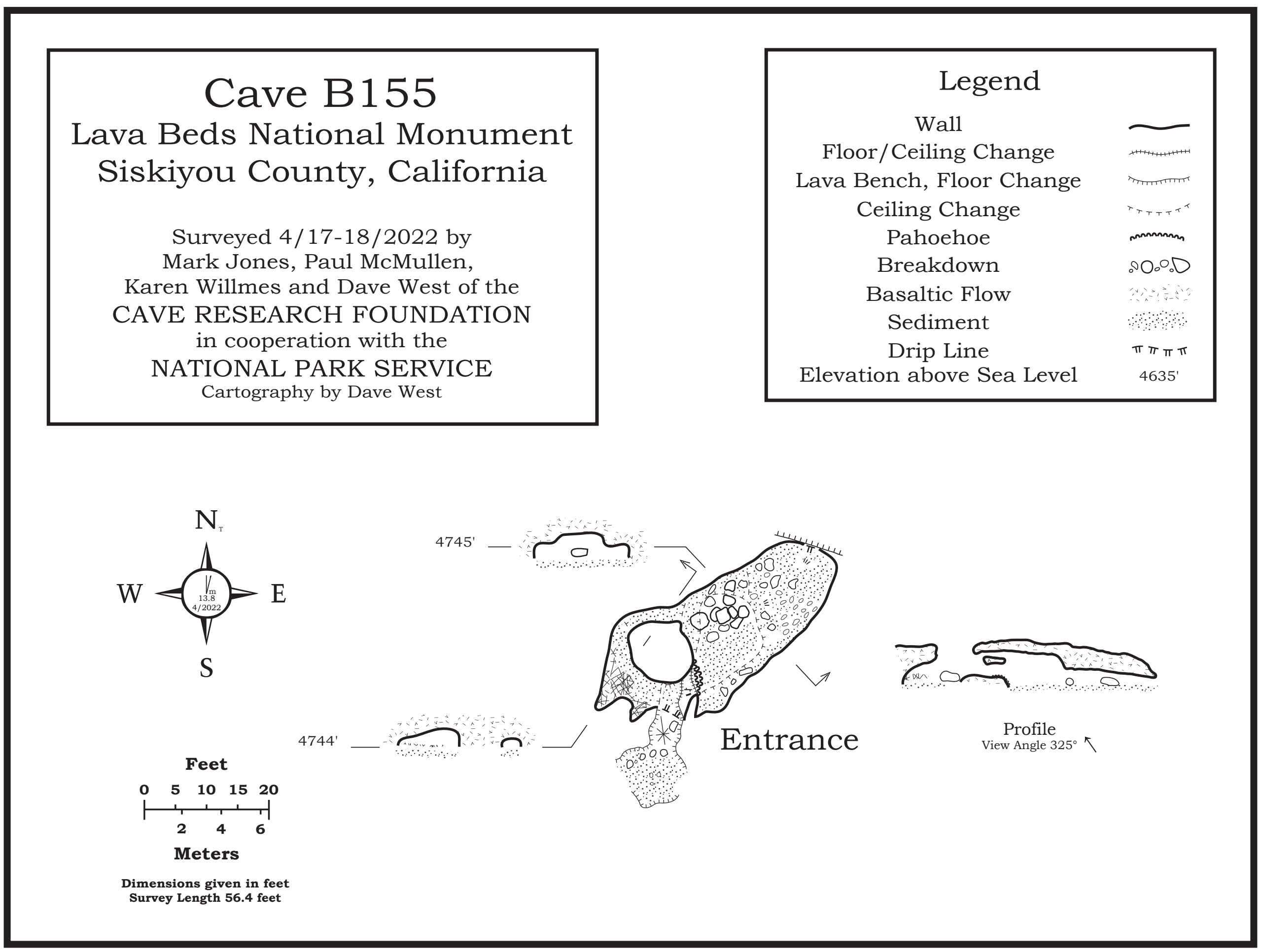
Lava Beds National Monument

Dave West

April 16–29, 2022

Karen Willmes and I arrived Saturday night finding Mark Jones and Paul McMullen already at the Research Center (RC). Informed we could go out on Sunday we proceeded to the surface survey in the south trench and surveyed an additional 1,513 feet. Paul found a number of obsidian flakes and shards. We got GPS locations and photos, which we provided to the Monument on Monday morning. We also located a few more cave leads to add to the list.

On Monday morning Dave Hays came to the RC to provide our research project numbers and advise which caves we could access. We were cleared for all of the previously documented caves we planned to survey. We were informed we could not go to Cave B010, which had not been requested as we had already mapped it. We went out to the surface survey to continue from the previous day, avoiding the area where the obsidian had been noted earlier. Cleaned up one area where a portion had gone off the page and moved on to another, getting in two shots before the wind made surface work impossible. We retreated to the RC to regroup to head underground. We went out to Cave B155 and rushed to get underground away from the wind. Cave 155 proved to be bit over 56 feet in length. It is a nice little



cave with a few pretties. When we returned to the surface, the wind had increased and we returned to the RC to ensure we wouldn't get caught in whatever storm was moving in.

Yesterday's storm left over an inch of snow on the ground. I didn't want to risk falling and elected to stay at the RC. Being more sure-footed, Mark and Paul went out to get a surface profile over B155 and begin survey of B135 and B310 caves. I began drafting on B155, finding that the "All-in-one" printer at the RC is fine for making copies, and one can print to it through a USB connection. It is of no value for scanning. Scanning requires network operation and then the scan is sent through the network as an attachment in an email. This is managed by the network admin that sets authorized senders and recipients. I took a picture of the sketch for B155 and used it for drafting. Karen addressed some ongoing issues at Eastern Operations. Paul and Mark finished B135, but only got started on B310.

Wednesday morning the weather cleared somewhat so we went back to the south trench and finished up the trench survey before the wind again increased. Paul and I climbed up the slope beyond B010 to a vent that looks to have some passage at the bottom. Got a GPS fix and then we all returned to the RC, winded again. I stayed in camp after lunch to do reports and more drafting and the others went out to B310 hoping to finish mapping it. But, it was not to be. They found a passage not shown on the Recon sheet while surveying through breakdown and got into real tube. We will have to go back.

And go back we did. We woke up to a landscape covered in over an inch of snow and it was still coming down. Mark and Paul were determined to finish B135 and went out after breakfast when the sun came out. They did finish up and returned in time for lunch. Ed Klausner and Elizabeth Miller arrived. We made plans for surveying B306 on Friday.

Paul and Mark joined Ed to work on his project (reported on separately). Karen, Elizabeth, and I went out to

Elizabeth Miller and Mark Jones. *Mark Jones*

Spring snowfall. *Mark Jones*

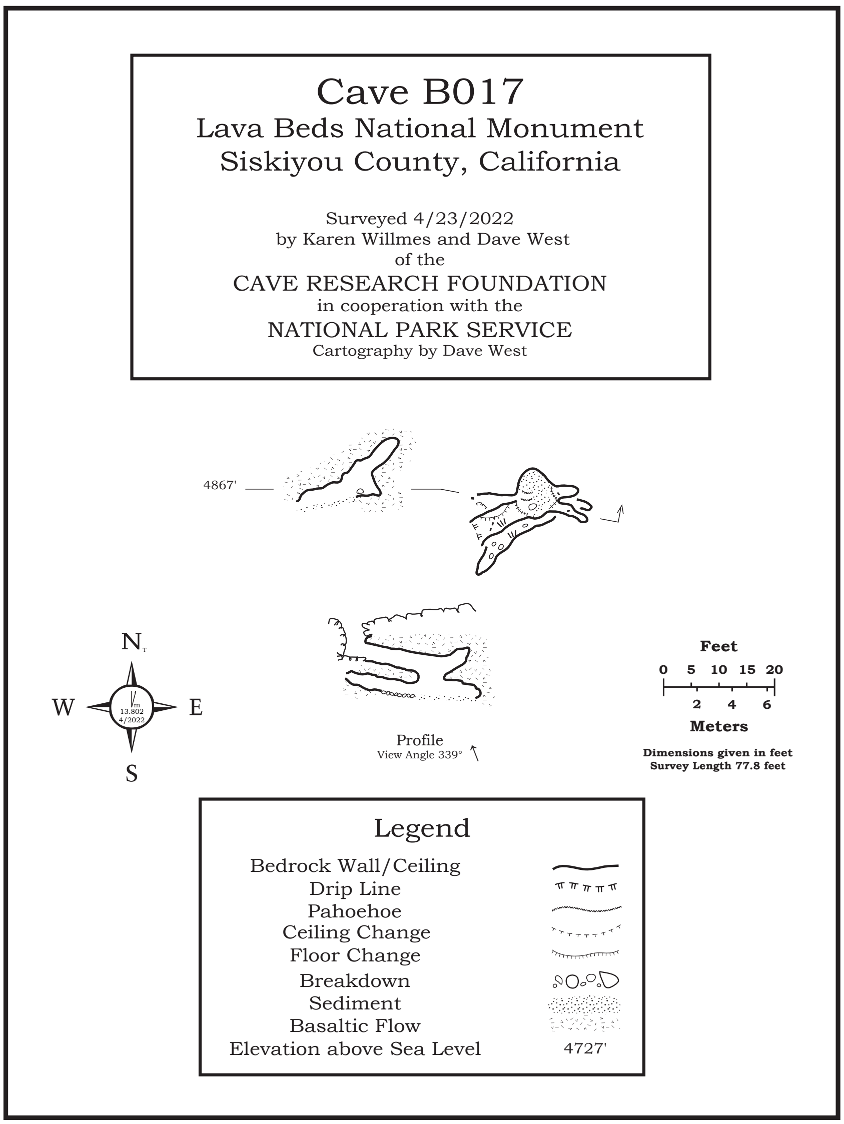
B306 and surveyed it. What an abusive cave. My memory of it was charitable to say the least. Nevertheless, it qualified as a cave under the 40-foot standard. Walls, floor, and ceiling were all breakdown. The entrance is 0.8' wide × 1.4' long × 6' deep. We rigged an etrier to assist in getting started up the squeeze to get out. It worked, but caver's vitamin I (ibuprofen) was needed after the trip. We retreated to the RC for lunch. After lunch we headed out to B155 to get some surface detail between it and another cave. We then obtained GPS locations at a number of leads on our way back to B306, where we got a surface profile above the cave. We found yet another lead on the way back to the car.

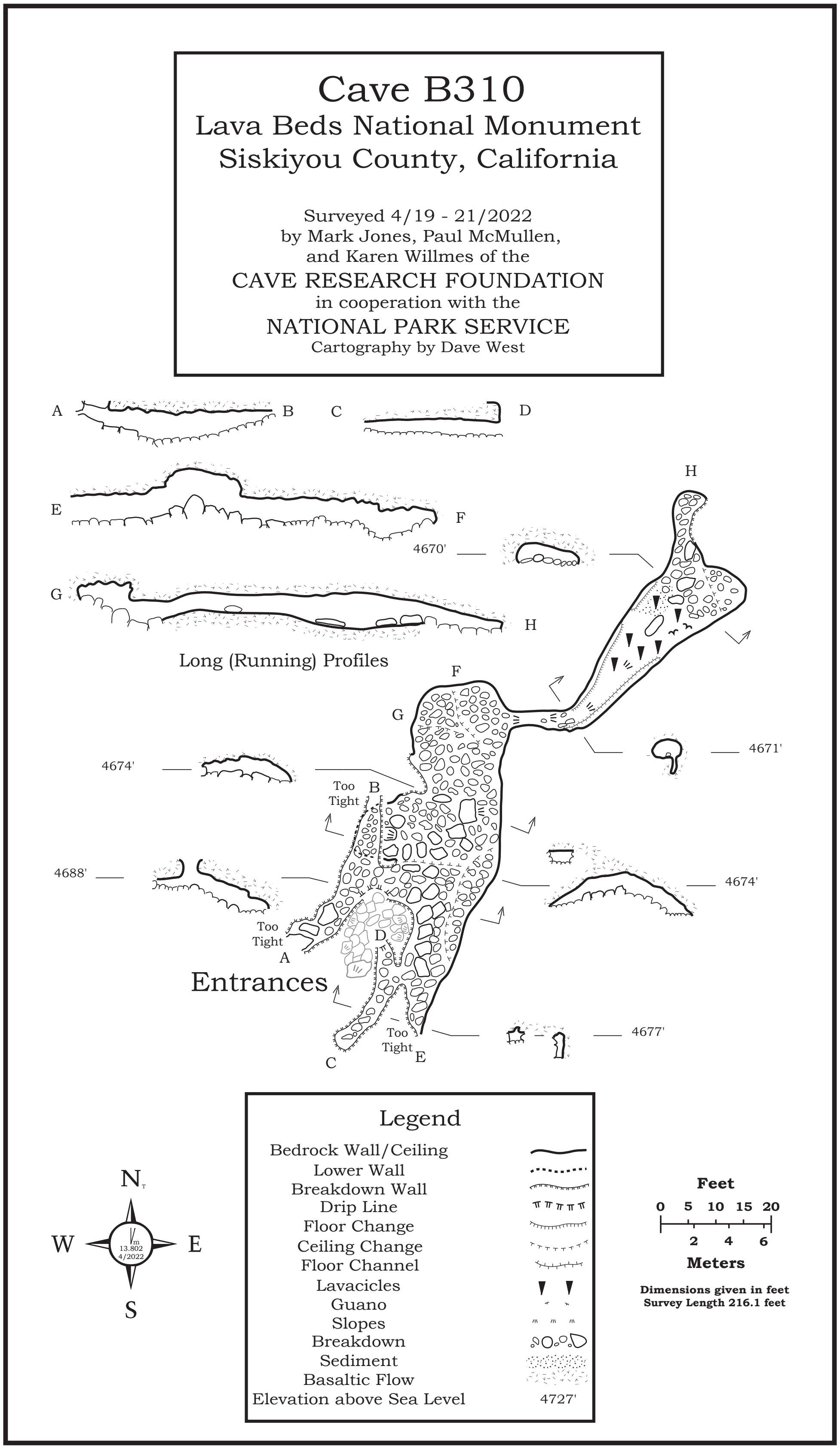
It turns out that the cave we surveyed to from B155 wasn't the cave we thought, it is another lead for the list. On Saturday Mark and Paul joined me and we returned to the vent to survey the cave and grotto within. En route we found more obsidian, got another photo and GPS location which was provided to the Monument the following day. Given that this vent was above B010, we dubbed it the B005 and grotto. The two features had just over 72 feet of survey between them. Then we surveyed the surface just over 410 feet down to B010, hoping to tie to the brass cap. Unable to tie to the cap as we couldn't find it, we tied to a point they remembered using although it was not marked or labeled. I turned over the book to Mark. He and Paul surveyed a lead just below B010 which became B011. The next lead to the north had no cave to survey. Mark and Paul surveyed the next in line and that became B013 which mapped out to 49 feet. We called it a day and returned to the RC.

On Sunday Karen and I went down to the Balcony parking lot for some surface survey. We surveyed first to a survey pin apparently put in for the paving project and over to a lead noticed when surveying B306 earlier. Then we surveyed a nearby trench collapse that led to more leads. Continuing down the trench, which was getting somewhat vague, we stopped at a lead in another collapse filled with shrubbery that apparently escaped the fire, at least for the most part. We dubbed it the Oasis and added it to the lead list, having left tie in stations in three locations for the leads. Took lunch, then went back to Bitty Pit and surveyed up to and around a relatively large collapse that contained at least one more undocumented lead.

