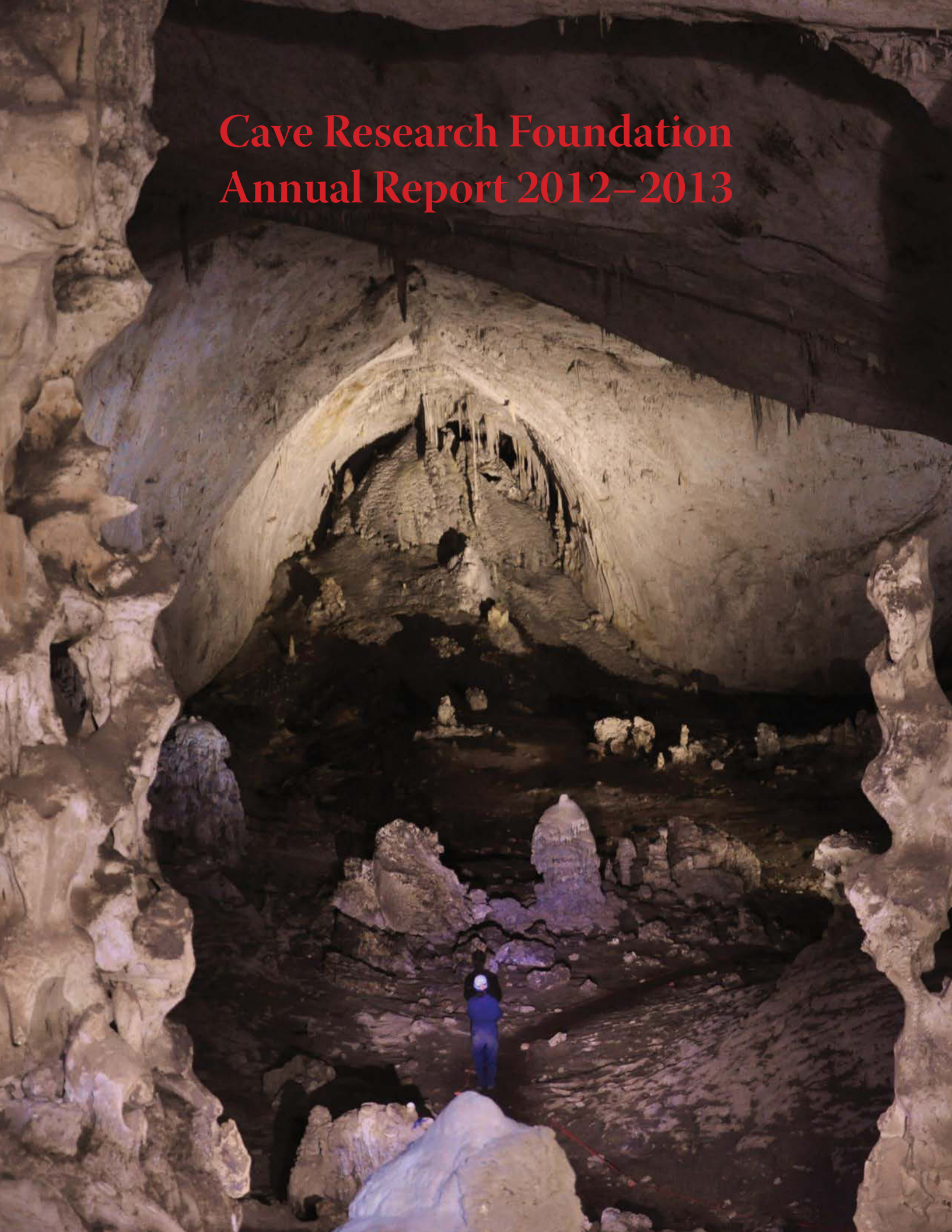
Cave Research Foundation Annual Report 2012–2013



Cave Research Foundation
Annual Report 2012–2013

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 2012–2013 Annual Report

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Front cover photo: The Tom Tucker Room in Slaughter Canyon Cave, Carlsbad Caverns National Park. Photo by Rick Olson.
Back cover photos: *top*, Tony Schmitt afloat in a mine. Photo by Dan Lamping. *Bottom*, Raemy Hinton reading compass in Bruce Hollow Cave, Mammoth Cave National Park. Photo by Ed Klausner.

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Eastern Operations Area

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Cumberland Gap National Historical Park

Ozarks Operations Area

R. Scott House
Mark Twain National Forest
Ozark National Scenic Riverways
Missouri Department of Conservation
Missouri State Parks
Buffalo National Scenic River

Sequoia/Kings Canyon and Mineral King Operations Area

John Tinsley
Sequoia/Kings Canyon National Park

Lava Beds Operations Area

John Tinsley
Lava Beds National Monument

Hamilton Valley Operation

Patricia Kambesis
Hamilton Valley Field Station
Cave City, Kentucky

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Phil DiBlasi

Newsletter Editor

Laura Lexander

Cave Research Foundation Awards

Each year, the Cave Research Foundation awards Fellowship in the CRF to those CRF members who have made significant long-term contributions to the CRF. Individuals who have made significant contributions in a particular area are awarded Certificates of Merit in appreciation of their efforts. The following people have received such recognition, for without their dedication, the work of CRF could not be possible.

EO: Eastern Operations
LABE: Lava Beds Operations
OZ: Ozarks Operations
SEKI: Sequoia Kings Canyon Operations
SW: Southwest Operations

2012 Fellows

Eric Hertzler (OZ)

Max White (OZ)

Charlie Young (OZ)

Mike Tennant (OZ)

Bob Lerch (OZ)

2013 Fellows

Jennifer Hopper (SEKI)

Stuart Daw (EO)

Charles Finney (EO)

Donald Dunham (OZ)

Certificates of Merit

Stu Daw (EO)

Charles Finney (EO)

Karen Masters (SW)

Matt Rasler (SW)

Daniel Greger (EO)

John Feil (EO)

Operations Area Reports

Mark Jones watches Don Dunham enter an entrance to Corral Cave, Lava Beds National Monument. *Scott House*

Eastern Operations Annual Report

Dave West

Eastern Operations Area Manager

2012

Eastern Operations members conducted 121 trips spending 4,545.3 hours on fieldwork, 4,134.3 hours on travel, and 2,171.25 hours on other support for multiple projects at and around Mammoth Cave National Park.

The trips primarily supported cartography in the Mammoth Cave section of the system. Fifty trips went in Mammoth, many focusing on the resurvey of the connection between Mammoth Cave and New Discovery both to support a dive in downstream Roaring River as well as to further define the original very early map. Other areas of work in the Mammoth Cave section of the system included the Labyrinth, Stevenson, Grunge Trail, the Belfry, the Ruins of Karnak, Napoleon's Dome and Carlos Way.

Mark Jones in Roaring River, Mammoth Cave. *Ed Klausner*

Much work was conducted in other areas of the system as well. In Unknown Cave, twelve parties focused heavily on a resurvey of Illinois Avenue, as well as continued efforts in Ralph's River Trail, Bretz River, the Helictite Route and Brucker Breakdown. An additional seven parties conducted survey in Colossal Cave focusing on Davidson and Omega Trails, Colossal and Wretched Rivers, and in the Sandstone Tumbledown. They used the Bedquilt entrance to avoid disturbing the colonies of bats. Five parties worked in Proctor Cave, five more in Salts Cave, four in Donkey Cave (the newest cave to be added to the system), and three in Crystal Cave supported continue survey work as well. Four parties went to Great Onyx Cave surveying the waterfall down to Lucykovah River and the Stairway Crawl.

Eastern Operations has been actively working in other caves in the park as well. Five parties supported the Small Cave Inventory, relocating some of the previously "lost" caves and correcting GPS coordinates. One new cave, which they named Rusty Bucket, was identified and mapped. Three parties went to Sanders Cave for a resurvey of this small cave to support Kurt Helf's studies of biota for Cumberland Piedmont Network, a park services inventory and monitoring network.

Eastern Operations also supported various projects outside of the Mammoth Cave boundaries. Eleven parties surveyed in Roppel Cave, with multiple trips to Snorkland and the area near the Roppel Mammoth connection. On our own property, Roger Brucker led three parties to Adwell Cave pursuing a dig in the effort to extend the cave to the other side of the entrance sink.

Seven parties supported Sarah Arpin, a Western Kentucky University graduate student, in her study of the Haney Limestone caves, which, with a few exceptions, are generally small and wet.

Two parties supporting historic studies, conducted by Stan Sides and Norman Warnell, went to Elmore Cave and Great Onyx Cave.