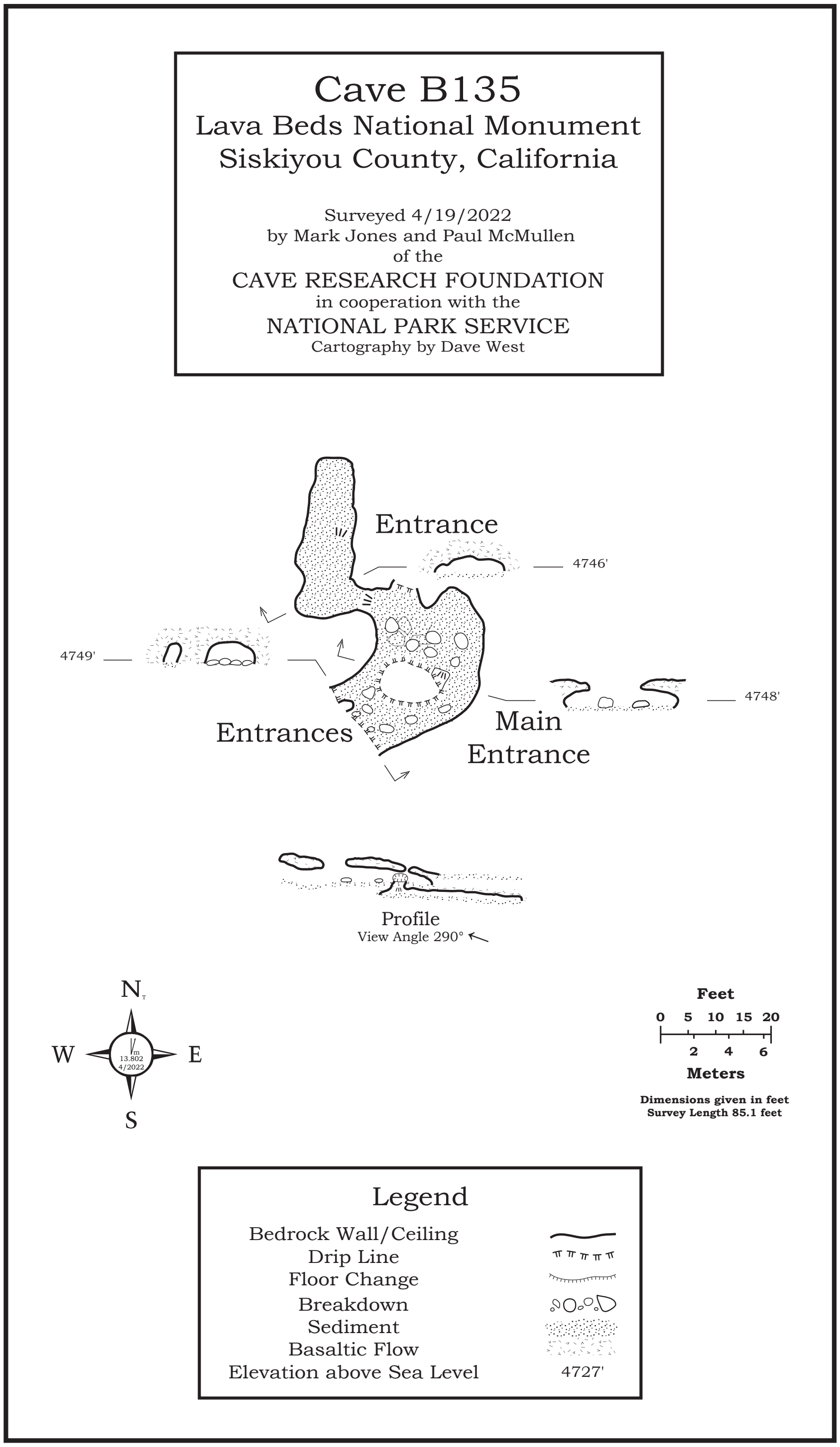
Monday Karen and I went to the Merrill parking lot to continue knocking off leads. It should be noted that all of these "leads" fit in one of two categories: 1. Either nobody or only one person on the surface survey trip that identified it thought they might fit, so its investigation was put off until smaller people could examine the lead. 2. The lead, having been entered and examined by us and others, did not meet an old standard of being 40 feet or longer and had no apparent cultural significance, and was therefore not documented. Some fit into both categories. The current standard, per Dave Hays, is whatever we think needs documentation. We are therefore backtracking to some degree. My own standard is fifteen feet, the Iowa Cave Standard used by the Iowa Grotto. Karen and I continued north from where the Saturday trip stopped. Karen is among the most petite members of our group. If she doesn't fit, it isn't a lead. We first eliminated a lead that was not on the Balcony Flow. We eliminated another ten "leads" as either non-existent or too small before finally locating one which when first entered, was seen to be about fifteen feet long, so we elected to survey it. Although the cave occupies about only twenty square feet of area, it turns out to be developed on two levels, and 77 feet of survey was required to map it. It became B017. Karen and I also found more obsidian, so we got a couple of photos and a GPS location. On our way back from the B017 we found a greater concentration a bit closer to the trench than the first grouping. As we had already documented the location, we moved closer still to the trench to avoid it as we returned to the RC.

Dave West sketching. *Mark Jones*



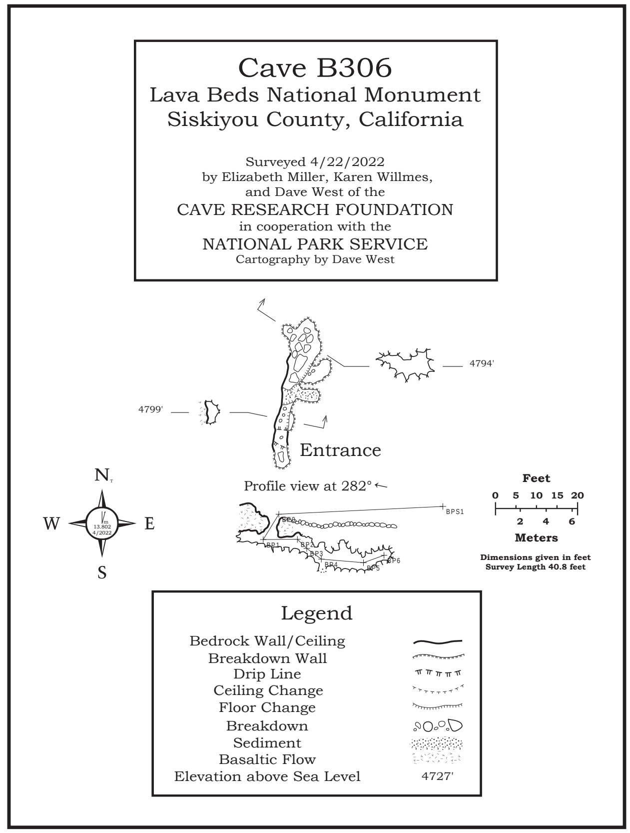

Cave B310
Lava Beds National Monument
Siskiyou County, California
Surveyed 4/19 - 21/2022
by Mark Jones, Paul McMullen,
and Karen Willmes of the
CAVE RESEARCH FOUNDATION
in cooperation with the
NATIONAL PARK SERVICE
Cartography by Dave West
A
B
C
D
E
F
G
H
Long (Running) Profiles
4670'
4671'
4674'
4688'
4674'
4677'
Too Tight
Too Tight
Too Tight
Entrances
Legend
Bedrock Wall/Ceiling
Lower Wall
Breakdown Wall
Drip Line
Floor Change
Ceiling Change
Floor Channel
Lavacicles
Guano
Slopes
Breakdown
Sediment
Basaltic Flow
Elevation above Sea Level
4727'
N
W
E
S
13.802
4/2022
Feet
0 5 10 15 20
2 4 6
Meters
Dimensions given in feet
Survey Length 216.1 feet

I was joined by Mark Jones on Tuesday and we went out to examine more of the leads that remained in the Balcony Flow. We first stopped at one Karen had balked at the day before and determined it was too small to survey. We then went to a spot in the trench that had escaped being sketched last year and I filled in the missing portion. Then on to B017 to recover my reading glasses. We continued north zig-zagging down flow checking leads, determining that one had no holes that went more than ten feet in breakdown. We surveyed B022. The next lead was too small. The next lead had already been placed on the map as one of three named grottos. A bubble was too small to enter. We mapped B027 and noted that another lead had the same coordinates, but was theoretically 57 feet lower in elevation. It was ignored. Our next lead was surveyed and noted as a grotto. Another lead was surveyed and also noted as a grotto. B031 was also surveyed. The next lead was too small to enter. Our next lead 182 had already been noted as a grotto. We then returned to the RC.

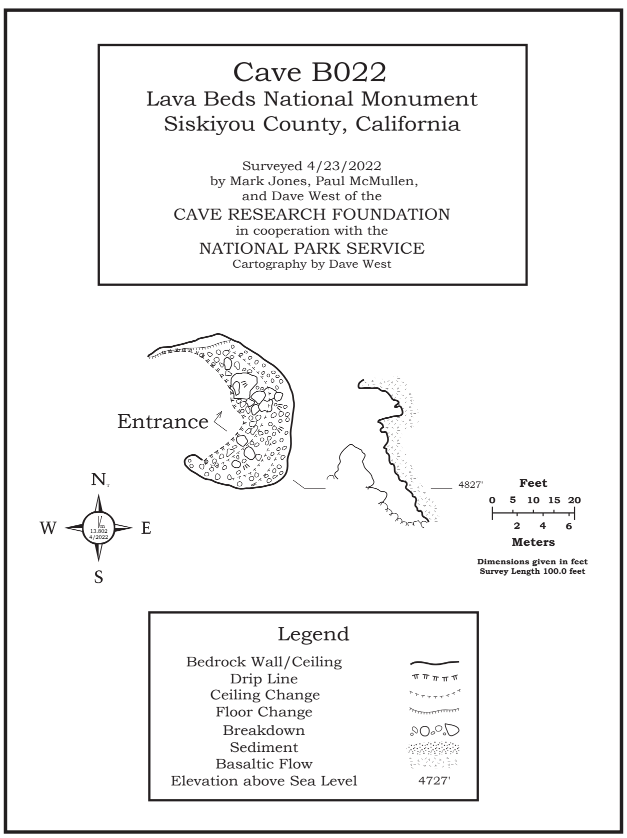


Karen and I picked up zig-zagging the next day. Our first lead had already been noted as a grotto. Next was just a five-foot void in breakdown. The next two were both too small to enter. Then a narrow, shallow pit with five feet of passage to the north and seven feet of passage to the south. I will sketch it in on the map. Our next fizzled in only four feet. Next was a 3' high × 12' wide × 4' deep grotto I will sketch in as well. Another lead had no cave. Next on the list was already mapped as B049. The next lead went all of two feet into a blister. The next two went in opposite directions in a small rift. Neither was long enough to consider surveying. Another went four feet into breakdown. Karen and I surveyed a two-shot surface tie-in to B046 which was already surveyed. A grotto became the only lead we surveyed all day. Still another was not a cave. Next was a small 3' high × 12' wide × 3' deep grotto that will be sketched onto the map. The next was located in Elmer's Trench and referred to Ed Klausner. Then a hole in breakdown that doesn't lead to cave. This was followed by a 5' × 12' blister with a 3' diameter center hole. Under the blister is less than a foot high. The next one was already surveyed and is in fact B054. The next turned out to be the lower entrance to B240 which is already mapped. We stopped at

Paul McMullen. *Mark Jones*



this point and returned to the car using a reasonably direct route. We had attempted this once in the past, and found the area to be almost impenetrable. Post burn the travel was easier. We identified five new leads during the day, four in the Balcony Flow which will be added to the list for our next visit. The fifth was found north of the Merrill parking lot. Also found a small depression with a number of barrel hoops and other metal debris which we duly reported.



Thursday morning we again awakened to a winter wonderland. I got caught up on reports and data entry. After lunch the snow had mostly melted so Karen and I went to Merrill to get the rental car gassed for our return to Reno. We got back and went out again parking at the Balcony lot. With relatively little time, we elected to determine whether leads needed survey or not. We examined another five sites and determined four of them needed survey.

Friday was time to pack up and go home. John Tinsley, Ed Klausner, and Elizabeth Miller were a tremendous help in getting RC ship shape before they left about 9 a.m. Karen and I needed to check in to our flight at 10:55. We got ourselves mostly packed up, keeping enough gear available to get a cross section in L040 before turning in all the LABE material to Resource Management. Then off to Susanville for the night before flying out of Reno Saturday morning.

Dave Hays was an enormous help to the group, ensuring we had all we needed. We can't thank him enough.

Elmer's Trench and Lower Cave Loop

Lava Beds National Monument

Ed Klausner

The April 2022 expedition to Lava Beds National Monument was attended by Elizabeth Miller, Mark Jones, Paul McMullen, Dave West, Karen Willmes, and Ed Klausner. Elmer's Trench and the Lower Cave Loop were my areas of study. Dave West's area was the Balcony Boulevard Flow, reported separately.

Note that accession numbers for caves will be used in this report as the Monument prefers that we don't use cave names. Also, we were supposed to locate leads and tell the Resource Office the locations before entering the new lead. Then the Resource Office would approve (or not approve) our survey of the leads that may have contained archaeological material. Later, we were approved to start surveying any newly found lead and stop if we encountered any archaeological material and alert the Resource Office of our find. During 2022, we were approved to enter leads found in 2021 and did not enter leads found in 2022.

On my first day at the Monument, Mark Jones and Paul McMullen joined me to look at some of the 2021 leads in the northeast section of Elmer's Trench. Our first lead turned out to be a 167-foot cave that may be longer if we can get someone smaller than our crew to get past a tight spot. It was given accession number E726. Later in the week, Karen Willmes got through the tight spot, and the surveyed length was 218.3 feet.

On the second day of our expedition, Mark Jones and Paul McMullen joined me in the Lower Cave Loop. Well known L800 was our first objective, and we completed 201.1 feet of survey. The ice had contracted enough for Paul to get down 13 feet to the floor and then put in another survey shot under the ice. There was a thin layer of water on top of the ice, and, unfortunately, we found many rocks that were thrown onto the ice.

From there, we located L810 and completed 107 feet of survey to finish the cave. It was still early, so we hiked to the L845 area and did a search in the immediate area. We found 4 new leads. L845 was quite complex and netted 189.7 feet of survey. Finally, we surveyed L850 and found it to also be quite complex. That cave was 199 feet of survey.

Ed Klausner squeezing into an entrance. *Mark Jones*

On the third day, Karen Willmes joined me on a trip to E726 to see if Karen could get through the tight spot. She could and we got four more survey shots in this new cave. From there, we headed over to E610 to hopefully survey the two approved leads. It turns out that the two leads are probably the same spot where one of the GPS devices was using a different datum. The cave looked really familiar to me, so we didn't survey it until I determined if this one was already done. Later, it indeed turned out to be one that was already surveyed.

From there, we headed north (down flow) to E750. There were two leads there and the first, E751 was 42.8 feet long. The second lead was too short to be a cave, and we didn't survey it. With our remaining time, we searched for additional leads and noted one.

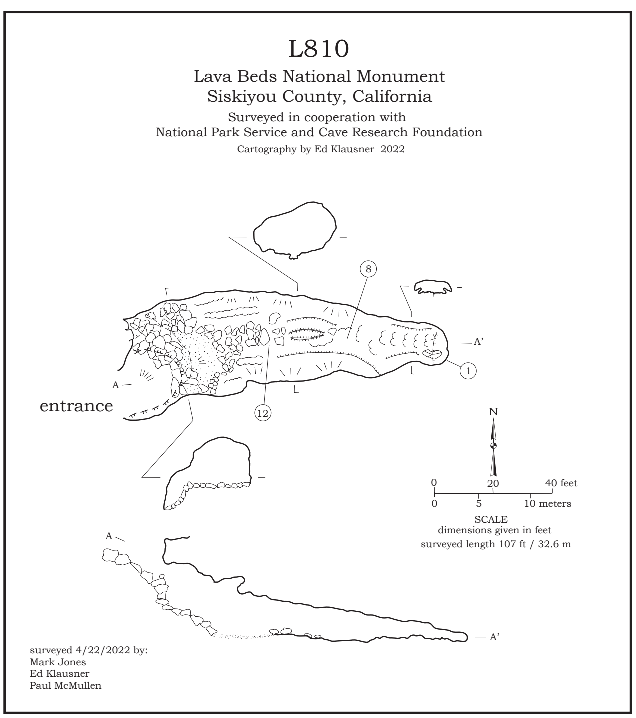
We set our sights on E695 in Elmer's Trench on Sunday with a team

Ed Klausner sketching. *Mark Jones*

of Elizabeth, Mark, and me. Finding it was no problem, and we saw a fairly complex cave. As the survey continued, the cave became more and more complex with upper and lower levels. We finally came out for lunch at 2 and then finished up the some of the upper levels after lunch.

We headed over to E680 and searched for the lead that was said to be halfway between E680 and E670. We could not find an opening anywhere in the area.

On April 25, Mark Jones and I headed north to the parking area where Devil's Homestead crosses the monument road. Our first lead had a tight entrance into a moderate sized room that led to a small crawl to a trail. We knew that this had to have been surveyed and followed the trail to the entrance to see the E550 brass monument.



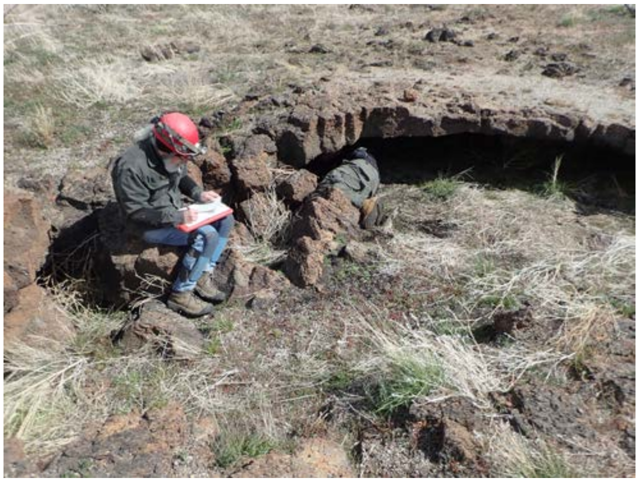
Mark Jones checking a lead. *Paul McMullen*

From there, we headed south to lead #4 from 2021. It has a vertical entrance drop that didn't have good footholds, so a cable ladder will be needed. Finally, we went to 44, lead #9 and surveyed a 25.4-foot cave named E408. We also found a new lead.

We then went back to our vehicle and moved to the Balcony Boulevard parking area. A trip west to the next set of leads netted four new caves and four new leads. The caves were assigned accession numbers E156, E157, E158 and E159.

April 26 was devoted to finishing the close caves in the Lower Cave Loop, so Elizabeth and Karen joined me. We had no trouble finding L860 and mapped it to 55.7 feet. L805 was also easy to find, and we mapped it to 41 feet. We had trouble finding L815. Once I have more information on the cave, it will probably turn out to be one of the noted leads. All in all, we mapped two caves and found eight new leads.

It was still early, so Karen and I went to Fleener Chimney Road and headed north to a surface tube lead. We found the lead, surveyed it, and assigned it E252. It was 33.6 feet of survey.



Ed Klausner and unidentified feet. *Mark Jones*

Ed Klausner amuses Mark Jones. *Paul McMullen*

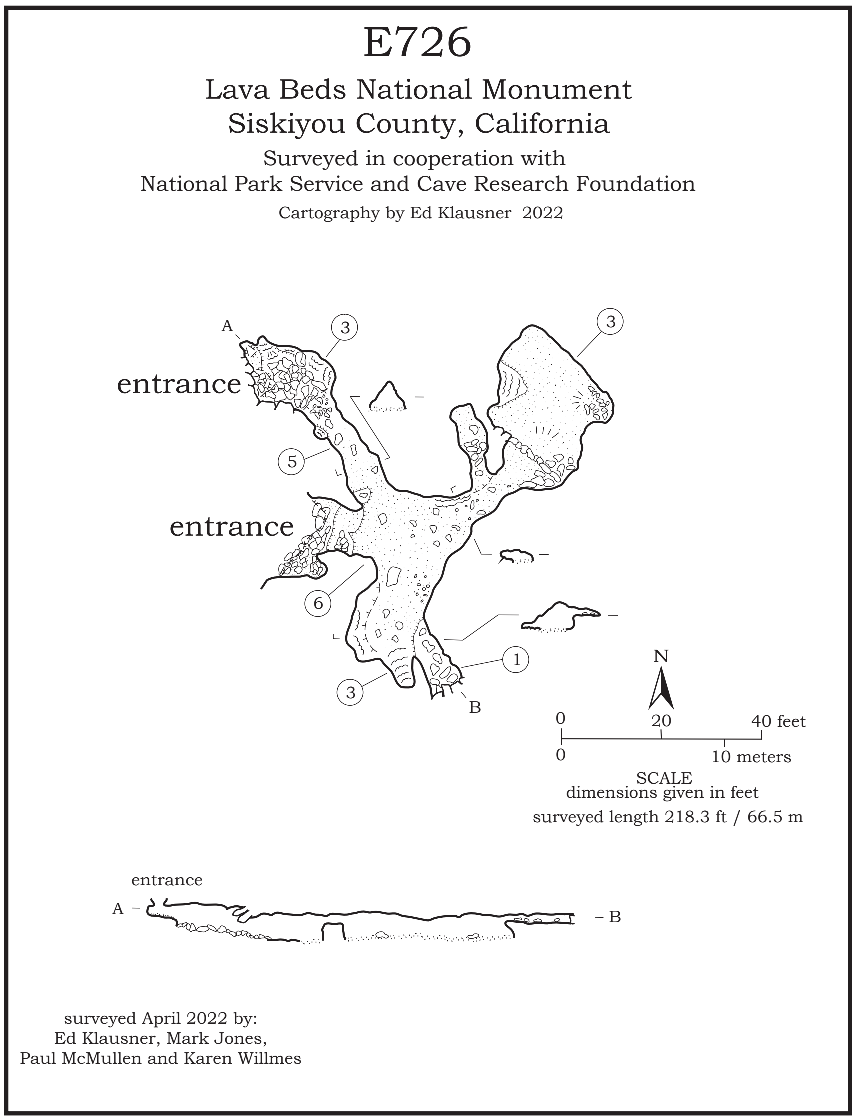
On Mark's last day (April 27), Mark and I took a cable ladder and webbing to the approved lead that we thought needed vertical gear. We assigned it E467 From the opening, it dropped down and we took several survey shots to alcoves. The cave was completely in breakdown but had a 20-foot ceiling in one spot. From there, we headed across Monument Road to E660 and got 229.1 feet of survey in this very comfortable cave with three bats.

On our return to our vehicle, Mark and I checked for caves east of Monument Road from E660 to Black Crater parking area and didn't find any potential caves to survey.

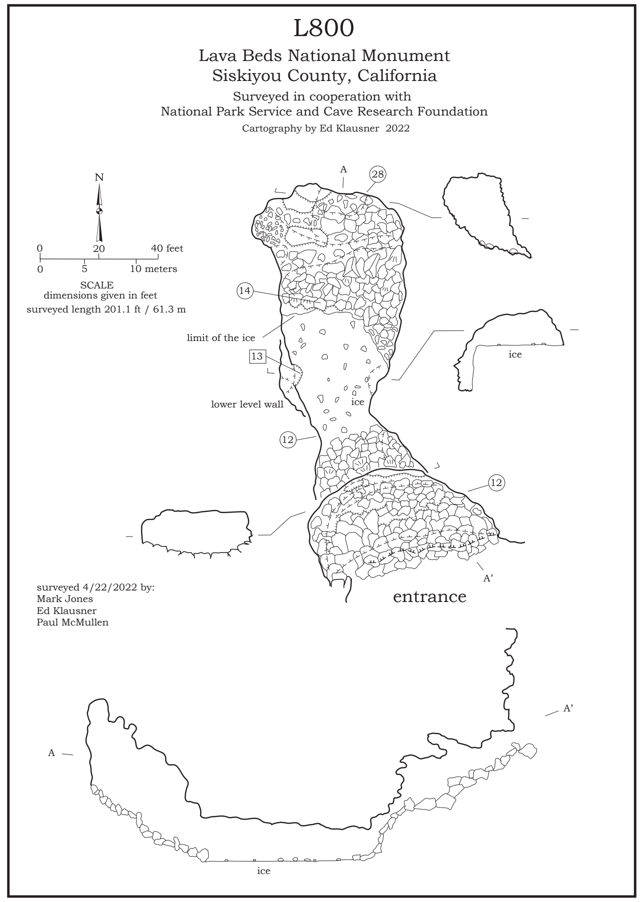
Our final day was snowy and cloudy in the morning, so we got a late start. Elizabeth and I went to Bat Butte to search for the last approved lead. It turned out to be a cave I had already surveyed.

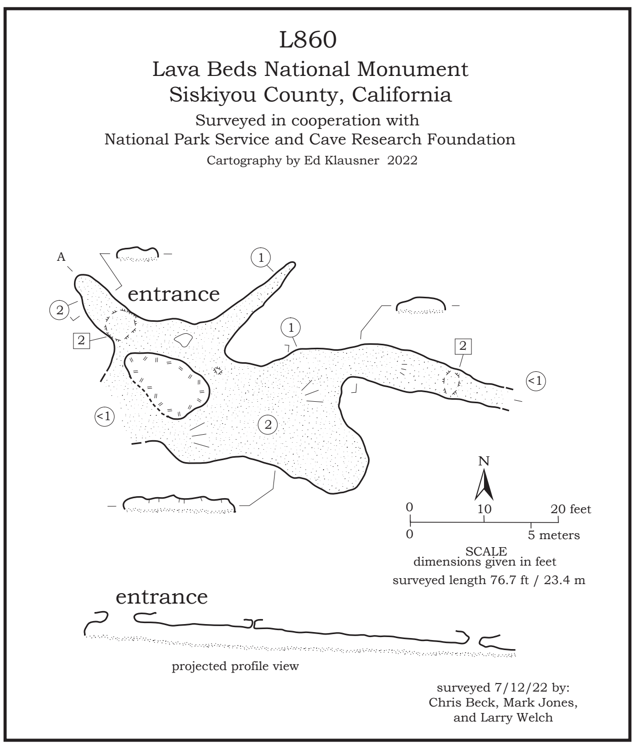
Elmer's Trench cave survey:

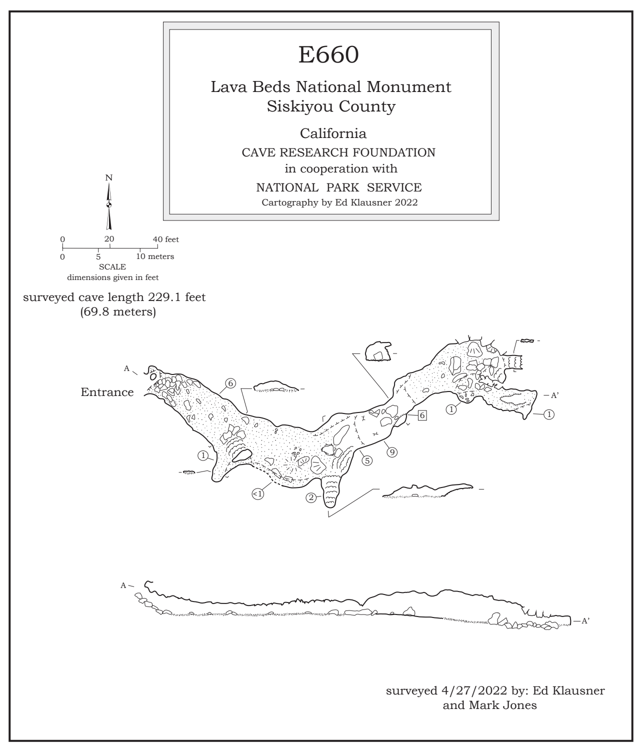
E726	218.3' (new find)
E751	42.8' (new find)
E695	765.6'
E408	25.4' (new find)
E156	29.5' (new find)
E157	43.5' (new find)
E158	39.3' (new find)
E159	25.7' (new find)
E252	33.6' (new find)
E660	229.1'
E467	63.5' (new find)



Ed Klausner in a lava tube. *Mark Jones*



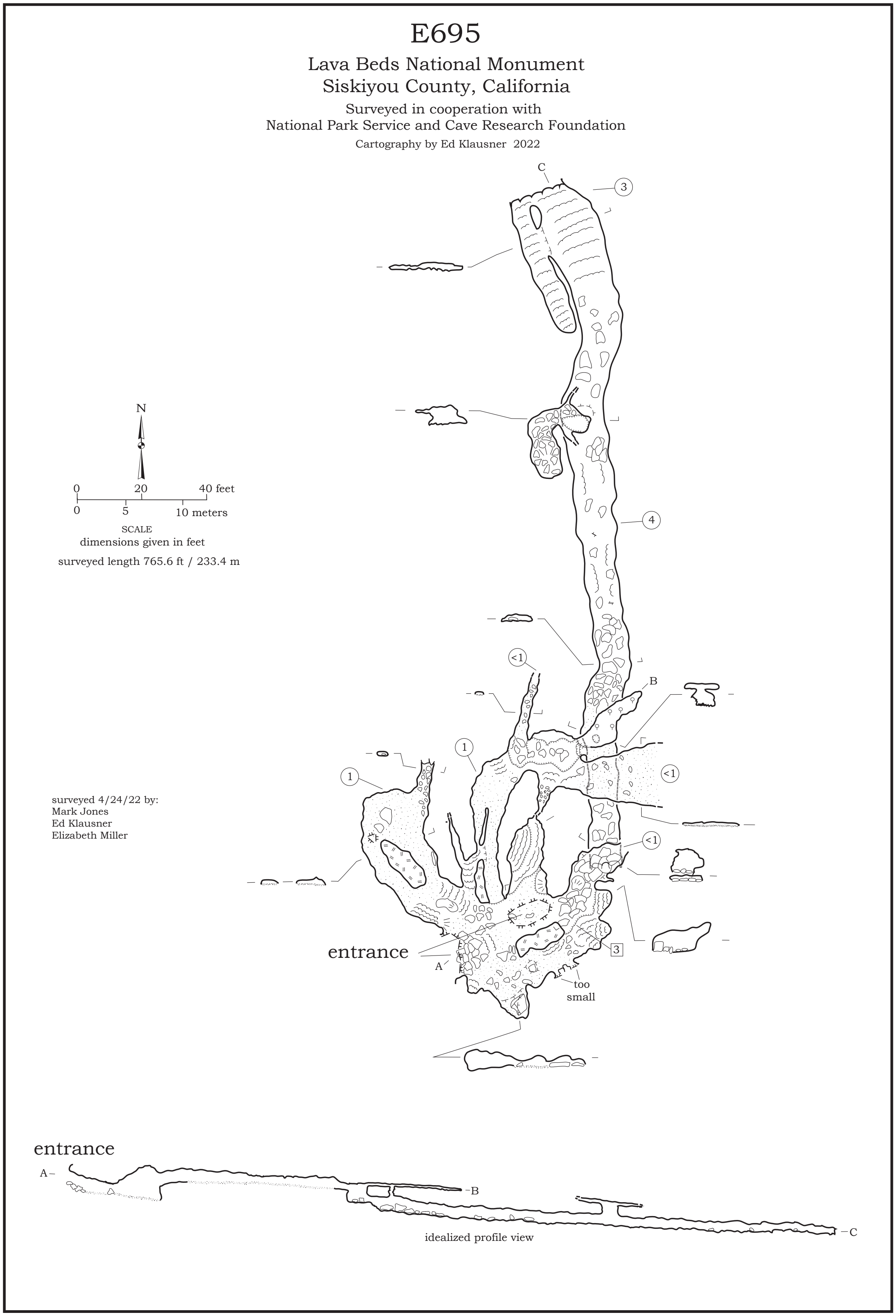




Lower Loop flow, down flow of Post Office Cave survey:

L800	201.1'
L810	107.0'
L845	189.7'
L850	199.0'
L860	55.7'
L805	41.0'

Our thanks to Dave Hays for the great support given to this project.


E695
Lava Beds National Monument
Siskiyou County, California
Surveyed in cooperation with
National Park Service and Cave Research Foundation
Cartography by Ed Klausner 2022
N
0
20
40 feet
0
5
10 meters
SCALE
dimensions given in feet
surveyed length 765.6 ft / 233.4 m
surveyed 4/24/22 by:
Mark Jones
Ed Klausner
Elizabeth Miller
C
3
4
<1
B
1
1
<1
<1
entrance
A
3
too
small
entrance
A
B
C
idealized profile view

Carlsbad Caverns National Park Restoration Project

William Tucker

William Tucker led one restoration project at Carlsbad Caverns National Park September 3–5, 2022.

The participants were: Ed and Tracey Knetsch, Barbe Barker, Frank Everitt, Jimmie Worrell, and William and Tammy Tucker.

The main task was to finish restoring a large pool basin in the Big Room. This pool basin is located just across the trail from Crystal Springs Dome and had been used as a dump site at various times in the past. William and his group started cleaning this pool in August of 2019, but they were unable to finish cleaning it as their work was interrupted by the COVID pandemic.

Other tasks completed include cleaning flowstone in Lower Cave which is impacted where the trail crosses it. Additionally, a few hours were spent removing coins from pools near the visitor trails. This task had not been performed in several years.

Pit (during). *William Tucker*

In total, the seven volunteers contributed 109 man-hours in these efforts.