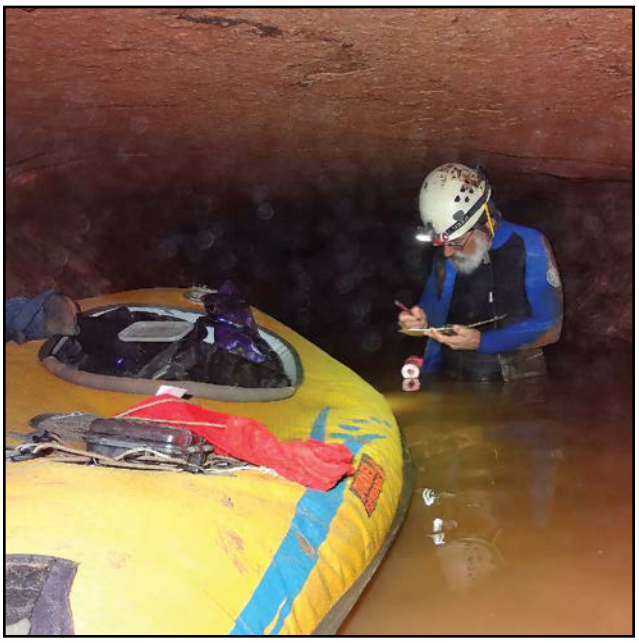
2013

Eastern Operations members conducted 145 trips investing 12,008 hours on support for multiple projects at and around Mammoth Cave National Park.

Eighty trips supported cartography in Mammoth Cave. Forty trips went into the Mammoth Cave section of the

Tim Green surveying in a side passage of Roaring River.
Elizabeth Miller

Elizabeth Winkler in Roaring River. The tape has a piece of styrofoam around it to keep the tape afloat while surveying. *Ed Klausner*



Ed Klausner sketching in a side passage of Roaring River.
Elizabeth Miller

system, many continuing the previous year's resurvey of the connection between the Mammoth and New Discovery areas of the cave to support a future dive trip in downstream Roaring River to survey areas not normally reachable. Other areas of work in Mammoth included the Labyrinth, Gallows Way, Sophys Avenue, Grunge Trail, Hog Wallow Way, Gratz Avenue, River Acheron, Procrastination Pit, Miller Avenue, Sylvan Avenue, and Carlos Way.

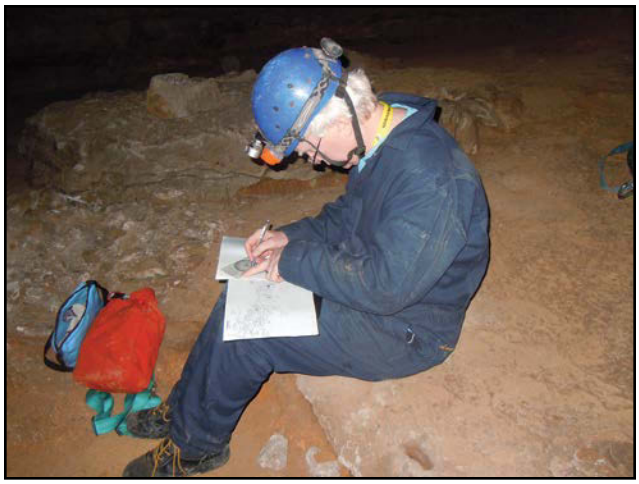
Many parties were sent to other parts of the Mammoth system as well during each expedition. On Flint Ridge, in Unknown Cave, seventeen parties finished a resurvey of Illinois Avenue, as well as continuing survey work in Ralph's River Trail, Pohl Avenue, Mather Avenue, White Way, Faust Avenue, and the X Survey. A survey trip to the Overlook was turned away by high water in Eyeless Fish Trail. One party worked in Proctor Cave, in the Roppel connection area.

Eight parties surveyed in Colossal Cave in Davidson Trail, Colossal and Wretched Rivers, Jones Shaft and the Z Survey. They used the Bedquilt entrance to avoid the bat colony. A party also began a survey of the Hazen entrance to the Bedquilt part of the system. Additionally, in Salts Cave seven parties worked in Pike Chapman, Blue Arrow, Indian Avenue, Salts Trunk, and East Salts. Five parties in Crystal Cave worked in Dyer Avenue, Skyhook Trail, B Trail, and Mud Avenue. Two parties continued the new survey in Donkey Cave. Finally, six parties went to Great Onyx Cave continuing the survey of the Lucykovah River and the Stairway Crawl.

Eastern Operations remains active in discovery and mapping of small caves on the park. New caves are often found in trying to relocate previously known caves that have not been recently visited. For example, Little Piglet Pit, found while en route to Hog Cave, was added to the Small Cave Inventory and surveyed the following expedition. Ridgewalking in Wilson Hollow turned up nothing new, but trips to Turnhole Bend were more successful, including the relocation of Peter Cave. A survey of this cave, which had been reported in 1811 but lost, has begun. A brass cap was installed for the park and the cave cataloged. National

Raemy Hinton reading compass in Bruce Hollow Cave, Mammoth Cave National Park. *Ed Klausner*

Rick Olson surveying in the Historic section of Mammoth Cave. *Ed Klausner*



Charles Fox sketching in the New Discovery section of Mammoth Cave. *Ed Klausner*

Park interns assisted in this and many other survey projects over the year.

Eastern Operations continues to provide support for park projects and research of independent scientists working through the park. The park requested support for Hilary Edginton for her study of salamander DNA, and sixteen parties accompanied her in many of the system entrances and small caves in the park, as well as some of those in Hamilton Valley during the Independence Day week-long expedition. Other park requested support included a trip to Proctor Cave in support of Randy Paylor's geology and hydrology work, a trip to Mammoth to support Horton Hobbs III's biology work, and additional trips to Mammoth to measure discharge at the bottom of the Maelstrom and check the data logger in the drain.

CRF members also provided support to the Lidar scanning efforts, with seven trips to Long Cave, Hickory Flats Cave, Adwell Cave, and of course multiple entrances of Mammoth Cave. With appropriate permissions in place, some of the results may eventually be seen on Animal Planet.

The balance of our efforts was outside the Mammoth Cave National Park boundaries. We continue our active relationship with the Central Kentucky Karst Conservancy's exploration and survey of Roppel Cave where eighteen parties worked in various parts of the cave. One expedition provided logistical and physical support for a successful dive team that replaced a dive line, resurveyed an underwater section, and surveyed Simmons Pit in addition to a lead off Swicegood Avenue.

Roger Brucker led two parties to Adwell Cave continuing a dig begun the previous year in an effort to extend the cave to the other side of the entrance sink. Other work in Hamilton Valley included trips to C1 Cave and C2 Cave to map them. On our non-governmental neighbor's property, we continued our efforts to determine the full extent of Dogwood Cave, Stan's Well, and Hickory Chicken Cave. Four parties supporting historic studies being conducted by Stan Sides went to Colossal Cave (Woodson Adair entrance), Gothic Cave, Pensacola Avenue in Mammoth Cave, and Hog Cave, which was also surveyed.

Additional work outside of the park included a trip to Neal Cave near Bonnieville to assist with a hydrology study, efforts to locate a dry entrance to Whigpistle Cave, which still eludes us, and the resumption of work in Hidden River Cave, with two parties providing survey support there.

Last, but not least, the announcement was made that the system length now exceeds 400 miles, and continues to grow.

Cumberland Gap Project

Federal Fiscal Year 2013 Survey Report

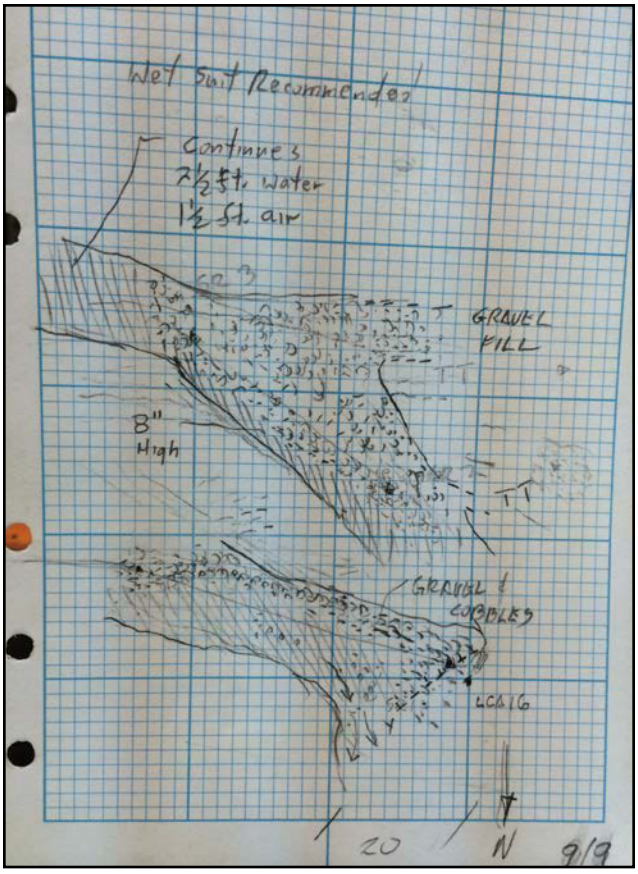
Mike Crockett

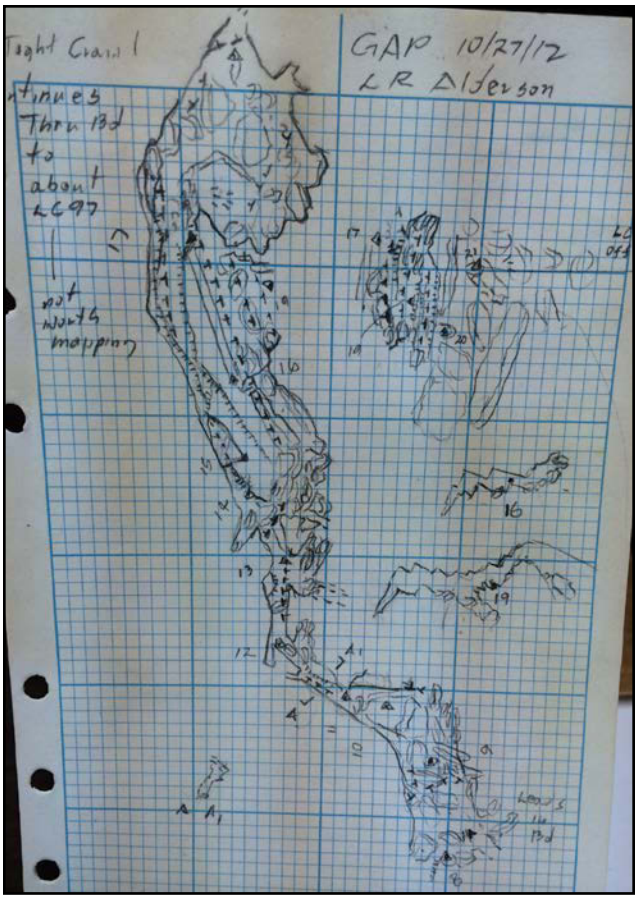
Project Coordinator

This is a summary report from raw unprocessed data using field notes returned from the field.

After each expedition the field notes are delivered to the National Park Service. The NPS scans them and delivers a copy to Project Cartographer Bob Gulden. The survey data and sketches are supplemented with a narrative trip report and processed by the Cartographer.

This report deals only with survey and does not address other project activities. Every survey includes an inventory of features and photographs. The project has an ongoing cultural resources investigation that reports separately. CRF is also involved in community and NPS activities. Examples include: a cleanup at the Cumberland Gap quarry bordering the town and the park was started



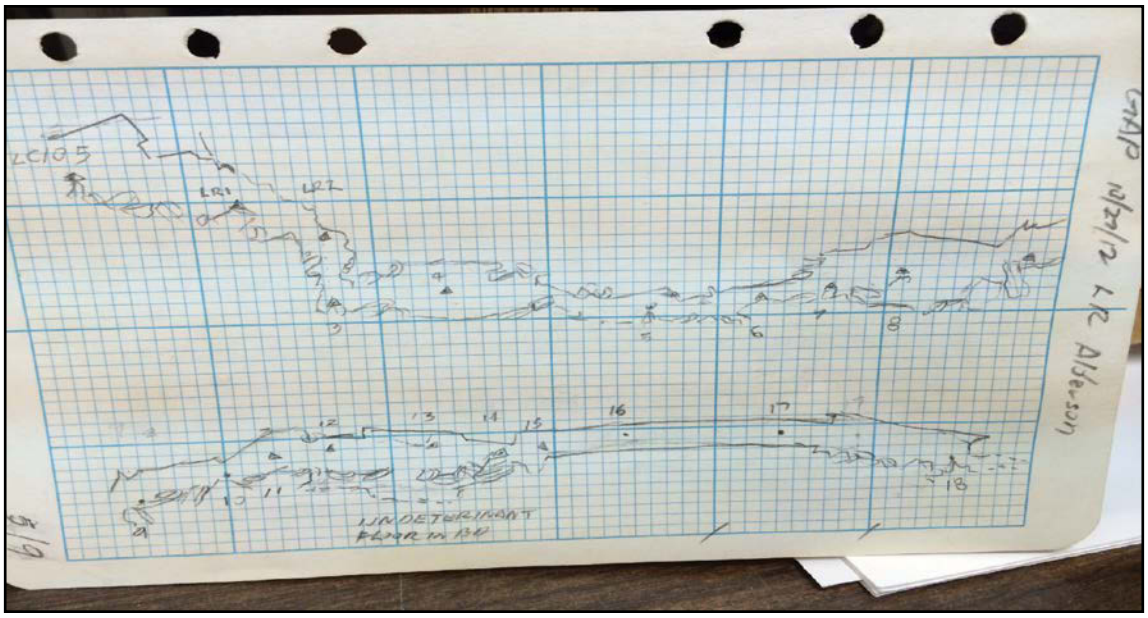


during this year in partnership with the NPS, the Town of Cumberland Gap, and the National Speleological Society Southeast Region Karst Task Force (SKTF). CRF led a Junior Ranger program that allowed youth to earn a badge in cooperation with the NPS. The JR program was called Cave Scene Investigation and was focused on cave and karst exploration and education in the cave.

Most importantly, the survey data is converted into a processed survey plot file and map by the Cartographer.

October 2012

On October 27, 2012 Bob Alderson led Joe Zokaites and Michael Rhinehart to the LC Survey in Gap Cave and added 400 feet of survey.



November 2012

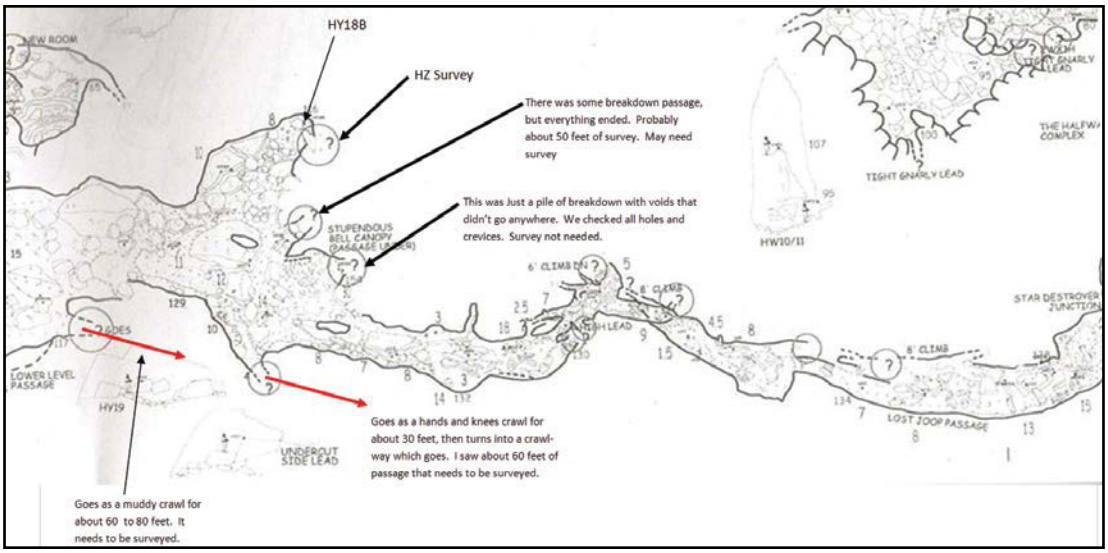
On November 24, 2012 Dave Socky led Micah Davis, J.P. McClendon, Cindy Burback, Janet Manning, and Stephanie Petri to the connection area between Cudjo's Cave and Big Saltpeter Cave to check the map and leads. They completed 200 feet of survey in a room behind the Stupendous Bell Canopy beyond Star Destroyer Junction in the southwest end of the Lost Joop Passage.

December 2012

No expedition.