Pit (before). *William Tucker*

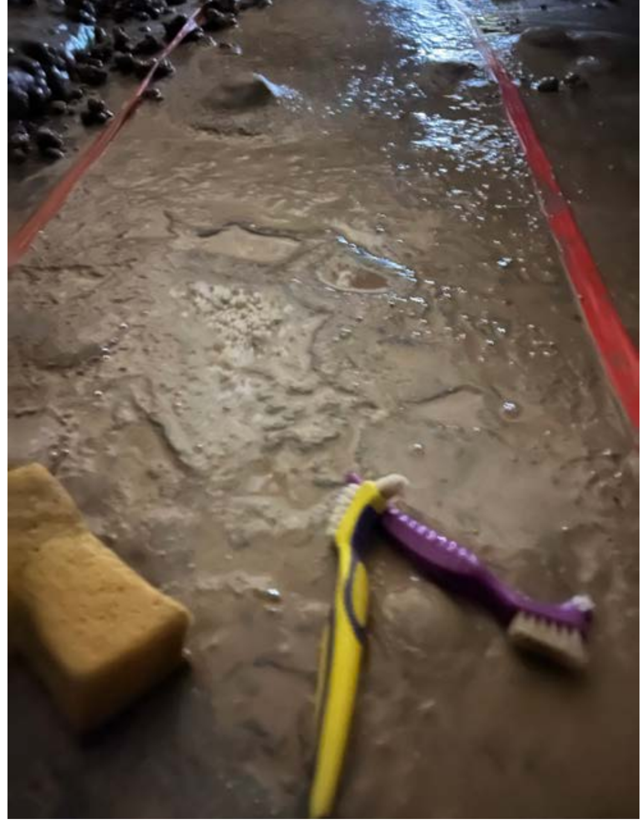
Pit (during) (2). *William Tucker*

Pit (after). *William Tucker*

Pit (during) (3). *William Tucker*

Pit (after). *William Tucker*

Bridges (before). *William Tucker*



Flowstone (before). *William Tucker*

Bridges (after). *William Tucker*

Flowstone path (before). *William Tucker*

Flowstone (after). *William Tucker*

Lower cave bridges. *William Tucker*

Flowstone (after) (2). *William Tucker*

Pools in Big Room. *William Tucker*

Science

A new gray bat colony in an Ozark Cave.
Scott House

2022 Philip M. Smith Graduate Research Grant for Cave and Karst Research

Funding Recommendations

Pat Kambesis and Kayla Sapkota

Grant Program Chairs

A total of eight grant requests were submitted for FY 2021–22 and eight proposals were accepted and funded. The reviewers for this year's funding round were:

- George Crothers
- Kurt Helf
- Pat Kambesis
- Leslie North
- Art Palmer
- Jason Polk
- Stan Sides
- Jeanne Sumrall
- Steve Taylor

Since we had a more money for funding this year ($15,000) we were able to fund all of the proposals though not necessarily to the amount requested. Award amounts were determined based on the quality of the proposals. One of the PhD proposals would have been qualified for $3,000 but the student only requested $1,500. We felt it not a good precedent to award more than requested

Cameron De Wet's CRF grant was approved from last year but COVID made his field work not possible. He has been granted an extension with a new completion deadline of July 31, 2023.

Masters Proposals

Kailey Alessi ($1,500)

University of Idaho, Department of Culture, Society, and Justice

Advisor: Dr. Katrina Eichner

A Pit Investigation: Historic Archaeology at the Historic Entrance of Mammoth Cave, Kentucky

Abstract—Mammoth Cave, located in southern Kentucky, is the longest known cave in the world, with 420 miles of mapped passages. In addition to being a geological wonder, it has been visited by humans for thousands of years. Many projects have focused on the prehistoric archaeology of the Historic Entrance to the cave, but none have focused exclusively on the historic archaeology of this site. This project will shed some light on the overlooked history and archaeology of the cave's historic period. Archival research, pedestrian survey, and archaeological excavation will be conducted at the Historic Entrance. Particularly, the focus will be on trying to identify and understand the fifty foot pit referenced in historic documents. The synthesis of historic documents and archaeological materials will facilitate a greater, more nuanced understanding of how people modified and interacted with the cave environment during the nineteenth and twentieth centuries.

Shikha Acharya ($1,000)

School of Natural Resources, University of Missouri, Columbia

Advisor: Dr. Shuangyu Xu

Understanding Cave Tourism: From the Perspective of Visitor On-site Experience

Abstract—Cave tourism attracts millions of tourists worldwide annually, generates significant economic impact to surrounding communities, and thus serves as an effective regional development plan for many countries. Although previous cave studies predominantly examined from environmental science (e.g., geology, biology) perspective, recent years have seen growing interests in cave tourism (e.g., tourist motivation, benefits). Still, research in understanding tourist on-site experience (e.g., satisfaction, preference, willingness to pay) is limited, let alone from the sensory experience (associated with five bodily senses of sight, smell, sound, taste, and touch) perspective. Sensory experience, widely applied in marketing research for its capability to influence individuals' behavior and satisfaction, is under-researched in the tourism field at large, not to mention in cave tourism in specific. Therefore, this proposed project aims to understand cave tourists' on-site experience, with an emphasis on their sensory experience (i.e., the association between cave lighting and tourist satisfaction). The study will be conducted at two show caves—Onondaga (State Park) and Meramec Cavern (private)—in the Cave State of Missouri, in Summer 2022. Visitors to these two caves will be asked to complete a survey asking their on-site experience (including their motivation, satisfaction and preference of cave activities/programs, willingness to pay, responses of cave lighting intensity), trip characteristics (e.g., length of stay, travel companion, and expenses) and their demographics. In addition to advancing cave tourism scholarship, results of this study will help inform cave managers of program design and delivery, enhance tourist on-site experience, and ultimately contributes to regional development.

Amy Hourigan ($1,500)

Department of Earth, Environmental and Atmospheric Sciences, Western Kentucky University

Advisor: Dr. Jason Polk

Investigating Carbon Cycling and Critical Zone Dynamics for Urbanized Karst Areas

Abstract—Steadily increasing atmospheric CO2 concentrations are correlated to rising temperatures and global climate change. Investigating the cumulative global carbon cycling processes is important to understanding and quantification the global carbon cycle, including currently undetermined sinks and sources. In karst landscapes, the chemical dissolution process results in features like sinkholes, caves, and underground rivers. This involves the transport of carbon in various forms, including its transformation from atmospheric, soil, and rock sources to dissolved species in groundwater systems and, eventually, potential sequestration through storage. Urban karst landscapes face abundant environmental issues caused by anthropogenic impacts, like increased impervious surfaces and localized greenhouse gas emissions. An important and understudied topic in urban karst groundwater systems is the flux of carbon during dissolution, storage, and precipitation in subterranean karst drainage systems. The proposed research is a longitudinal investigation of the carbon flux in the Lost River Cave system, from source to final discharge point, to characterize and quantify the carbon cycling processes underway using geochemical and carbon isotope data. Lost River Cave is over 10 km in length and is directly located under, and impacted by, the dense urbanized portion of Bowling Green, Kentucky, which is an iconic, well-studied karst landscape. The expected outcomes of this project include quantification of the carbon flux and sourcing of dissolved inorganic carbon in an urban karst system, an improved methodology for calculating these in urban systems to include land use, and contribution to the global carbon flux quantification to include these types of landscapes.

Jakub Wcisło ($1,200)

Institute of Geological Sciences, Faculty of Geography and Geology, Jagiellonian University in Kraków, Kraków, A

Advisor: Professor Michał Gradziński

Chemistry of Dripwater in Caves Located in the National Park and Urban Area—Case Study from Southern Poland

Abstract—Karst aquifers are important source of freshwater, providing about 20–25% of the Earth's population water for drinking, agricultural, and industrial use. Karst systems are highly vulnerable, since the potential contaminants can easily reach phreatic zone (saturated with water) through conduit networks, fractures, and vugs. Recharge and contamination commonly occur via vadose zone (unsaturated with water), that functioning is still poorly understood. Proposed project is aimed at investigation of vadose zone water chemistry from caves located in areas characterized by different anthropopression: protected area (Ojców National Park) and urban area (Kraków city) in southern Poland. The chemical composition of dripwater will be monitored for 1-year period, with monthly water sampling. The collected data will be used to determine and compare degree of anthropogenic impact on groundwater chemistry in shallow karst systems. To do this, the data will be statistically analyzed with descriptive and multivariate analysis (HCA and PCA). Moreover, the study will demonstrate change of chemical composition of these waters through the relatively long time (>20 years). To determine this variability, nowadays results will be compared to the data collected from the same caves by the team of professor Jacek Motyka in 1997–99.

Doctoral Proposals

Sarah M. Arpin ($1,500)

Department of Earth and Environmental Sciences, University of Kentucky

Advisor: Dr. Alan E. Fryar

Hydrogeology of Silvertip Mountain, Bob Marchall Wilderness Area, Montana

Abstract—The goal of this project is to understand the contributions of different water storage components to discharge of spring(s) in the understudied alpine karst aquifer of Silvertip Mountain, located in the Bob Marshall Wilderness Area of northwestern Montana. Alpine environments are particularly susceptible to the impacts of climate change. Water storage is vital to regional water availability, but year-round snowpack may disappear with a warming climate, reducing the contribution of recharge from that source. At more than 1.5 million acres, the Bob Marshall Wilderness is one of the largest wilderness areas in the USA outside of Alaska. As human activities continue to reduce pristine environments around the globe, areas not significantly impacted by these activities become more important to understand and protect. In examining the water storage dynamics of Silvertip Mountain, this project aims to determine where water is stored and over what time scales. I hypothesize that winter precipitation is stored as snowpack and frozen groundwater until warmer seasonal temperatures melt these frozen reservoirs and meltwater enters talus and karst systems below. Storage and flow through these groundwater components feeds regional rivers and streams, sustaining water supply downstream. Hydrologic measurements, geochemical sampling, tracer tests, and continuous monitoring are being used to understand the Silvertip karst aquifer. Initial logging at the outlet spring suggests a diurnal temperature signal, which may be associated with meltwater pulses. Solute and C isotope analyses, together with solute speciation modeling, indicate that groundwater chemistry reflects meteoric recharge modified by carbonate weathering, as expected.

Luis Omar Calva ($2,368)

Department of Systematic, Zoology and Ecology, ELTE Eötvös Loránd University. Pázmány Péter sétány 1/C. H-1117. Budapest, Hungary

Advisors Gábor Herczeg and Gergely Balázs

Taxonomy, Phylogeny and Biogeography of the **Niphargus** ***(Amphipoda, Niphargidae) Populations of the Northern Range, Hungary***

Abstract—While there are over 350 *Niphargus* species and subspecies worldwide, the taxonomic status of the few species recorded from Hungary remains unknown. The majority of the descriptions were written with minimal morphological information and few pictures, and the type locality was frequently unknown. The taxonomic review of Hungarian species is complicated by the fact that most holotypes are no longer available in type collections due to a variety of factors. There are 20 *Niphargus* species in Hungary, according to the literature but only nine species were found to be both genuine and part of the actual Hungarian biodiversity. *Niphargus tatrensis* is a troglobitic crustacean living in the karst waters of Austria, the Czech Republic, Hungary, Poland, and Slovakia. It can be found in caves, karst springs, and wells in the karstic areas. The sampling implies intense fieldwork. The know Hungarian *N. tatrensis* species complex populations live in caves of two areas namely Bükk Mts. and Aggtelek Karst (Northern Range, Hungary) and the genetic study relies on widely used genetic markers including Cytochrome c oxidase subunit I (COI), 28S rDNS (28S 22, 28S 35) fragment, H3 histone coding fragment, and Internal transcribed spacer ITS. For these markers numerous data are available for other *Niphargus* species in the databases, making it possible to include the focal populations in complex phylogenic analyses. If we combined morphological and molecular analyses, it will lead to describe a new species from Hungary.

J. Romero-Gelvez ($2,000)

Department of Geological and Atmospheric Sciences, Iowa State University, Ames, IA and Department of Earth and Planetary Sciences, University of California, Davis, CA

Advisor: Isabel Montanez

Hydroclimate, Width and Migrations of the Intertropical Convergence Zone (ITCZ) through the Last Glacial Cycle from Stable Isotopes and Trace Elements in Northern South American Stalagmites

Abstract—The intertropical convergence zone (ITCZ) is dynamically coupled to Earth's climate and thus it migrates to establish an energy balance between the hemispheres. Ice-age ITCZ movements occurred in response to inter-hemispheric temperature asymmetries originated in the north Atlantic region, and related to the strength of the Atlantic meridional overturning circulation (AMOC). However, multiple proxy reconstructions in the southern hemisphere suggest that changes in ocean circulation and sea surface temperatures in the Southern Ocean, Pacific Ocean, and tropical south Atlantic preceded temperature variations in the north Atlantic. As atmospheric processes are mostly subordinated to large scale oceanic reorganizations, reconstructing the temporal and spatial evolution of the ITCZ from archives with high temporal resolution and precision, such as speleothems, will refine the timing of occurrence and reveal the potential drivers of past periods of climate change. Currently, ITCZ movements reconstructions in South America are confined to the subtropics where the presence of the south American monsoon can obscure a correct interpretation of glacial ITCZ dynamics. Moreover, sediment cores ITCZ records from the region, lack the temporal precision to make accurate comparisons between high latitude temperature variations and tropical paleorainfall. Here, I propose a reconstruction of paleorainfall from stable isotopes and trace elements in stalagmites tied to Uranium-thorium chronology from four locations in the tropical Andes covering a latitudinal extent of 8°. Clusters of paleorecords with enough latitudinal extent can allow reconstructions of temporal and spatial ITCZ patterns in response to high latitude temperature forcing. Output from fresh water housing/sea surface warming experiments in the Southern Ocean. South Atlantic will complement the proxy reconstructions and interpretations resulting from this study.

Alexandra Tsalickis ($1,500)

Doctoral Project Affiliation: Department of Crop, Soil, and Environmental Sciences, Auburn University, Auburn, AL 36849, Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC 29634

Advisor: Dr. Jess Hartshorn

Previous major advisor: Dr. Matthew Waters

Constructing a Paleoclimate Record in the Southeastern United States: Hydroclimate and Vegetation Implications

Abstract—The need to understand past hydroclimate and vegetation changes throughout the Holocene is crucial in determining the intensity of future global warming projections caused by anthropogenic sources. Bat guano is a well-documented and reliable proxy for hydroclimatic and vegetation changes via analyses of δ 2H, δ 15N, and δ 13C stable isotopes. Spanning thousands of years throughout the Holocene, bat guano can provide longer chronologies than standard paleoclimate records such as tree rings, soil profiles, or lake sediments. Bat guano can also serve as a paleoclimatic record from cave systems where standard proxies of paleoclimate records (e.g., speleothems) do not exist. Reconstructing hydroclimate records will indicate how past precipitation changes altered the local ecosystem and allow us to predict future precipitation changes expected by natural climate cycles and anthropogenic induced climate change. There is currently a significant gap in knowledge regarding hydroclimate records in the southeastern U.S. To address this gap in knowledge, I will analyze stable isotopes from a bat guano core extracted from Key Cave in Florence, AL, to determine changes in moisture conditions in the southeastern U.S. over time. My Key Cave guano core will span throughout the Holocene time period as compared to other bat guano cores and a speleothem record analyzed from the same area—providing a long-term record of hydroclimatic change that can be used to identify changes in seasonality and provide evidence for historic climatic events.

Taxonomy, Phylogeny and Biogeography of the *Niphargus* (Amphipoda, Niphargidae) Populations of the Northern Range of Hungary

Luis Omar Calva

Ph.D. Student, Institute of Biology, Faculty of Science, Eötvös Loránd University, Budapest, Hungary

This report summarizes my research progress from September 2021 to June 2023, highlighting the use of the Philip M. Smith Graduate Student Research Grant for Cave and Karst Research 2022.

1. Abstract

Members of the *Niphargus tatrensis* species group are a troglobitic species of crustacean in the family Niphargidae, living in the karst waters of Austria, the Czech Republic, Hungary, Poland, and Slovakia. It can be found in caves, and also in karst springs and in wells in the karstic areas. The genus *Niphargus*, with over 425 described species distributed in the Western Palearctic, is almost completely tied to groundwaters, except for a few species recorded from surface lakes, streams, and peat bogs. The problems of exhaustively reviewing the taxonomy of the genus are partly due to the scarcity of material collected. In the first place, the subterranean habitats are difficult to access (especially caves, which may require advanced speleological techniques), most species have restricted distribution ranges and sometimes species are known from single or few localities difficult to trace using old taxonomic literature and museum labels. Second, the morphotaxonomy of this group is very unsatisfactory; morphological characters are highly homoplastic and differences between species are weak while intraspecific variation can be high, requiring the examination of an unpractically large, usually unattainable number of specimens from each locality. Although molecular techniques have been found to be powerful tools for complementing the traditional morphotaxonomy of *Niphargus*. The findings combined morphological and molecular analyses with *Niphargus* species in Hungary and Austria are examples of the crucial steps in the upcoming phylogenetic reconstruction analysis needed to understand the natural history of the group. Therefore, with the information available on the geological history of the Aggtelek region, by coupling the morphology and phylogeny, it is possible to detect geological events that influenced the dispersal and speciation of populations belonging to the *Niphargus* group of Hungary.