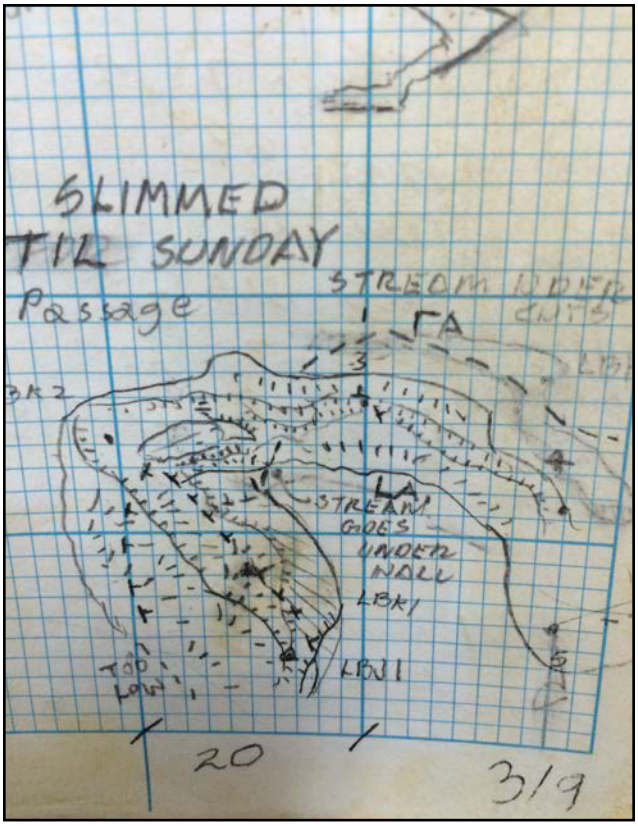
January 2013

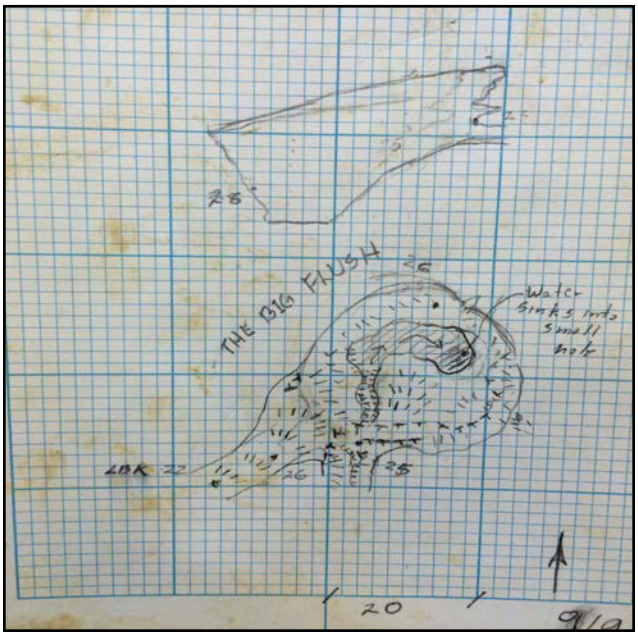
A major ice storm moved across Kentucky and Tennessee on January 25, 2013. North of Cumberland Gap significant snowfall led to the closure of Interstate 75 for a short time in Rockcastle County. South of the Gap one quarter inch of ice accumulated. The National Park Service closed Cumberland Gap National Historical Park. The scheduled Cave Research Foundation project was canceled. A potential first time volunteer supporter traveling from Ohio was called with news of the cancellation moments after being involved in a non-injury auto accident in central Kentucky. The procedure agreed upon with the National Park Service for similar future closures was: end activities in a safe and reasonable manner and leave the Park as soon as possible.

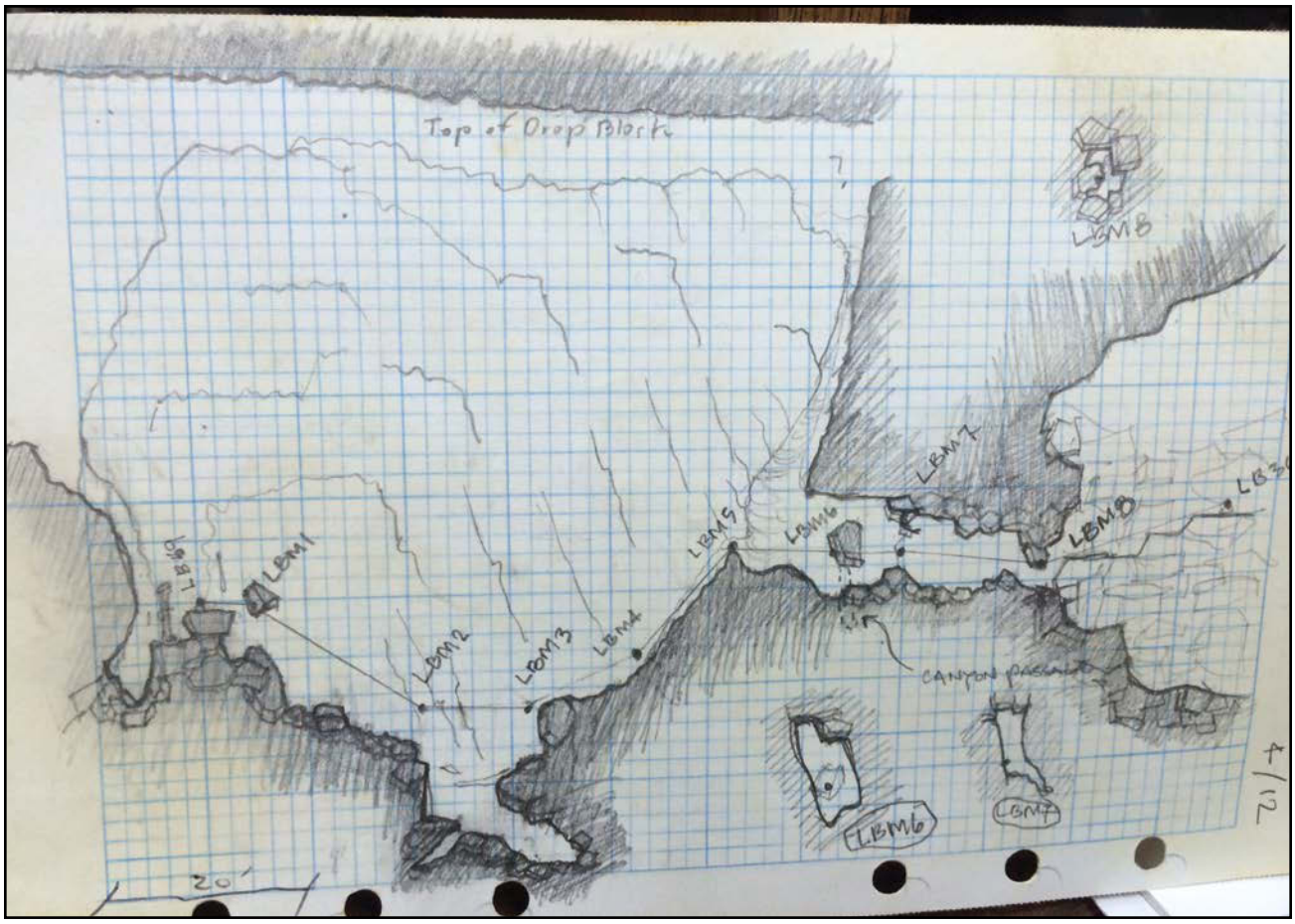


February 2013

On February 23, 2013 Bob Alderson and Dave Socky led Stephanie Petri, Joe Zokaites and Matt Tomlinson to an area below the Big Dork. Socky and Petri surveyed 323 feet in Club Foot Crawl and Did Not Dig. Nearby, Alderson, Zokaites and Tomlinson surveyed 349 feet in Slimed Til Sunday down to The Big Flush.







March 2013

On March 30, 2013 Bob Alderson led Dave Socky, Joe Calderone, and Matt Tomlinson to an area beyond the Big Dork. They surveyed 371 feet at Block Party Drop Block.

April 2013

On April 27, 2013 Dave Socky led Joe Calderone, Michael Rhinehart, and Stephanie Petri to a very wet area in the stream on the HG Survey and completed 462 feet. Meanwhile Bob Alderson led Joe Zokaites, J.P. McLendon, and Micah Davis to a very wet area in the stream on the LR survey and completed 567 feet.

May 2013

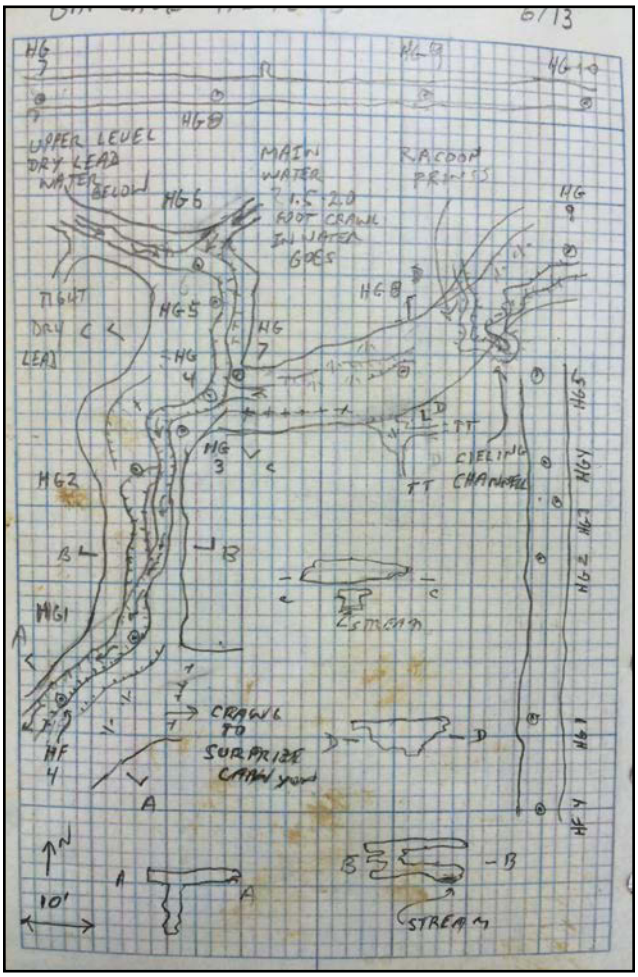
On May 25, 2013 Bob Alderson led Micah Davis and Dave Socky to check leads and the map in the Big Saltpetre Room section. The area they wished to survey was too tight for one of the team members. Map check and 30 feet of new survey was completed. The rigging in the vertical section of the cave was also checked.

June 2013

On June 29, 2013 Bob Alderson led Joe Calderone, Nick Socky, and Dave Socky to Grassy Spring Cave. They surveyed 330 feet of which 312 feet was added to the length of the cave. They left several going leads including a cobble stream crawl at the bottom of a pit with sharp eroded pinnacles.

July 2013

On July 28, 2013 Bob Alderson led Matt Tomlinson and J.P. McLendon to Lewis Hollow Bridge Cave. They completed 345 feet of survey.



August 2013

On August 24, 2013 Bob Alderson led Stuart Daw and Natalie Pheasant to the Walk-In Entrance of Big Saltpeter Cave. They explored the area about 300 feet into the cave from the entrance down a 30 foot drop called the Window Section. They completed cultural resources inventory, map check, and lead check. No survey was completed.

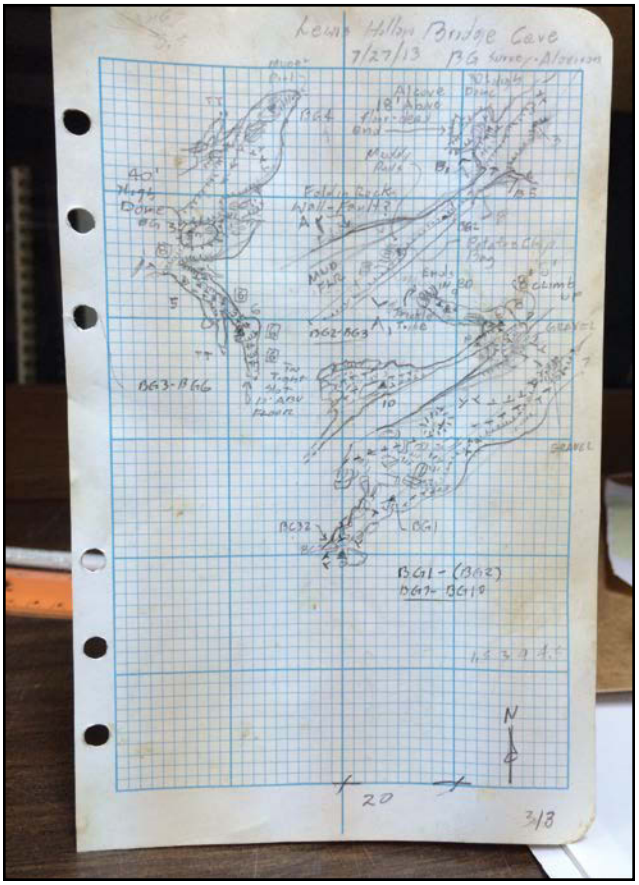
September 2013

No expedition.

Summary for FFY 2013

October 2012	Gap Cave	400′
November 2012	Gap Cave	200′
December 2012	No Expedition	
January 2013	No Expedition	
February 2013	Gap Cave	672′
March 2013	Gap Cave	371′
April 2013	Gap Cave	1029′
May 2013	Gap Cave	30′
June 2013	Grassy Spring	312′
July 2013	Bridge Cave	345′
August 2013	No Survey	
September 2013	No Expedition	
	Gap Cave Total	2702′
	Other Caves Total	657′
	Total Survey	**3359′**

All distances are from raw unprocessed data.



Cultural Resources Survey at Cumberland Gap

FY2013 Activities

Charles Finney

Date	Target	Team	Time	Report	*
2012-10-27	Main entrance area	3	15.8	2012-11-02	A
2012-11-24	Stream entrance & Rat Passage	3	15.3	2012-12-09	A
2012-12-29	Rat Passage & Signature Passage	4	25.6	2013-01-01	A
2013-02-02	Dance Floor & Ante Room	6	25.3	2013-02-07	A
2013-02-23	Stream Passage	6	36.0	2013-03-22	A
2013-04-27	Stream Passage	3	18.5	2013-05-05	A
2013-05-25	Main entrance area to Rat Passage	3	15.0	2013-05-26	A
2013-06-29	Stream Passage	5	31.3	2013-07-14	A
2013-07-27	"A. Willard" & Ante Room/Coke Bottle Room	4	20.0	2013-09-11	R
2013-08-24	Big Salt entrance window drop	3	18.8	2013-09-11	R

Team ***refers to team size, in participants;*** **Time** ***refers to total person-hours in cave.***

** Report status is denoted by* **A** *for* **Activity Report** *or* **R** *for* **Research Report**.

The Cultural Resources Inventory team made 11 survey trips involving 221.6 person-hours in cave. All the trips were in Gap Cave, with all entrances (Main, Stream, Soldiers and Big Salt) receiving at least one visitation. The table summarizes the expeditions along with report dates.

Particular focus was placed on documenting evidence of Civil War and early-settler visitation and relating that to the known historical narrative of the cave as well as the historical and pre-historical context of the local surroundings. Most of the cultural features documented were of the following types: signatures and related graffiti made by inscribing or marking rock surfaces with soot, charcoal, pencil or other dark or colored media; fragments or whole items made of clothing, wood, glass, metal, or other discarded anthropomorphic materials; clay or mud figures, and signs of disturbed soil related to foot traffic or excavations. As much as possible, each documented feature was located approximately (or in some cases precisely) relative to previously marked survey stations. In limited cases, no clear stations were found, and cultural features were located in terms of other prominent landmarks (e.g., stairs or tourist trails). Photographs were made of each documented feature whenever possible.

Although not documented, considerable time (more than in-cave time) was also spent outside the cave researching historical records related to the documented items. These included extensive searches of military and census records, newspaper files, library archives, and interviews with present and past local residents.

Highlights for each trip:

October 27: Several previously undocumented early-1800s signatures were documented just inside the main Gap Cave (lower) entrance (near stations B5 and B6) and in the Pump Room area. Some of the signatures seem to correspond with documented early settler families. Evidence suggests that this may have been on the main route taken by early explorers in Gap Cave.

November 24: Because water levels were low, the stream entrance area was examined, where a few signatures that were not previously documented were observed. Deeper in the cave, near the Rat Passage and around station AC1, several early-1800s signatures were observed, some seeming to correspond with documented area settlers.

December 29: Many significant early-1800s signatures were documented in the entrance area (near stations B5 and B7), the signature area near the Rat Passage, and in the Signature Passage. A prominent '1814' date appeared to resemble one seen in the stream passage near station H10 and is thought to be associated with surveys for nitrate deposits. The 1814 date would appear to correspond to similar dates in the Big Salt portion of the cave where extensive nitre mining took place.

February 02: Many of the signatures on the Pillar of Hercules were documented. Special attention was paid to

identifying stations in the Ante Room and tying in cultural artifacts to these stations (splay shots).

February 23: Several more early-1800s signatures were documented along the stream passage up to station H10. Evidence from at least two early-1900s surveys was observed. A date of '1814' scratched into the mud was documented near H10; the writing appeared to match that seen several other places in the cave and is thought to be associated with surveys for nitrate deposits.

March 30: This was an administrative day to organize data in the digital archives.

April 27: Several early-1800s signatures were documented along the stream passage between the end of the tourist trail and Hellhole. Dark deposits on the passage floor near Hellhole were speculated to indicate some type of burning, but this could also have been associated with some type of mineralization. Attempts to find a prominent signature area seen several years back near Hellhole were unsuccessful; however, future potential leads to this area were identified.

May 25: Several early-1800s signatures were documented both in the connection between the tourist area and the Pump Room (an area known as "The Blast" by early settlers) as well as in the bat-colony area along the stream. A UV light was also used on walls with signatures, with mixed results. It appears that further refinements will be needed to make the UV marking system practical.

June 29: Special UV-florescent paint, with limited visibility in regular light, was viewed (painted onto cardboard and stones taken into and removed from the cave) for possible use in marking survey stations. Visitations up to and around the Hellhole area in the stream passage were documented.

July 27: Park Historian Martha Wiley viewed the signature of "A. Willard", thought to correspond with Civil War soldier Archibald MacNeal Willard of the 86th Ohio Volunteer Infantry, who later painted the famous *Spirit of '76*, as well as early-1800s signatures around B5 and B6, at the top of The Blast. Higher-quality images of interesting features in the Coke Bottle Room were taken for better archival documentation.

August 24: The first drop to the right in the walk-in Big Salt entrance was explored and documented. Many early-1900s signatures were documented, but the objective of finding a connection to Cliff Cave was not realized. Of great significance was the discovery of the signature of Stephen Keyes Fletcher of the 115th Indiana Volunteer Infantry: Fletcher's signature had been seen in the Coke Bottle Room, probably dating from an earlier visitation in June 1862. His published journal documented his cave visits.

The team continues evaluation of previously documented features and investigation of potential connections to historical records outside the cave. All significant findings are reported to the National Park Service.