2. Progress to Date

The project is divided into three stages. The collection of specimens (fieldwork), the morphological and molecular (integrated taxonomy) study, and the phylogenetic and biogeographic analysis. So far, 95% of the first stage has been completed, and 50% part of the third stage happened between May and June 2023 at the University of Ljubljana, in the Biotechnical Faculty, under the supervision of Dr. Cene Fišer.

2.1. First Stage

Previously to the fieldwork, the first year of the Ph.D. research, training was conducted by my co-supervisor. He collected some specimens of the *Niphargus* and *Gammarus* genera and taught the preparation techniques and the terminology used to measure the samples. A total of 45 specimens were dissected and prepared to practice. **Also, at the beginning of the second year, the specialized gear was bought, as it was mentioned in the research budget plan.**

Also, the Aggtelek Karst region was delimited and divided into eight hydrological units for sampling. Well-known caves where the specimens of interest are found were selected and new sites were added. A total of 46 caves and springs were considered to explore and collect the *Niphargus* specimens.

The fieldwork consisted of four field trips. The first was during the Cave Biology course, to familiarize me with the region and the caves in the area. Three caves were visited: Baradla cave, Kossuth cave, and Vass Imre cave. The three caves belong to one sub-hydrological unit. On this occasion, 10 specimens of *Niphargus aggtelekiensis* were collected for my training in their preparation. The total of days for the collection was three for the first field trip.

The other field trips were conducted in 1) December 2021; 2) February 2022; 3) December 2022. **In December, two field trips were made using the travel cost grant destined to travel to the Aggteleki National Park and the**

daily allowances for food and accommodation for the whole team. We spent a total of 924 Euros for the six days. Most of the expenses were related to the accommodation place and the extra fees for the National Park services.

Between these fieldworks, eight of the hydrological units were explored. Seven caves (Baradla cave, Kossuth cave, Vass Imre cave, Rákóczi 1 cave, Meteor cave, Szabadság cave, and Beke cave) and four springs (Szezsfozdei, bedela, eger-lyuk, and tetves springs) have evidence of *Niphargus* specimens, and 128 specimens were collected to use in the research project. It is worth mentioning that the fieldwork consisted of exploring around 45 sampling sites. The last hydrological unit was explored by my co-supervisor at the beginning of June 2023, completing our sampling goal.

2.2. Second Stage

Based on recently published genetic results, it looks like there is a considerable difference between the Baradla cave and the Kossuth cave population. For that reason, the recent collection will focus on samples from Baradla cave and Kossuth cave to work on the morphological comparison of these two populations and add a from Rákóczi 1 cave and Meteor. These four sample sites have 45 specimens collected. The slide preparation is advancing with sex determination and morphological measurement. Also, to prepare samples for DNA, the appendages and antennas of all specimens were removed (128 specimens), while the rest of the traits were kept for the morphometrics measures.

2.3. Third Stage

The grant proposal mentioned the training in Slovenia after the sampling, which was planned to be completed in early 2023. However, due to difficulties at the last sampling sites and the unavailability to receive me in Slovenia on the established dates, the training finally took place between May and June of this year.

The traineeship was between May 21 to June 30, 2023. During the training, I analyzed samples of *Niphargus* from the Western Carpathian mountains, to define their species structure and phylogenetic origin. Most of the samples were already sequenced and are available for analysis. I started with creating a dataset and studying different methods for species delimitation, using DNA sequences of three standard genetic markers: Cytochrome c oxidase subunit I (COI), 28s rDNA (28S 22, 28S 35) fragments, and the Internal transcribed spacer (ITS) for sequenced in literature and the data of 250 individual sequences of *Niphargus* from the Carpathian region. These sequences are from neighboring geographical regions, which is a crucial context for the project. After compiling the data set, the species delimitation analyses were made with unilocus and multilocus approaches and haplowebs, to conclude with the phylogenetic analyses applying Maximum likelihood and Bayesian analysis. All these steps are the same I will use during my phylogenetic analyses of the *Niphargus* population of the Northern range of Hungary.

At the end of June 2023, the crucial part of my research project was done. The extraction, amplification, and isolation of DNA material of the 128 samples using the MicroLab Start Hamilton Robot. A robot programmed to pipette and extract and isolate the material of interest from 95 samples in less than 6 hours.

The collaboration with the University of Ljubljana will continue online. We will work on the spatial analysis of the Western Carpathian study and the roles of the upcoming manuscript. **The internship at the Biotechnical Faculty of the University of Ljubljana was 980 euros covering accommodation, travel costs and food.**

3. Conclusion

Thanks to the grant, the most essential and significant stages of the research project were covered. The fieldwork and sampling have been completed. The training held in the University of Ljubljana open an opportunity to work and collaborate with them. From here on, during the rest of this year I will work with two manuscripts. The first one will be related to the analyses performed during my stay in Slovenia, while the other one will emerge after obtaining the DNA sequences of the samples from Hungary. It is expected to publish between three and four of our results.

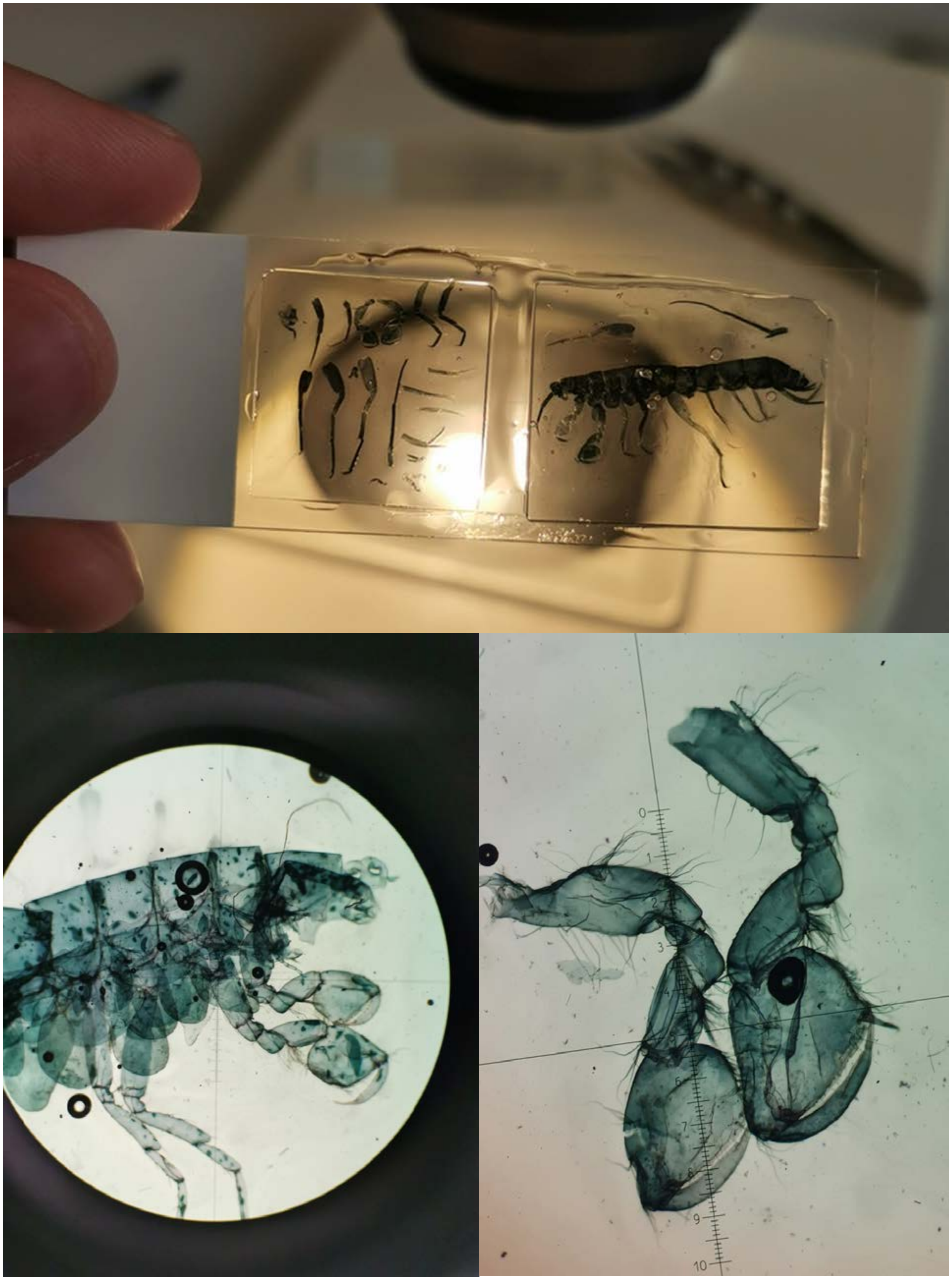
4. Acknowledgment

I would like to express my gratitude for the grant you have awarded me. I am immensely grateful for your support in funding our project. With this grant, we will be able to make a significant impact in the knowledge of the *Niphargus* species of Hungary.

I understand the responsibility that comes with this grant and assure you that I used the funds as we planned. I will provide regular updates on our progress related with publications and presentation in congress or any event. Thank you once again for the opportunity.

5. Evidence (Photos)

Niphargus ***population sampling caves and springs around Aggtelek Karst region.***



Niphargus ***preparation for morphological measurement.***

Training and DNA extraction in the University of Ljubljana, Slovenia.

frontiers in Earth Science

ORIGINAL RESEARCH
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Monitoring of Sierra Nevada Caves Reveals the Potential for Stalagmites to Archive Seasonal Variability

Barbara E. Wortham[1]*, *Isabel P. Montañez*[2], *Kimberly Bowman*[3], *Daphne Kuta*[2], *Nora Soto Contreras*[2], *Eleana Brummage*[2], *Allison Pang*[2], *John Tinsley*[4] and *Greg Roemer-Baer*[4]

[1]Department of Earth and Planetary Science, University of California, Berkeley, Berkeley, CA, United States, [2]Department of Earth and Planetary Sciences, University of California, Davis, Davis, CA, United States, [3]Department of Water Resources, West Sacramento, CA, United States, [4]The Cave Research Foundation, Fresno, CA, United States

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Edited by:
James Baldini,
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Maharaja Sayajirao University of Baroda, India

Correspondence:
Barbara E. Wortham
babswortham@berkeley.edu

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In the southwestern United States, California (CA) is one of the most climatically sensitive regions given its low (≤250 mm/year) seasonal precipitation and its inherently variable hydroclimate, subject to large magnitude modulation. To reconstruct past climate change in CA, cave calcite deposits (stalagmites) have been utilized as an archive for environmentally sensitive proxies, such as stable isotope compositions ($\delta^{18}O$, $\delta^{13}C$) and trace element concentrations (e.g., Mg, Ba, Sr). Monitoring the cave and associated surface environments, the chemical evolution of cave drip-water, the calcite precipitated from the drip-water, and the response of these systems to seasonal variability in precipitation and temperature is imperative for interpreting stalagmite proxies. Here we present monitored drip-water and physical parameters at Lilburn Cave, Sequoia Kings Canyon National Park (Southern Sierra Nevada), CA, and measured trace element concentrations (Mg, Sr, Ba, Cu, Fe, Mn) and stable isotopic compositions ($\delta^{18}O$, $\delta^{2}H$) of drip-water and for calcite ($\delta^{18}O$) precipitated on glass substrates over a two-year period (November 2018 to February 2021) to better understand how chemical variability at this site is influenced by local and regional precipitation and temperature variability. Despite large variability in surface temperatures and precipitation amount and source region (North Pacific vs. subtropical Pacific), Lilburn Cave exhibits a constant cave environment year-round. At two of the three sites within the cave, drip-water $\delta^{18}O$ and $\delta^{2}H$ are influenced seasonally by evaporative enrichment. At a third collection site in the cave, the drip-water $\delta^{18}O$ responds solely to precipitation $\delta^{18}O$ variability. The Mg/Ca, Ba/Ca, and Sr/Ca ratios are seasonally responsive to prior calcite precipitation at all sites but minimally to water-rock interaction. Lastly, we examine the potential of trace metals (e.g., Mn^{2+} and Cu^{2+}as a geochemical proxy of recharge and find that variability in their concentrations has high potential to denote the onset of the rainy season in the study region. The drip-water composition is recorded in the calcite, demonstrating that stalagmites from Lilburn Cave, and potentially more regionally, could record seasonal variability in weather even during periods of substantially reduced rainfall.

Keywords: karst, drip water geochemistry, trace element (TE), oxygen isotope (δ18O), cave monitoring

INTRODUCTION

The monitoring of caves and surface environments (the karst system) is an important approach for understanding processes that impact paleoclimate proxy records developed using cave calcite deposits ("speleothems"). Monitoring the cave environment allows for a quantification of the impact of temperature, precipitation and CO_2 variability, and cave processes on stable isotopic compositions ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$) and trace element concentrations (Mg, Ba, Sr, etc.), commonly applied proxies in stalagmite paleoclimate reconstruction (McDermott, 2004; Wong and Breecker, 2015). For example, precipitation source, precipitation amount, and precipitation type (i.e., snow or rainfall), as well as relative humidity, and temperature all can influence drip-water and stalagmite $\delta^{18}O$ values (Banner et al., 2007; Fairchild and Baker, 2012; Oster et al., 2012; Luo et al., 2014; Baker et al., 2019). Furthermore, studies have shown that vegetation density and wildfire activity can impact hydrologic recharge to a cave system leading to drip-water $\delta^{18}O$ variability (Nagra et al., 2016; Treble et al., 2016; McDonough et al., 2021). Trace element variability (Mg/Ca, Sr/Ca, and Ba/Ca) and $\delta^{13}C$ compositions are also influenced by precipitation amount as well as bedrock composition and pCO_2 ventilation regimes in a cave (Fairchild and Treble, 2009; Wong et al., 2011; Oster et al., 2012; Oster et al., 2014; Casteel and Banner, 2015; Oster et al., 2015). Therefore, inferring environmental conditions from stalagmite geochemical compositions is complicated by the confounding effects of multiple influences on their signatures (Lachniet, 2009; Fairchild and Baker, 2012). This reflects the fact that geologic and hydrologic conditions of the karst system (i.e., soil, epikarst, and cave) control how the climate signal is transferred to the geochemical compositions of the drip-water and mineral precipitate as well as their included fluids (e.g., Dreybrodt and Scholz, 2011; Tremaine et al., 2011; Feng et al., 2014). As a result, the proxy signals can be dampened, enhanced, or biased by karst processes, and predominant environmental influence(s) can vary by cave, within a region, and by drip site within a single cave (Hendy, 1971; Mickler et al., 2004; Fleitmann et al., 2009; Markowska et al., 2015; Mickler et al., 2019). Thus, spatial variability in drip-water and stalagmite geochemical compositions can potentially be unrelated to the external climate signal.

In addition, recent studies have further documented that stalagmites are robust archives of paleo-fire activity (e.g., Nagra et al., 2016; Treble et al., 2016; Bian et al., 2019). Given the more than doubling of extreme seasonal fire weather conditions in CA over the past 4 decades (Goss et al., 2020), there is an opportunity to integrate fire-derived proxies into cave monitoring studies in fire-prone regions. Despite the clear research benefits of monitoring cave systems from which stalagmite-based reconstructions are developed, there have been only three cave monitoring studies in California (Oster et al., 2012; Oster et al., 2017; Oster et al., 2020).

Here we present 2 years of monitoring data from Lilburn Cave in Sequoia and Kings Canyon National Parks (herein referred to as "SEKI"). The results from this study are integrated with cave monitoring and precipitation data from Black Chasm (Oster et al., 2012), precipitation monitoring data from SEKI (McCabe-Glynn et al., 2016). Additionally, the results are compared to modeled drip-water and stalagmite $\delta^{18}O_{cc}$ time series, which were produced using the forward proxy system model, Karstolution (Treble et al., 2019). This study provides a monitoring framework that is applicable more broadly to stalagmite studies from other seasonally dry karst systems. Notably, this work was done as part of a vertically integrated mentoring program in which a diverse group of undergraduate researchers were taught theoretical science through experiential learning in the classroom, the lab and in the field (www.blogofbarbarawortham.com). In turn, the undergraduate researchers developed hypothesis-driven research projects as undergraduate theses and mentored younger undergraduate students in the field and in the lab. The data presented here is from these research projects and this article represents a culmination of that effort into one coherent study.