2012–2013 Lava Beds Operations Summary

John Tinsley

Manager, CRF California Operations

In 2012, a new Memorandum of Understanding (MOU) between CRF and Lava Beds National Monument (LABE) was signed, enabling a way forward and ending a multi-year operational hiatus occasioned chiefly by the expiration of the former MOU. John Tinsley agreed to manage operations at Lava Beds with the idea of organizing future projects there on a proposal-based operational framework, much as has been the case at Sequoia and Kings Canyon National Parks and elsewhere in CRF's operations areas across the United States.

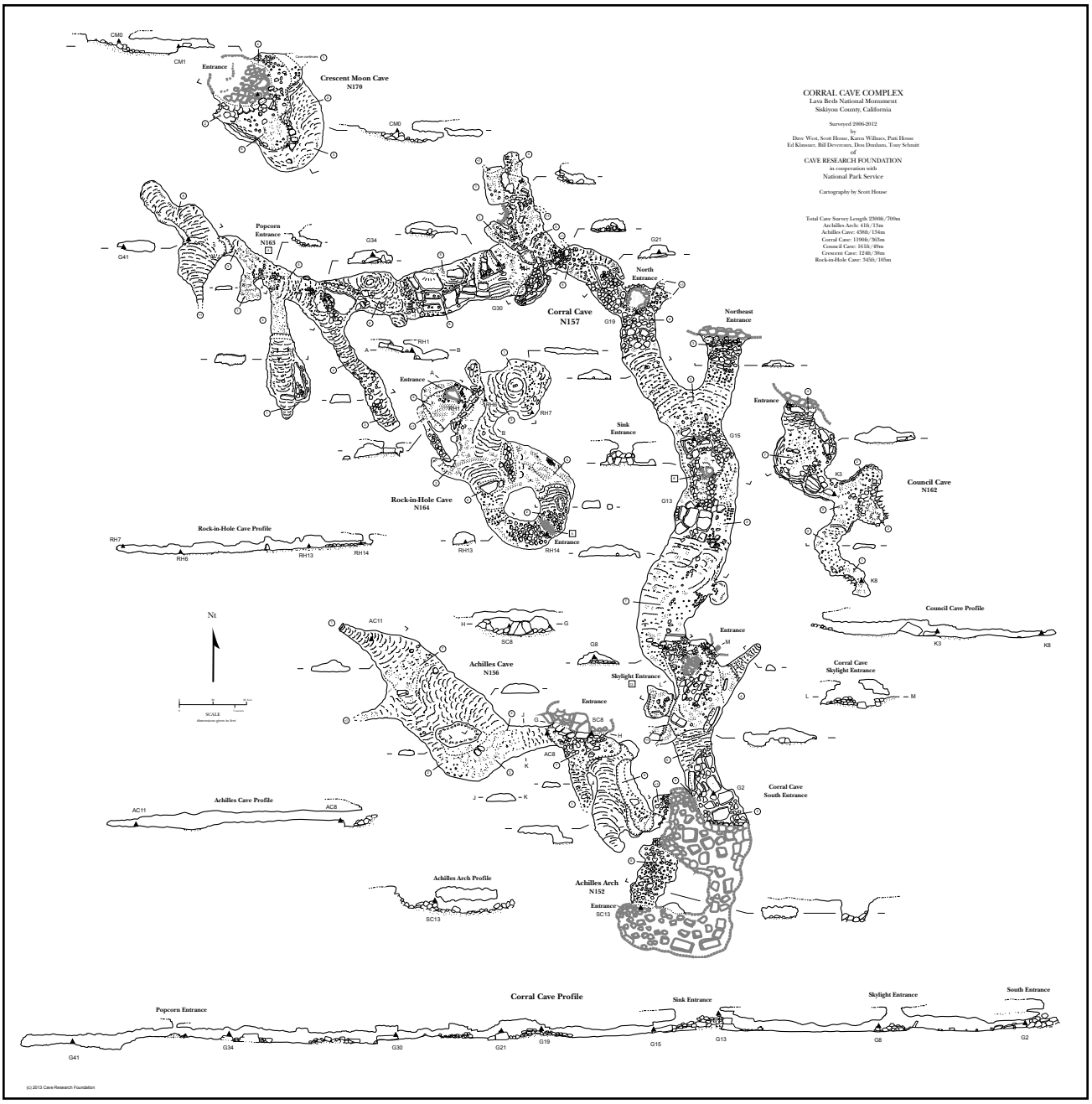
The initial task was to write and submit proposals to LABE management, each proposal to be directed by a Principal Investigator who would be directly responsible for seeing to the completion of the proposed research endeavor to standards and producing final products as specified in the proposal. The initial suite of projects is summarized below; those proposals drew heavily on prior work and expertise among long-time CRF personnel who had worked at LABE since CRF's advent in 1989, and years earlier in some cases. Liz Wolff agreed to be the project's chief cartographer, and we quickly got her RP approved to work on resurvey and exploration of the Monument's Cave Loop caves. Scott House also submitted an RP for caves in the Hardin Butte area, and he and his productive crew saw to it that completed cave maps appeared very quickly. Enthusiastic and insightful NPS management greatly abetted the CRF efforts and a productive partnership is being forged.

Joyce Hoffmaster at one of the entrances to Aladdin Cave.
Scott House

Looking from Hardin Butte toward North Castle Flow. Gillem's Bluff in left background.
Scott House

Present Status

1. Liz Wolff's research proposal (RP) to re-map Cave Loop caves has been approved, is underway, and is rapidly making up for any lost time. Highly productive, Liz has completed at least one major cave per annum for several years, including caves like Catacombs, now Sentinel and Labyrinth, with Paradise Alley and others to follow. There have long been planimetric maps of these caves, but the NPS does not have the survey data, nor are there profiles and cross sections. The caves are important because these are where most of the visiting public goes to tour lava caves.

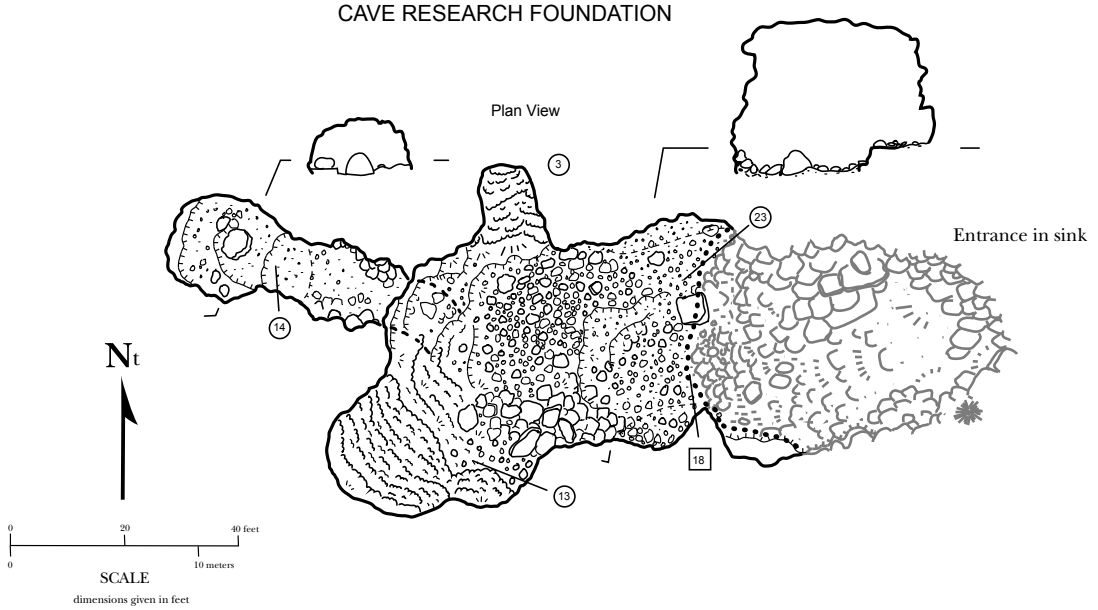


Corral Cave Complex. Cartography by Scott House.

BATTLEFIELD CAVE

(Square Tube Cave)
N010
Lava Beds National Monument
Siskiyou County, California

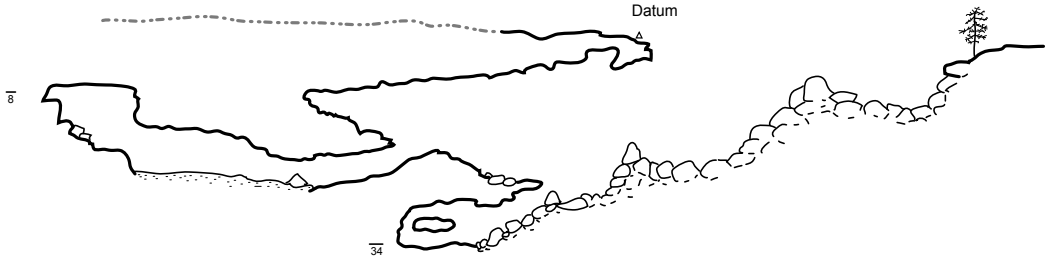
Surveyed 15 May 2012 by
Scott House, Tony Schmitt, Dan Greger, Craig Williams
of
CAVE RESEARCH FOUNDATION



Cave Length 230ft/70m

Cartography by Scott House

Generalized Profile

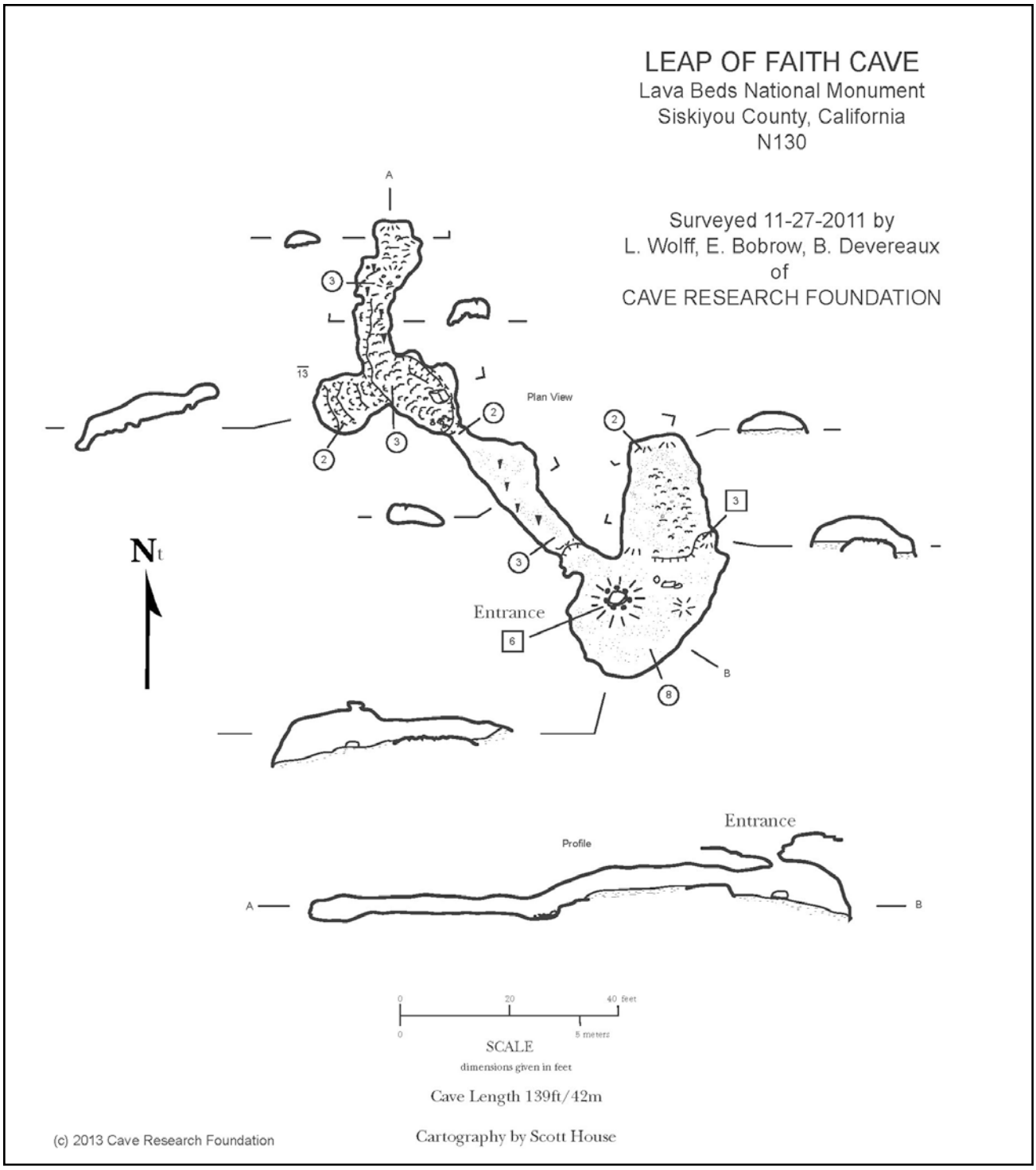


Craig Williams examines artifact in a Lava Beds National Monument cave. *Scott House*

The Elongated Caver. Two NPS seasonal workers at the entrance of Flying Leap Cave. *Scott House*

2. Bill and Peri Frantz are conducting a photomonitoring project focused chiefly on lava tubes designated by LABE Resources Management as targeted for Inventory and Monitoring activities. This project thus continues work that the Frantz's commenced in 1989 when CRF operations at LABE began, then under Janet Sowers' leadership. Archival photos commonly go back to the 1930s at Lava Beds. This project emerges as a marvelous photographic archive and likely will spawn studies of landscape evolution and plant succession as well as cave monitoring. Some issues with the NPS photo database are identified, and not all photos therein are scanned to suitably high resolution; Peri is presently addressing these issues as her time permits. The Frantz's work regularly with physical scientist Shane Fryer and Resources Management to identify new targets and to maintain old "threads" of photos of single sites.
3. Scott House has worked initially mainly at Hardin Butte and environs, but also has initiated mapping at other key caves. Ed Klausner has spearheaded mapping of Post Office cave. Dave West is poised to address the Balcony Boulevard caves and environs.
4. Bill Devereaux maintains the ice cave monitoring program. This database goes back to the late 1970s, long before CRF was active at Lava Beds. A number of the Monument's caves trap cold air in the winter; air circulation is poor, and thus these caves contain perpetual deposits of frozen drip water as formations and floors. With the growing awareness of climate change and its impacts on the environment, the ice caves offer a perspective from which to gauge the problem locally.
5. Bill Broeckel has a long-standing research proposal with Modoc National Forest to map the numerous caves there. So far, Bill's emphasis has been to map caves adjacent to the Monument, caves that are part of the Monument's cave population geologically, but which happen to fall outside the political boundary that was drawn to retain significant timber resources accessible to private interests.
6. John Tinsley is soon to submit a research proposal to map and inventory Craig Cave, a 1800-foot-plus system located in the eastern lobe of the Mammoth Crater flow near the eastern border of the Monument, in a wilderness area. Access requires hiking 1.5 to 3 miles each way from the Research Center, depending upon the route. Work there must respect occupation by hibernating Plecotis (Thompson's Big-Eared Bats). It is a management-critical cave owing to the bats. The system fed much of the lava fields that extend all the way to Tule Lake. As with Cave Loop, there are no survey data nor profiles nor cross sections in NPS files. There is significant scientific potential for study of the eruptive sequence that composed the Mammoth Crater flow system dated about 35,000 years before present.

We continue to explore potential projects and to seek interested individuals to lead those efforts. With more than 700 caves known, and more being found on each expedition, the potential for future productive projects is incalculably huge.


LEAP OF FAITH CAVE
Lava Beds National Monument
Siskiyou County, California
N130
Surveyed 11-27-2011 by
L. Wolff, E. Bobrow, B. Devereaux
of
CAVE RESEARCH FOUNDATION
Plan View
Entrance
Profile
Entrance
SCALE
dimensions given in feet
Cave Length 139ft/42m
(c) 2013 Cave Research Foundation
Cartography by Scott House

Cave Loop Survey Project Annual Report 2012–2013

Lava Beds National Monument

Liz Wolff

Principal Investigator

"Cave Loop" refers to a dense cluster of lava tubes developed in the Mammoth Crater lava flow on the Medicine Lake shield volcano, located west of the Cascades continental volcanic arc of northeastern California. The lava caves are accessed via paved Cave Loop Road and are one of the principal caving areas within Lava Beds National Monument. These caves are often complex, contain multiple levels and display many aspects of lava flow processes, as well as a plethora of features that record the natural and cultural history of the region. In the past 5000 years, Medicine Lake Volcano has had more eruptive activity than any Cascades region volcano, most recently about 1000 years ago (Donnelly-Nolan et. al. (2007).

The Cave Loop Survey Project began following a rescue in 2004 from Catacombs Cave when the rescue crews were given incomplete maps to guide them in their search. A survey project was initiated by the Monument to produce complete detailed maps, vertical information for each cave, and a better understanding of the relationships of the caves to each other. Protocols include taped distances, fore and back sights agreeing within two degrees, inclinometers agreeing within one half degree for each station, LRUD's for each station as well as intermediately for greater detail in the sketch and finished map. The compass and clinometer agreement seems a no-brainer, but lava contains iron and other magnetic minerals to one degree or another, making perfect instrument agreement difficult at best.