SITE DESCRIPTION

Lilburn Cave, in the Kings Canyon NP portion of SEKI, is hosted in a northwest-southeast trending band of Mesozoic marble bounded by relatively insoluble granite and granodiorite (Tobin and Schwartz, 2012). The majority of Lilburn Cave is developed in calcite marble, although dolomitic marble and limy dolomite marble have been observed (Tinsley et al., 1981). The cave occurs in Redwood Canyon through which Redwood Creek submerges underground to the lowest level of Lilburn Cave, and ultimately resurfaces at Big Spring. Multiple smaller streams feed Redwood Creek throughout the watershed (Tobin and Schwartz, 2012).

In this study of Lilburn Cave, we monitored three drip-water sites, at different levels within the cave, from May 2018 through February 2020 (**Figure 1**). At the shallowest site, Glacier (GC) (~30 m to surface/entrance), a stalactite feeds a small stalagmite and rim pool. We sampled water from the rim pool at the GC site that is directly fed by the stalactite drip. Big Yellow Hungus Thing (BYHT) occurs at mid-level in Lilburn Cave (~61 m below surface) and is a flowstone that is fed by pools, which receive drip-water from the cave ceiling. We sampled BYHT from a 6-inch-wide pool fed directly from the cave ceiling. The third site, Canopy (CP), is closest to the historic entrance in the cave (a sinkhole), is ~61 m from surface, and has a stalagmite fed by drip-water sourced from the cave ceiling (**Figure 1**).

The climate of SEKI is mediterranean with cool wet winters and warm summers. Precipitation is greater in higher elevations in the southern Sierra Nevada, although there is a smaller range in the south than in the northern Sierra Nevada) (Caprio and Lineback, 1997). The climatology from 1981 to 2010 demonstrates that lower elevations in SEKI receive 900–1,000 mm of precipitation annually, whereas higher peaks receive 1,270–1,524 mm (PRISM, 2021). Additionally, annual average temperature from 1981 to 2010 varies from 3.9 to 6.1°C (PRISM, 2021). Snow accumulations in winter are common above 1,515 m (Caprio and Lineback, 1997). Over

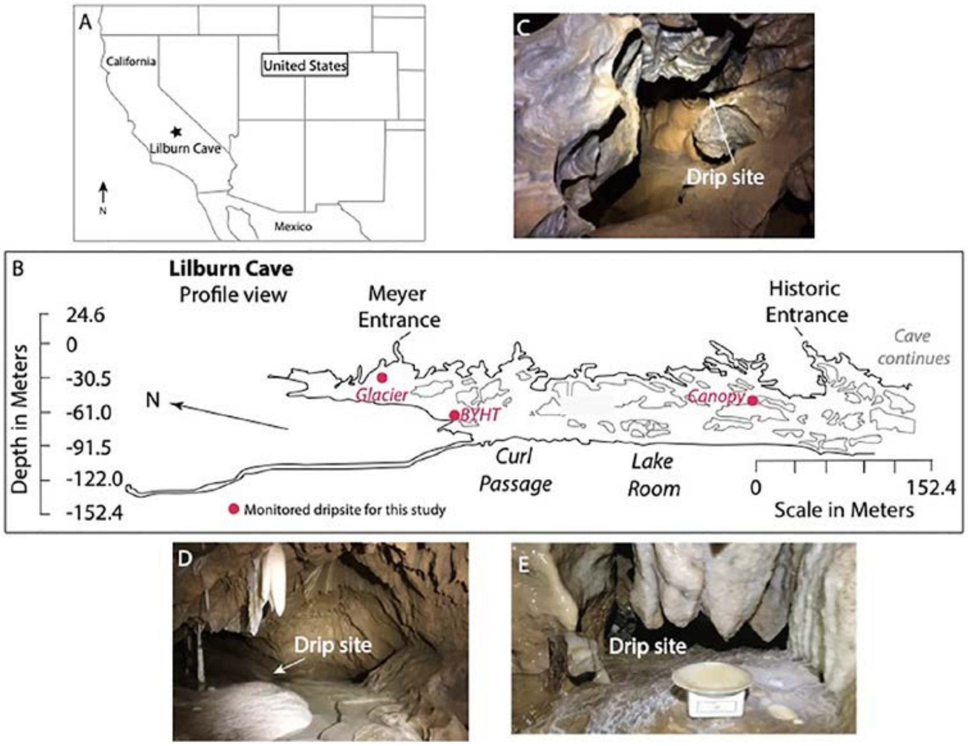

FIGURE 1 | (A) Map of United States and Northern Mexico showing the location of Lilburn Cave. **(B)** Profile map of Lilburn Cave adapted from Mosenfelder et al. (2018). The cave consists of 30 miles of mapped passage and is located within Sequoia and Kings Canyon National Park (SEKI). Sampled drip sites [from shallowest to deepest: Glacier (GC), BYHT, and Canopy (CP)] are shown by the red-filled circles and are distributed between two natural entrances widened by human construction. Meyer Entrance is in an outcrop of rock and Historic Entrance is in a sinkhole. Lilburn Cave remains in a natural state with the exception of the gates placed at the two entrances,. The known extent of the cave and its passages are shown by the black line, unmapped regions or areas that are solid rock are demarked by the gray lines. [Sampling site BYHT **(C)** and site GC **(D)**]. **(E)** Sampling site CP with "farmed" calcite plate and stalagmate drip counter (see Methods).

the monitoring period (2018–2021), the precipitation at Grant Grove Ranger station ranged from 0 to 400 mm with snow accumulation from December through May, typically (WRCC, 2021). Previous studies demonstrate that the Sierra Nevada receive rainfall from the N. Pacific and from the subtropical Pacific (Oster et al., 2009; Oster et al., 2015; McCabe-Glynn et al., 2016).

METHODS

Monitoring at Lilburn Cave sites began in May of 2018. Drip-water was sampled and cave pCO_2 was measured monthly through March of 2020 after which the National Park restrictions in response to the COVID-19 pandemic precluded further access to the cave. Winter sampling (January–May) of Lilburn Cave is excessively difficult due to depth of snowpack and National Park road conditions and/or road closures. Instruments to automatically record cave-air pCO_2 (Vaisala M170), relative humidity (RH) and temperature (Onset HOBO logger model Pro V2) were placed at BYHT from 2018 through 2019. Automated measurements were made throughout this monitoring period. Temperature (via thermometer) and pCO_2 were spot measured by hand every month at GC and CP. Automatic measurements of drip rates (Stalagmate Drip Counter from Driptych) were made at the CP and GC sites throughout 2019. Automated measurements were taken every 12 h between cave trips and were verified with spot measurements during monthly visits. We sampled drip-water at each site for $\delta^{18}O$ and $\delta^{2}H$ and trace element (herein referred to as TE) analysis and for pH, and alkalinity measurements (details in **Section 2**) following the methods of Wong et al. (2011) and Oster et al. (2012). Three water samples were taken at each site during monthly visits: drip-water was collected in 1) clean HDPE 15 ml bottles for TE analysis, 2) clean 2 ml glass vials for $\delta^{18}O/\delta^{2}H$ analysis, and 3) clean 20 ml amber glass vials for alkalinity and pH analysis.

Additionally, surface water samples at the creeks and streams in Redwood Canyon were taken in 2018 and 2020 following the aforementioned protocol and snow samples were obtained in February 2019 and February 2020 following the protocol of Earman et al. (2006). Snow was sampled by digging trenches in snow drifts at the North end of Redwood Canyon and sampling at 6-inch intervals to the ground surface (**Supplementary Figure S1**). Snow samples were sealed in clean sampling bags and taken back to the Sedimentary Geochemistry Lab at UC Davis, where they were slowly melted in sealed containers at room temperature and subsequently sampled as water for analysis.

To understand how the drip-water signal is imprinted in the stalagmite calcite, we placed two sanded watch glasses (10 cm diameter) under the drip at the CP and GC sties (**Figure 1**) in November 2018. Watch-glass plates were used to initiate calcite growth on a material that could be sampled using the approach of Banner et al. (2007). The watch glasses were retrieved in February 2021 and the calcite on each plate was subsampled for analysis of stable isotopic compositions ($\delta^{18}O$ and $\delta^{13}C$), TE and trace metal concentrations. The watch glass from CP was sampled five times along a transect from the center to edge of the calcite growth on the plate, mimicking the subsampling of a stalagmite from the proposed "growth axis" to the outer "flank" of the stalagmite.

The stable isotopic compositions ($\delta^{18}O$ and $\delta^{2}H$) of drip-waters were analyzed at the Stable Isotope Facility, University of California, Davis (UC Davis), and calcite $\delta^{18}O$ and $\delta^{13}C$ were analyzed at the Stable Isotope Lab, UC Berkeley. TE concentrations of waters and calcites (Sr, Mg, Ba, Fe, Mn, etc.) were analyzed at the Interdisciplinary Center for Plasma Mass Spectrometry, UC Davis).

To better understand the drip-water and calcite data, we used the forward model Karstolution (Treble et al., 2019) and the precipitation data from SEKI, measured between 2001 and 2011 (McCabe-Glynn et al., 2016), as well as from Black Chasm (Oster et al., 2012) to simulate drip-water and calcite $\delta^{18}O$ compositions for the Lilburn karst system. We compared the modeled $\delta^{18}O$ time series to the measured values of Lilburn Cave drip-water and stalagmite calcite. Additionally, we calculated a series of threshold ratios for Mg/Ca, Sr/Ca, and Ba/Ca to determine the influence of water-rock interaction (WRI), prior-calcite precipitation (PCP), as well as to assess evidence for incongruent dolomite or calcite dissolution (IDD), following the methods of Sinclair (2011), Sinclair et al. (2012), and Casteel and Banner (2015). We compared these results to thresholds empirically derived concentrations calculated using K_D values for Mg, Sr, and Ba (Sinclair, 2011; Sinclair et al., 2012; Casteel and Banner, 2015).

RESULTS

Results of Lilburn Cave Drip-Water and Calcite Measurements

For all three Lilburn cave sites, air pCO_2, RH, and temperature remain constant throughout the year (Summary: 678 +/− 43 ppm, 100% humidity, 7.4°C; **Supplementary Table S1**). A typical period between when automated sampling devices were deployed and retrieved is shown in **Supplementary Figure S2**. Drip rates at BYHT were not recorded when sampling as the drip-water flowed continuously from the ceiling of the cave to the top of a flowstone. At the nearest site to the entrance, GC (**Figure 1**), the drip rate ranges from the highest recorded value (six drips/second) during March to May and decreases to the lowest values (<1 drips/second) throughout the summer and into the early winter months (June through December) (**Figure 2**). At CP (**Figure 1**), drip rates range from one to three drips/second, with the highest drip rates occurring between March to May (**Figure 2**) and the lowest during August through December. All stable isotope and trace element results are tabulated in **Supplementary Table S2**. Seasonally, the drip-water $\delta^{18}O$ compositions are similar at GC and CP, with the highest values occurring during the autumn and early winter months (September–December). In contrast, BYHT drip-water $\delta^{18}O$ compositions reach their lowest values in autumn and early winter (September–December) and rise to their highest values in the spring (March–May) (**Figure 3**). The single $\delta^{18}O$ measurement of "farmed" calcite grown *in situ* at GC is -8.7‰ and the $\delta^{18}O$ of calcite at CP ranges between −8.6 and −9.4‰ (±0.06%).

Drip-water $\delta^{18}O$ and $\delta^{2}H$ values for Lilburn Cave define a slope and intercept ($\delta^2H = 6.5 * \delta^{18}O–3.4$) that lie between those defined by precipitation compositions from SEKI ($\delta^2H = 7.6* \delta^{18}O + 8.5$), and of surface water from Redwood Canyon ($\delta^2H = 5.4* \delta^{18}O–17.8$) (**Figure 4**). We compare the slopes of drip-water $\delta^{18}O$ and $\delta^{2}H$ compositions to that of precipitation from SEKI for 2001 to 2011 (McCabe-Glynn et al., 2016) as well as to snow and surface water compositions from Redwood Canyon sampled during the period of cave monitoring (**Figure 4**). The slope for the drip water at Lilburn Cave falls between that of the SEKI precipitation and the Redwood Creek stream water. Drip-water compositions do appear to not represent precipitation or surface water alone.

Seasonally, the TE/Ca ratios for CP and BYHT decrease in the autumn, contemporaneously with the increase in autumn precipitation in SEKI (**Figure 4**). The decrease of drip-water TE/Ca ratios at BYHT in the autumn is contemporaneous with a decrease in the $\delta^{18}O$ compositions. Alternatively, the decrease in TE/Ca ratios at CP occurs when $\delta^{18}O$ compositions are increasing. The signatures at GC, however, reveal that drip-water TE/Ca ratios at this site increase in the autumn and mirror an increase in $\delta^{18}O$ compositions (**Figure 4**). The TE/Ca ratios at the three sites each respond differently to the variability in SEKI precipitation. To further examine the source of this variability, we analyzed the relationship between Ba, Sr, and Mg using the approach of Sinclair (2011), Sinclair et al. (2012), and Casteel and Banner (2015). A cross-plot of ln (Mg/Ca), ln (Sr/Ca), and ln (Ba/Ca) ratios in the drip-water of each cave site exhibits calculated slopes that range from 0.8 to 1.1 (**Figure 5**). The Black Chasm drip water slope for Mg/Ca and Sr/Ca is 0.99 (**Figure 5**). Values of Ba/Ca were not measured for Black Chasm.

The TE concentrations from the calcite grown *in situ* at Lilburn Cave are comparable (taking into account K_Ds) to the drip-water concentrations at GC and CP. Sr, Mg, and Ba concentrations in the *in situ* precipitated calcite at the shallowest and furthest sites from the Meyer Entrance (GC and CP, respectively) are comparable to those of the drip-waters from these sites (**Supplementary Table S2**). The concentrations of Mg at these Lilburn Cave sites range from 4,230 to 4,456 ppb at CP and 23989 to 2,790 ppb at GC as compared to 1,092 ppb and 701 ppb in the calcite from CP and GC, respectively. The Sr concentrations in the drip-water at these sites range between 190 and 196 ppb at CP and 110–128 ppb at GC as compared to

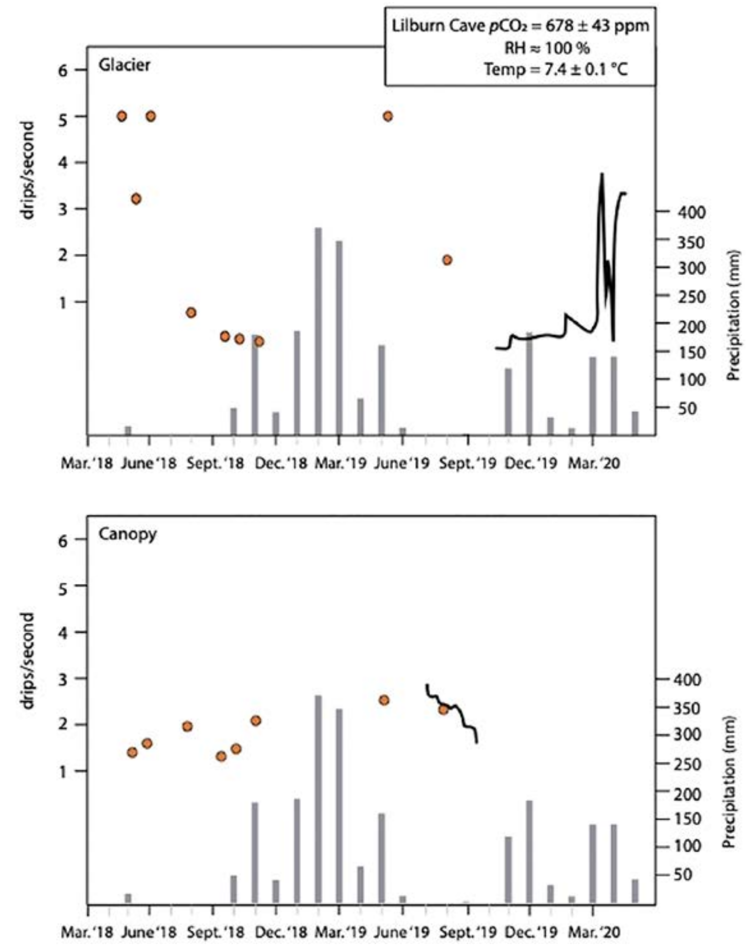

FIGURE 2 | Water data from Lilburn Cave and SEKI for 2018 to 2020. Drip rate counts at Glacier and Canopy sites as spot (orange dots) and automated (black line) measurements plotted against monthly precipitation amount (grey bars) for Grant Grove Ranger Station, SEKI. Sampling at Lilburn Cave in the winter was limited by National Park road conditions and snow levels in SEKI. Lilburn Cave pCO_2, RH, and temperature results from the automated measurements are summarized in the inset and represent the monitored portion of the cave. Spot measurements **Supplementary Table S1**. A typical log file for automated measurements is shown in **Supplementary Figure S3**.

191 and 183 in the farmed calcite from CP and GC, respectively. The concentrations of Ba at these drip sites range between 89 and 102 ppb at GC and between 74 and 83 ppb at CP as compared to 68 and 154 ppb in the farmed calcite from GC and CP, respectively.

The concentrations of less commonly applied trace metals (Cu^{2+}, Mn^{2+}, Fe^{3+}) in the Lilburn drip waters were examined to determine their viability as a new geochemical signal of seasonal recharge in this cave. To evaluate these elements, we compared the seasonal trend in their concentrations in the drip water to the precipitation amount in SEKI. Mn^{2+} concentrations in the shallowest and intermediate depth sites (GC and BYHT) vary seasonally with minimum values (0.0–1.5 ppb) in the spring and summer that increase 2 to 6-fold in autumn (0–3.0 ppb) contemporaneously with an increase in precipitation amount (**Figure 6**). In contrast, the Mn^{2+} concentration at CP is more variable, although there is a rise in values contemporaneous with an increase in precipitation amount, comparable to the other two sites (**Supplementary Table S2**). Cu^{2+} concentrations at all three drip sites exhibit a similar seasonal trend to Mn^{2+} concentrations and increase in concentration in the drip-water synchronous with an increase in precipitation amount. One notable exception is that Cu^{2+} concentrations at all three drip sites double in August of 2019 relative to August 2018 concentrations (**Figure 6**). Fe^{3+} concentrations at all three drip sites are more variable with overall low values through 2018 (~5–10 ppb for the bulk of the dataset) but increase overall (range of ~10.0–60.0 ppb) in 2019. Concentrations of all three metals in the "farmed" calcite at CP (Mn = 4 ppb, Fe = 223 ppb, and Cu = 2.4 ppb) and at GC (Mn =

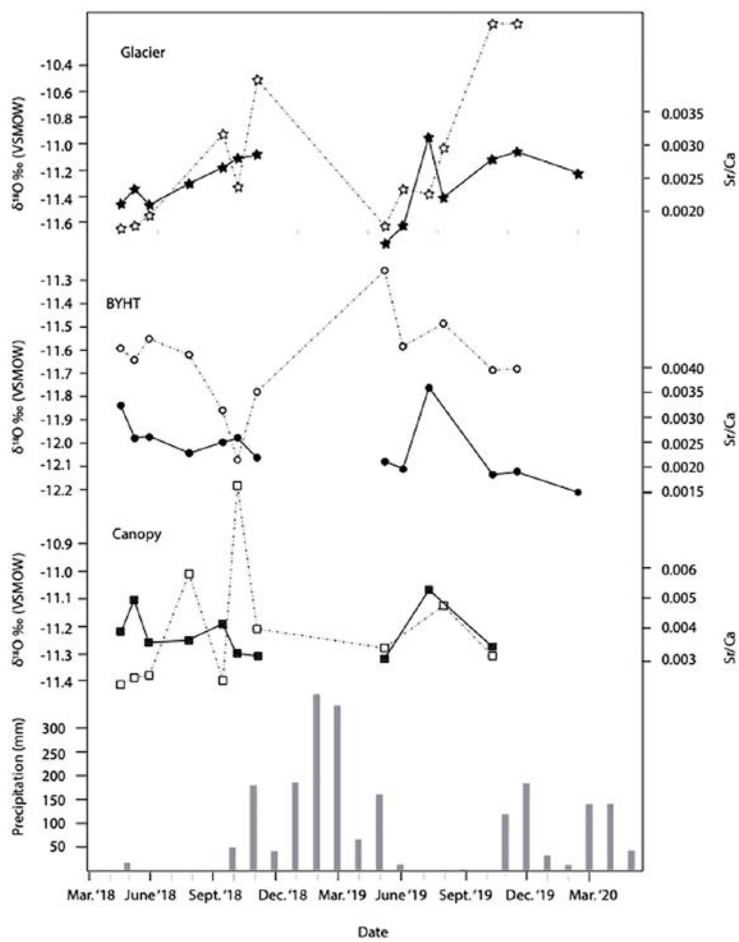

FIGURE 3 | Sr/Ca ratios and $\delta^{18}O$ compositions for the three Lilburn drip-sites. Sr/Ca ratios (filled symbols) are plotted alongside $\delta^{18}O$ compositions (open symbols) for the Glacier (stars), BYHT (circles), and Canopy (squares) sites. Precipitation amount (as in **Figure 2**) ranges from 0 in to 16 inches per month.

2 ppb, Fe = 66 ppb, Cu = 22 ppb) are 10-fold higher overall than drip-water concentrations (ranges listed above; **Supplementary Table S2**) accountable by their K_D values.

Results From a Previous Cave Monitoring Project in the Central Sierra Nevada, California

To further interrogate the Lilburn Cave monitoring results, we compare the data to a five-year cave monitoring dataset from Black Chasm, a cave from the foothills (elevation of 300 m) of the central Sierra Nevada (Oster et al., 2012). To summarize that study, 5 years of drip water monitoring at five sites in Black Chasm, as well as surface monitoring, revealed that Black Chasm has an average temperature of 12.3°C, with 5°C annual variability (Oster et al., 2012). The pCO_2 at Black Chasm ventilates seasonally when cold dense air displaces summer air in the autumn. The relative humidity at Black Chasm varies seasonally but remains >80% through most of the year. Seasonally, the $\delta^{18}O$ of Black Chasm drip water varies in response to changes in precipitation $\delta^{18}O$, with a lag of ~3 weeks, and the precipitation $\delta^{18}O$ varies depending on precipitation source and temperature. The $\delta^{13}C$ and TE/Ca results from Black Chasm reveal that seasonal variability in rainfall amount drives prior calcite precipitation (Oster et al., 2012).

DISCUSSION

Cave monitoring data provides insight into drip-water amount and chemistry variability within a cave system, which reflects the variability of the karst system and can be used to interpret changes in the region when coupled with paleoclimate records from stalagmites. The monitoring data for Lilburn Cave demonstrates that although the cave air conditions (pCO_2, RH,

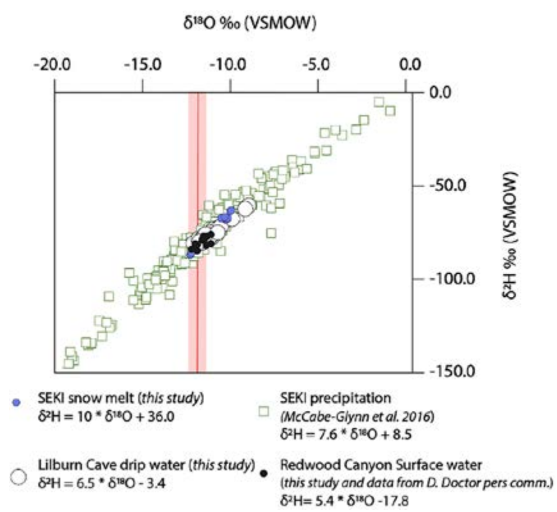

FIGURE 4 | Water $\delta^{18}O$ vs $\delta^{2}H$ values for SEKI and Lilburn Cave. Precipitation $\delta^{18}O$ vs $\delta^{2}H$ from SEKI (open green squares) (McCabe-Glynn et al., 2016) compared to values of melted snow from SEKI (blue circles), surface water from Redwood Canyon (black circles), and Lilburn drip-water (open circles). Associated equations are for the best fit line through the data or the meteoric water line. Drip-water $\delta^{18}O$ values modeled using SEKI precipitation data (green squares; McCabe-Glynn et al., 2016) and the forward proxy model Karstolution is shown as the mean and 1 SD of the values (pink shading and line).

and temperature) remain constant throughout the year, drip rate and the stable isotopic and geochemical compositions of drip waters vary seasonally. We discuss below the seasonal variability at each drip site, integrating each geochemical signal to interpret what process (temperature, precipitation amount, etc.) the drip site may be responding to. Furthermore, we compare the results from this study to drip-water $\delta^{18}O$ compositions and measurements from another monitoring study at Black Chasm to assess the latitudinal differences along the Sierra Nevada. Finally, we compare how measured and modeled drip-water and calcite values compare to evaluate equilibrium conditions at Lilburn Cave. This allows us to separate drip sites that respond to surface processes and those that respond to in-cave dynamics. Trace metals in drip-water have been tested in recent cave monitoring studies as proxies of aerosol contribution to soil (Tadros et al., 2019), prolonged droughts (Liao et al., 2021), and fire influence on drip-water geochemistry (Nagra et al., 2016; Bian et al., 2019). Below, we evaluate Mn^{2+}, Cu^{2+}, and Fe^{3+} in drip water from Lilburn Cave and its relationship to precipitation amount and drought in SEKI.

Understanding Drip Water Variability

The geochemical variability and drip rates at each drip site in Lilburn Cave reveal seasonal variability related to precipitation amount above the cave, and for GC and CP, airflow regimes in the cave (**Figure 3**). Drip rates at GC and CP increases in response to increased precipitation in the autumn and decreases in response to precipitation loss in the summer, albeit with a 3 months time lag. This relationship indicates that drip rates at these two sites respond to precipitation amount above the cave. Variability in Mg/Ca, Ba/Ca, and Sr/Ca ratios in cave drip waters has been attributed to the type and composition of bedrock, soil composition above the cave, the fluid flow-path through the epikarst (i.e., conduit vs. diffuse), and the change in degree of water-rock interaction driven by water residence time in the epikarst. Additionally, the extent of prior calcite precipitation controlled by both water amount and rate of CO_2 degassing impacts water TE concentrations, which may or may not be governed by the same processes controlling water availability, and the incongruent dissolution of dolomite and/or calcite (Fairchild et al., 2000; Fairchild and Treble, 2009; Sinclair, 2011; Wong et al., 2011; Oster et al., 2012; Sinclair et al., 2012; Casteel and Banner, 2015).

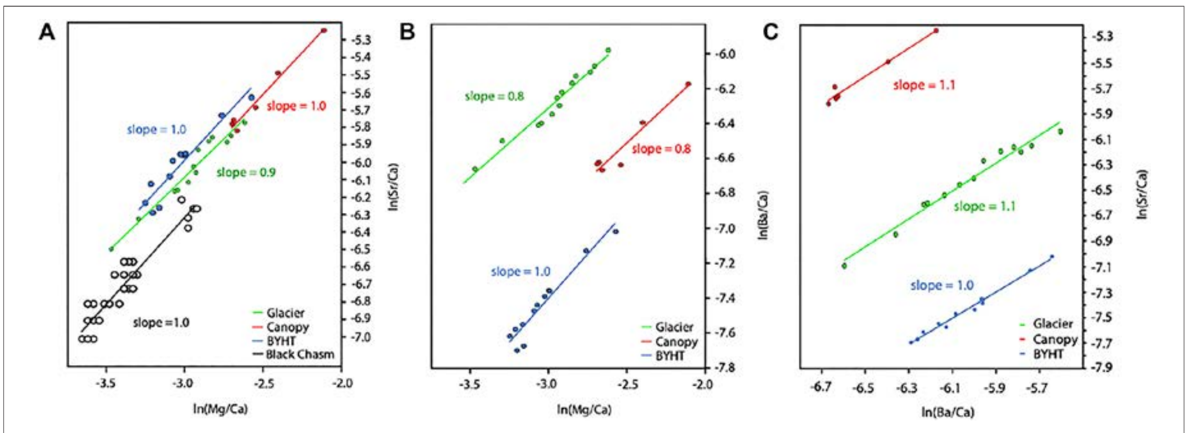

FIGURE 5 | Calculated slopes of trace element/Ca ratios for drip waters from Lilburn Cave and Black Chasm. Best fit lines and calculated slopes for Lilburn Cave drip sites (green, red, and blue) and Black Chasm (black) for **(A)** ln (Mg/Ca) vs. ln (Sr/Ca), **(B)** ln (Mg/Ca) vs. ln (Ba/Ca), and **(C)** ln (Ba/Ca) vs. ln (Sr/Ca).

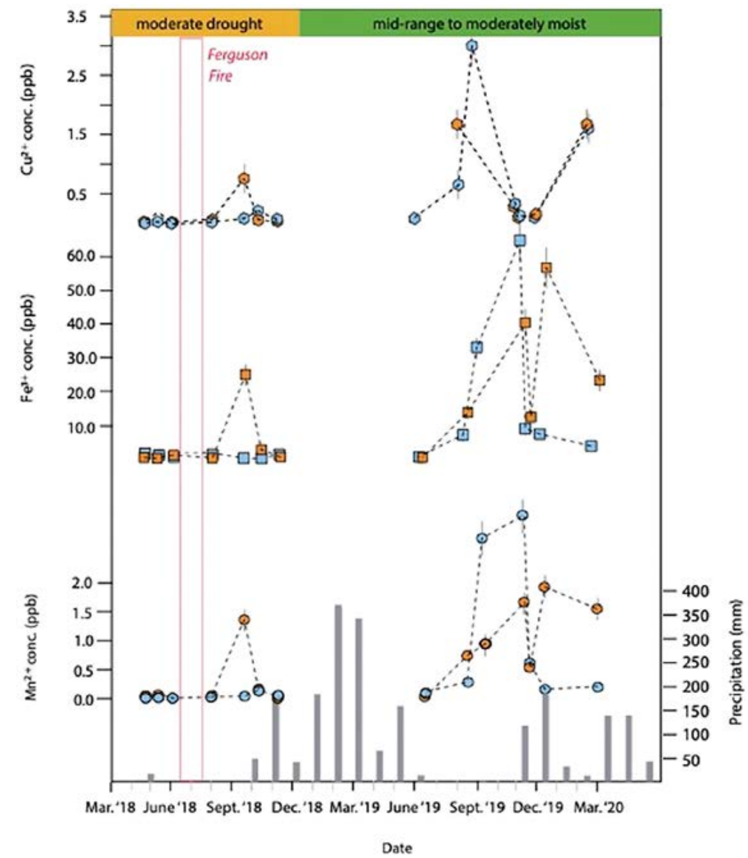

FIGURE 6 | Trace metals in Lilburn drip water. Mn, Fe, and Cu concentrations for the shallowest site GC (blue symbols) and intermediate site BYHT (orange symbols) plotted with precipitation amount (gray bars) at Grant Grove Ranger Station (SEKI) over the sampling period. Red outlined box is the period of the Ferguson Fire (~160 km away from Lilburn Cave). The Palmer Drought Severity Index for the region of Lilburn Cave (PDSI, 2021) is denoted at the top with a moderate drought extending from March 2018 to Dec. 2018 followed by a mid-range to moderately wet period from January 2019 through to the end of the monitoring period (February 2021).

Based on the aforementioned studies, when the TE/Ca ratios are controlled by water-rock interaction and precipitation amount, it is expected that TE/Ca ratios will increase during periods of lower precipitation amount and higher water-rock interaction and/or prior calcite precipitation. We interpret the seasonal trends in TE/Ca ratios at drip sites in Lilburn Cave as responding directly to prior calcite precipitation and/or water-rock interaction driven by local precipitation amount. At CP and GC, the trends in TE/Ca (see Sr/Ca in **Figure 3**) decrease as drip-rate increases as would be expected if the trend is driven by precipitation amount. The same relationship is also observed at BYHT, although no drip-rate information is available for this site. It is notable, however, that the change in TE/Ca ratios at the GC site lags several months behind the change in precipitation amount in the autumn; this lag is not observed at the CP and BYHT sites (**Figures 2**, **4**) that both exhibit changes in TE/Ca ratios directly after the changes in precipitation amount in September and/or October.

Although it is useful to understand the seasonal relationship between precipitation amount, drip rate, and TE/Ca, it is not possible to use these trends to tease apart the separate processes of water-rock interaction (WRI) and prior calcite precipitation (PCP). This is because both can cause seasonal variability in TE/Ca values. To address this, we used a mathematical approach that isolates WRI from PCP and assesses the influence on drip-water Mg/Ca, Sr/Ca, and Ba/Ca values (**Figure 5**) (Sinclair, 2011; Sinclair et al., 2012; Casteel and Banner, 2015). Based on this method, the formula $K_{D\text{-}Sr}-1/K_{D\text{-}Mg}$ -1 or $K_{D\text{-}Ba}-1/K_{D\text{-}Mg}-1$ is used to derive slopes for ln (Mg/Ca) vs ln (Sr/Ca) or ln (Mg/Ca) vs. ln (Ba/Ca) while replacing the K_D values for the appropriate TE/Ca ratio in question. These slopes and the TE data are subsequently used to produce plots that distinguish between PCP or incongruent calcite dissolution (ICD) and WRI in drip-water values (**Figure 5**) (Sinclair, 2011; Sinclair et al., 2012; Casteel and Banner, 2015). Based on these calculations, the TE/Ca ratios for Lilburn Cave and Black Chasm are driven by PCP or incongruent dolomite or incongruent calcite dissolution. Lilburn Cave is mostly developed in calcite marble, although dolomitic marble and limy dolomite marble have been observed (Tinsley et al., 1981). We cannot rule out the influence of incongruent dissolution of calcite or dolomite, by which trace elements (Mg, Sr, or Ba) are dissolved preferentially and result in increased TE/Ca ratios in the drip water. The observation that Mg, Sr, and Ba concentrations vary in the drip water in the same direction at each site (**Figure 5**) cannot be explained by variability in bedrock composition. We propose that the TE/Ca ratios in Lilburn Cave drip-waters primarily record PCP in the epikarst. Furthermore, the "farmed" calcite TE/Ca values indicate that the calcite directly records drip-water TE/Ca ratios (**Supplementary Table S2**), suggesting the high potential for Lilburn stalagmites to record temporal variability in precipitation amount in this cave.

Variability in the drip-water $\delta^{18}O$ values at the three Lilburn sites further document the influence of seasonal variability in temperature and precipitation, and/or continuous CO_2 ventilation. Notably, the drip-water $\delta^{18}O$ and δ^2H values at all three sites are within the range of the precipitation and snow $\delta^{18}O$ and δ^2H in the region (**Figure 4**). The variability in precipitation $\delta^{18}O$ and δ^2H from 2001 to 2011 reflects the large temperature and source variability in storms that arrive at SEKI. Although the precipitation monitoring period does not overlap with the drip water monitoring period, we assume here that the McCabe-Glynn et al. (2016) dataset is representative of potential precipitation variability through the monitoring 2018 to 2021 in the same area. Alternatively, snow and drip-water $\delta^{18}O$ and δ^2H were not as variable during 2018–2021 in comparison to the period 2001–2011 (**Figure 4**). This is likely due to mixing of precipitation from different storm events in the soil, surface water, or epikarst zone. In comparison, drip-water $\delta^{18}O$ and δ^2H is much less variable than precipitation $\delta^{18}O$ and δ^2H at Black Chasm (**Supplementary Figure S2**; Oster et al., 2012), which is interpreted to be due to mixing in the epikarst.

To better understand the seasonal variability in drip-water $\delta^{18}O$ (**Figure 3**), we modeled annually resolved time series for drip-water $\delta^{18}O$ at Lilburn Cave using Karstolution (Treble et al., 2019) to determine the primary influence(s) on measured $\delta^{18}O$ variability. Karstolution is a forward proxy model that includes measured precipitation $\delta^{18}O$, precipitation amount, evapotranspiration amount, and temperature in its parameterization. Furthermore, Karstolution considers evaporative enrichment of water from the soil zone, however, all other processes in Karstolution assume equilibrium fractionation when the RH is set to 95% humidity, a setting that is relevant for Lilburn Cave. Consequently, although calculated evaporative enrichment of the $\delta^{18}O$ composition at the "modeled" surface of the cave, from the soil zone, may be impacting the drip-water compositions from Karstolution, in-cave kinetic effects are not incorporated into the modeled drip-water compositions in this analysis. The model applies a range of processes of mixing and storage and outputs a time series of drip-water $\delta^{18}O$ compositions and five different time-series of calcite $\delta^{18}O$. To parameterize Karstolution, we used the 10-years record of precipitation $\delta^{18}O$ composition and amount data from SEKI (McCabe-Glynn et al., 2016) and corresponding temperature and pan evaporation measurements from a nearby weather station (National Oceanic and Atmospheric Administration (NOAA), 2021). The modeled drip-water $\delta^{18}O$ values from Karstolution are similar in composition to the measured $\delta^{18}O$ in drip water from BYHT year-round and are similar to the measured $\delta^{18}O$ of drip water from GC and CP in the spring months (**Figure 7A**). Accordingly, the comparison between the measured drip-water $\delta^{18}O$ and the modeled drip-water $\delta^{18}O$ indicate that the $\delta^{18}O$ compositions at BYHT are representative of the variability in precipitation $\delta^{18}O$ from 2001 to 2011 in SEKI, precipitation amount, temperature, and evaporation (**Figure 7A**). This is a significant result as this behavior suggests that out of the three drip sites monitored at Lilburn Cave, BYHT may be the most ideal to develop a speleothem paleoclimate record that captures precipitation variability in SEKI. In contrast, the $\delta^{18}O$ compositions at GC and CP are experiencing seasonal enrichment (autumn and early winter) as demonstrated by the increased $\delta^{18}O$ in drip water at these sites in comparison to the modeled $\delta^{18}O$ compositions (**Figure 7A**). It is important to note that precipitation monitoring did not occur over Lilburn Cave during the monitoring period and that the increases at GC and CP could reflect variability in precipitation $\delta^{18}O$ in 2018 and 2019 that was greater than the precipitation $\delta^{18}O$ variability captured in the precipitation monitoring effort from 2001 to 2011. However, given that BYHT matches the modeled drip-water $\delta^{18}O$ results closely, we posit that GC and CP are instead influenced by in-cave kinetic effects or dynamics such as increased airflow as they are near the two entrances of the cave (**Figure 1**). Others have found that increased ventilation near entrances potentially leads to variability in $\delta^{18}O$ of calcite (Tremaine et al., 2011; Oster et al., 2012). The enrichment is due to decreased pCO_2 in well ventilated cave passageways that can lead to increase CO_2 degassing from drip water that rapidly changes the $\delta^{18}O$ values of the dissolved inorganic carbonate (DIC) forcing the DIC pool out of equilibrium (Mickler et al., 2004; Mickler et al., 2006; Dreybrodt and Deininger, 2014; Carlson et al., 2020). Additionally, a decrease in cave air RH can lead to increased evaporation from the drip water, forcing the $\delta^{18}O$ values of the water and the DIC pool out of equilibrium (Mickler et al., 2004). These two cave air parameters are the driving cause of is termed in-cave kinetic effects. Cave air pCO_2 and RH remained constant throughout the monitoring period, however, the pCO_2 in Lilburn Cave remained quite low (average of 678 ppm), potentially due to enhanced ventilation and may have led to the increased $\delta^{18}O$ values observed at GC and CP. Although in-cave kinetic effects have been extensively studied (Mickler et al., 2004; Mickler et al., 2006; Riechelmann et al., 2013) they are mainly relegated as a cause for concern or as a reason to disregard a cave, region, or stalagmite sample. The seasonal signal at these two sites, however, can be reframed as a significant finding as the $\delta^{18}O$ enrichment happens in the autumn season of both monitoring years. Future stalagmites taken from Lilburn Cave, given extensive monitoring to determine the relationship between $\delta^{18}O$, airflow, cave air parameters, and

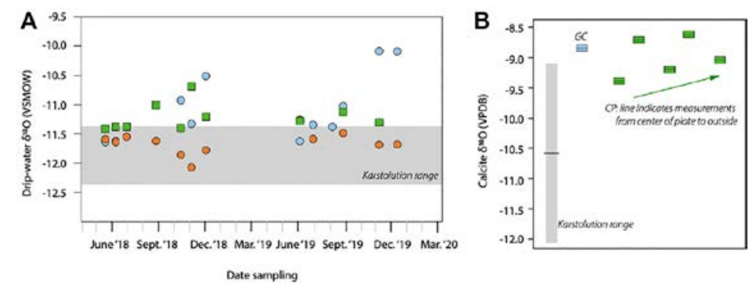

FIGURE 7 | Modeled and measured drip-water $\delta^{18}O$ values for Lilburn Cave. **(A)** Measured drip-water $\delta^{18}O$ values for drip sites GC (blue circles), BYHT (orange circles), and CP (green squares) superimposed on modeled drip water values (gray shading). **(B)** Box plot of modeled calcite $\delta^{18}O$ values (range: gray shading; average: black line) and measured $\delta^{18}O$ values and 1σ uncertainty of calcite grown *in situ* ("farmed") at sites GC (blue box) and CP (green boxes). Green arrow indicates the positionality of the samples on the plate from CP, which are ordered from center **(left)** to outer most edge **(right)**.

precipitation $\delta^{18}O$, could preserve a signal such as that observed at GC and CP that denotes seasonal variability in ventilation. Furthermore, the "farmed" calcite grown *in situ* at Lilburn Cave reveal calcite $\delta^{18}O$ that are similar to the modeled calcite $\delta^{18}O$ from Karstolution, but with an enrichment of ~1% (**Figure 6B**), which would be expected if the $\delta^{18}O$ are impacted by in-cave kinetic effects. Additionally, the calcite $\delta^{18}O$ compositions from CP reveal an enrichment from the center of the watch glass to the edge of the calcite on the watch glass (**Figure 7B**) a finding consistent with the hypothesis proposed by many others that in-cave kinetic effects lead to variable $\delta^{18}O$ of calcite away from the center of stalagmite growth (Hendy, 1971; Mickler et al., 2006; Tremaine et al., 2011; Riechelmann et al., 2013). Consequently, we propose that stalagmite paleoclimate records developed from these sites in the future be used as records of seasonal ventilation or airflow in the cave system but should be treated with caution as records of precipitation $\delta^{18}O$ and temperature.

We further modeled drip-water $\delta^{18}O$ for the central Sierran foothill cave, Black Chasm, using a five-year record of precipitation $\delta^{18}O$ (Oster et al., 2012) and temperature and evaporation data from a corresponding weather station (National Oceanic and Atmospheric Administration (NOAA), 2021). The modeled drip-water $\delta^{18}O$ for Black Chasm agrees with the measured drip-water $\delta^{18}O$ from Black Chasm (**Supplementary Figure S2**) indicating that Black Chasm drip-water $\delta^{18}O$ is not influenced by in-cave dynamics such as low RH or airflow. This is a significant result as it suggests that Black Chasm drip sites are ideal locations for developing stalagmite paleoclimate records of precipitation $\delta^{18}O$ and temperature, as well as site BYHT from Lilburn Cave. Our interpretation is consistent with the original interpretation from Oster et al. (2012) that the cave hydrology, including drip rates, responds immediately (within hours to days) to large precipitation events (Oster et al., 2012). Dampened variability in the modeled drip-water $\delta^{18}O$ compositions for Black Chasm (−10.5 ± 0.6%), relative to the measured values, is likely due to overrepresentation of mixing in the Karstolution model. The comparison of the modeled and measured drip-water $\delta^{18}O$ compositions from Black Chasm and Lilburn Cave reveal that the seasonal enrichment experienced at two sites (GC and CP) and Lilburn Cave is not a regional phenomenon but is instead constrained to these two sites. It is important to note that Black Chasm and Lilburn Cave are separated by 2° of latitude and 4,000 ft of elevation. These differences, however, do not lead to observable difference in the overall variability in precipitation $\delta^{18}O$ (**Supplementary Figure S2**). The elevation and latitude could explain the −1.5% difference in dripwater $\delta^{18}O$ as this is consistent with a lapse rate of −0.35%/km. The explanation, however, could equally be a difference in time between the Black Chasm study and the study presented here. The cross-cave comparisons highlight the need to monitor unique cave environments.

Metals as an Emerging Proxy for Variability in Recharge and Onset of the Rainy Season in Mediterranean Climates

The Lilburn Cave drip water compositions indicate that trace metal concentrations (Cu^{2+}, Mn^{2+}, and Fe^{3+}) may be sensitive to hydrologic recharge in the cave system (**Figure 7**). The increase of Cu^{2+}, Mn^{2+}, and Fe^{3+} concentrations in the autumn suggests that Mn^{2+} is responding to the first available recharge to the system either through increase soil mobilization or through a wash through event by increased recharge in the cave or bedrock system. Additionally, we hypothesize that the change in concentrations of Cu^{2+} and Fe from 2018 to 2019 (**Figure 7**) is due to the region of SEKI experiencing a moderate drought in 2018 followed by a period of greater effective moisture in 2019 (PDSI, 2021). Other studies have demonstrated that these metals are transported and measured in drip waters under peak flow conditions due to the observations that humic-derived organic matter binds metals such as Cu^{2+}, Mn^{2+}, and Fe^{3+} and aides in their transport to the drip site (Hartland et al., 2011; Hartland et al., 2012). We propose that Mn^{2+}, Cu^{2+}, and Fe^{3+} concentrations in drip waters may be a sensitive proxy of recharge intensity and of the onset of the wet season after dry summer months or following a prolonged drought.

These metals can also be concentrated in soils during fire events (Treble et al., 2016) and/or be transported into the cave at a higher rate directly after fire events due to increased recharge

(Treble et al., 2016). Although we know of no proximal fires in the SEKI region during the monitoring period, a controlled burn in Redwood Canyon (2016) may have contributed increased Cu, Mn, and Fe concentrations in the soil above Lilburn Cave. Additionally, the Ferguson Fire (96,901 acres) occurred in Yosemite National Park (~160 km away) in summer 2018, potentially leading to increased aerosols that were transported to SEKI, such as found in other studies (Tadros et al., 2019). Although further work is needed to better understand the transport of trace metals in California cave systems, the observed seasonal trends of these trace metals in Lilburn drip waters and the strong correlation to variability in precipitation amount indicate that increases in the concentrations of these trace metals in drip waters may capture the onset of the rainy season in CA caves. If this hypothesis is shown by further study to be correct, then concentrations of these trace metals in stalagmites would be a critical proxy for reconstructing variability in the timing of the onset of the rainy season in CA, which has been strongly linked to the duration of the fire season (Lukovic et al., 2021; Swain 2021). Moreover, the concentrations of Mn, Cu, and Fe are recorded in the "farmed" calcite from Lilburn Cave at the same levels as they are measured in drip water. The results of this study, despite spanning only 2 years, document that many monitored variables respond to seasonal variability in precipitation amount and temperature. The monitoring results further demonstrate the potential for Lilburn Cave to archive a longer-term record of seasonal variability in stalagmites. Future studies of stalagmites from southern Sierra Nevada caves will benefit from the monitoring study presented in this paper.

SUMMARY

Cave monitoring is a crucial practice to develop and understand paleoclimate reconstructions from speleothems. This study provides a monitoring framework that is applicable to stalagmite studies from seasonally dry karst systems both inside and outside of CA. In this study, we demonstrated that the TE/Ca ratios in Lilburn Cave drip-water and calcite are sensitive to seasonal variability in precipitation amount suggesting that Lilburn Cave speleothems have the potential to accurately record seasonal precipitation changes through time. Additionally, the $\delta^{18}O$ compositions of drip-water at one site is sensitive to precipitation $\delta^{18}O$, however, at two other sites the $\delta^{18}O$ primarily reflects in-cave dynamics, highlighting the need to monitor multiple sites within one cave. Furthermore, trace metals in drip-water from Lilburn Cave are potentially sensitive to the onset of the rainy season in SEKI. Based on this cave monitoring effort, we posit that trace metals and elements are capable of resolving the ambiguity present in studies that focus on paleoclimate reconstructions using $\delta^{18}O$ from speleothems in semi-arid environments. Despite a clear research interest in monitoring the impacts of seasonality on drip-water composition in semi-arid environments, there is to date a relative paucity of monitoring studies for CA karst systems. The results from this study will better inform future work that seeks to provide seasonal context to interpretations drawn from proxy records of stalagmites. Finally, cave and precipitation monitoring studies are an excellent avenue for undergraduate research theses that increase students' retention of geochemical concepts through hands-on learning in the field and the lab.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

BW designed the project, did some of the sampling, some of the analysis, wrote the manuscript, and supervised all other analyses. IM aided in the project design, oversight, and manuscript writing and editing. KB, DK, NC, EB, and AP aided in sampling and in analyses. JT aided in project conceptualization and design as well as in permitting and processes related to the National Park. GR-B aided in sampling and project conceptualization.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2021.781526/full#supplementary-material

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