The 2012–2013 project work is as follows:

1. Ovis/Paradise Alleys Cave System: This system consists of six separate caves (Ovis, Paradise Alleys, Paradise Annex, Ovis Annex, Surprise, and Buckled) totaling 2150 feet of cave plus surface traverses to tie it all together. Most of the survey was completed over the July 4 weekend 2012. Statistics: 14 trips; 11 cavers; 1859 man-hours; 117 stations on four levels; 12 entrances. System maps are completed.
2. Labyrinth Cave: This survey is in progress; progress is unpredictable, because portions of the cave are closed seasonally in order to protect hibernating or maternity colonies of bats. Labyrinth Cave has three named entrances and two unnamed entrances. To date, total survey is 5445.4 feet in the cave with surface traverses of 1448 feet conducted to complete loops. Statistics: 23 trips; 15 cavers; 2070 man-hours of survey in 10 loops in this aptly named cave. The Lava Brook section of the cave remains to be surveyed.
3. Garden Bridges: This cave complex is a maze of fourteen caves, bridges and two arches with Desert Sweet, Desert Sage and other wildflowers and shrubs growing in the entrances to several of the caves, thus giving the area its name. Surveys from 1999–2007 are being used, which require check surveys in order to ensure accuracy and levels of detail equal to other surveys of Cave Loop caves, yet cutting down on the total survey to be done. Statistics to date: (old) 10 trips; 24 cavers; (new) 8 trips; 10 cavers; 560 man-hours of survey or check surveys.

Reference Cited

Julie M. Donnelly-Nolan, Manuel Nathenson, Duane E. Champion, David W. Ramsey, Jacob B. Lowenstern, and John W. Ewert, 2007, Volcano Hazards Assessment for Medicine Lake Volcano, Northern California: U.S. Geological Survey, Scientific Investigations Report 2007-5174-A.

2012–2013 Ice Level Monitoring in Lava Tubes

Lava Beds National Monument

Bill Devereaux and John Tinsley

The Cave Research Foundation has conducted systematic measurements of ice levels in a dozen selected lava tubes of Lava Beds National Monument (LBNM) since 1990. This data set continues to be collected and maintained, with measurements made in late spring and late autumn at times corresponding to seasonal maxima and minima of ice levels in most Monument caves. Occasionally caves may be added or deleted from the monitored roster per the requirements of Resources Management, LBNM. All considered, these data afford a basis for making comparisons of long-term ice level changes and ice volumes there.

Measurements are typically made at established fixed reference points (usually two points, sometimes more) marked by a screw or pin inserted into the rock wall or ceiling above an ice floor. Using tapes, CRF personnel measure the distance from the reference pin to the ice floor. A decrease in the distance indicates positive ice accumulation; an increase indicates a net ice loss. Time-series analysis can be employed to learn if ice volume is accumulating or waning with time. This set of data is among the longer-lived sets of data at LBNM that has potential to shed light on effects of climate change in Monument lava tubes that preserve perennial ice deposits. A research summary is being prepared by others analyzing these data; we look forward to seeing that article in print in 2014.

Ozarks Operations, 2012–2013

Scott House and Kayla Sapkota

CRF Ozarks Operations continued to be very active in 2012 and 2013, with even more field trips than ever, despite WNS-related restrictions. The approximate breakdown of field trip days by major projects is as follows:

- Ozark National Scenic Riverways cave management, survey and inventory—79
- Mark Twain National Forest gating, survey and inventory—139
- Buffalo National River cave survey and inventory—84
- Berome Moore Cave survey—32
- Pioneer Forest inventory and survey—6
- Missouri State Parks inventory and survey—27
- U.S. Fish and Wildlife Service/ Missouri Department of Conservation mine survey—32

A photogenic snail in an Ozark Riverways cave. *Scott House*

There is some overlap in projects between field trips resulting in a total of 406 field trip days during 2012 and 2013. The field time alone amounted to approximately 15,100 hours. At a modest volunteer rate of $18/hour, that equals a value of over $270,000 in skilled, professional service. And that is without counting the other expenses: more than 300,000 miles driven to and from projects, the person-hours involved in driving, drafting time, time spent writing cave reports, or the subsistence cost of 1350 people-days in the field, only some of which was reimbursable.

The situation with White Nose Syndrome remained a large concern as it has now spread to Missouri. CRF continues to follow the situation closely and to offer advice and assistance to cave managers. In general, caves on public lands remain closed to the general public but open to researchers with considerable safeguards.

Buffalo National River (NPS)

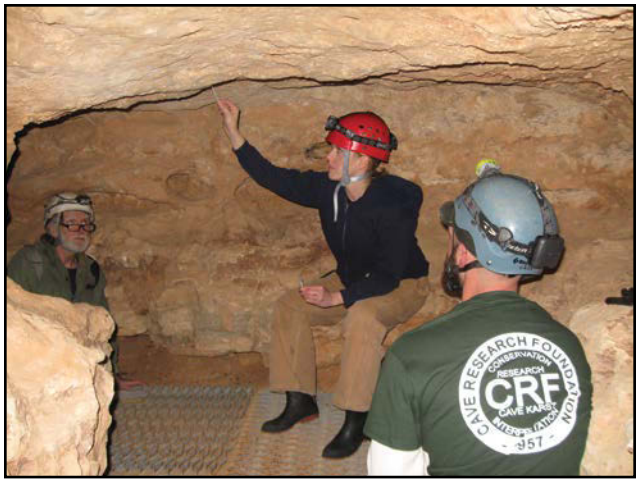
BNR trips were taken monthly from the beginning of 2012 until mid-September of 2013, when CRF was asked to place BNR trips on hold after the discovery of WNS in the state of Arkansas. Trips included surveying of the caves and karst features and monitoring of cave biology and for potential cave disturbance.

Monitoring and surveying of caves in the Broadwater Hollow and Cecil Creek areas continued to be an area of emphasis. The resurvey of the Bat Passage and 21 Jumps sections of Fitton Cave, which is Arkansas's longest cave, was continued from efforts begun in 2008. Trips were also made to survey and monitor various other popular caves in the area. Additionally, a new cave, Blood Root Pit, opened up with the recent heavy rains and was surveyed.

A new area of focus was Big Hollow, which boasts a dense smattering of small caves and karst features. Several caves and karst features were documented, surveyed, and monitored in this area, yielding many new maps. Efforts in Big Hollow are ongoing.

A handful of caves were surveyed in the Boxley Valley area, most of which were dry and short in length. In Lost Valley, the survey of Eden Falls Cave was continued to

Indiana bats. *Scott House*



NPS biologist Kim Houf swabs for WNS in Round Spring Cave, Ozark National Scenic Riverways, as Mick Sutton and Billy Dooling watch. *Scott House*

Dan Lamping and Tony Schmitt prepare to enter Lawrence Hollow Pit. *Scott House*

include a profile, completing the map of arguably the most frequently visited cave. Survey work in Novak Springs continued, bringing the length of this wet, bio-diverse cave to over 2,500 feet.

The resurvey of Copperhead Cave, a formerly frequently visited cave by Boy Scout troops, was completed in 2012 after 3 years of survey. The 1976 map of the cave put its length at 1,812 feet, but the efforts of diligent survey crews brought the final surveyed length to 4,379 feet with 136 feet of vertical extent.

As a result of the construction of a concentrated animal feeding operation on a significant infeeder to the Buffalo National River, focus moved to monitoring and surveying caves in the Big Creek area. Survey was completed in Jawbone Cave, and survey of Tom Barnes Cave was begun. Additionally, smaller caves along the Buffalo National River near the Big Creek infeeder were surveyed and monitored on canoe and kayak trips.

Ozark National Scenic Riverways (NPS)

ONSR projects accounted for a high proportion of CRF-Ozarks field trips; this was made possible through a contract for cave management services, including data acquisition. This highly successful program, headed up by Scott House, emphasized cave monitoring but included cave survey and record keeping. Trips involved large numbers of CRF members from several states. Most of the trips were small but some, such as Martin Luther King Weekend, involved numerous people and parties. A warm winter helped: bat surveyors came out of one Riverways cave in January and promptly washed off waist-deep in the Current River on a 67 degree day.

Shawn Williams emerges from a lead in McCubbin Hollow Cave, Ozark Riverways. *Ed Klausner*

Tony Schmitt examines a newt, rare to most caves. *Tony Schmitt*

One of the surveying highlights was the continuing survey of Bealert Blowing Spring Cave, a long, wet virgin cave that has defied efforts to find an end. Several other wet caves surveyed included Akers Spring Cave and Ditch Cave. Surveying continued in Alphen Hollow Spring Cave, a long stream cave with numerous low-air spaces; several trips also finished up the survey of Sluiceway Cave, an important site on the upper Jacks fork River. And a survey of Wallace Cave, also known as Bob Wallace or Wind Cave, was finally begun; the cave has been known for many years and other maps have been started, but this is the first CRF effort at mapping the cave. Most of these wet cave surveys are on expeditions or trips led by Dan Lamping. Two trips were taken to finish the survey of McCubbin Hollow Cave, and to begin the mapping of nearby McCubbin Spring Cave.

A number of smaller caves were also surveyed, mostly along the upper Jacks Fork River; most are nominally dry but some wetter caves were also done. The survey of one new pit cave was begun on land just outside the boundaries; the landowner was cooperative in facilitating this work on an area that is ranked highly for purchase by a conservation fund.

Most of the trips led into the park were for cave management issues, including restoration, monitoring, gate maintenance, and sign installation. CRF performs the bulk of this "grunt" work in the park, which results in the park having some of the most consistent cave management anywhere. CRF also participated in Junior Ranger Days (a school day) and provided leadership for two university class trips into Round Spring Cave, one from Western Kentucky and the other from Missouri State. Support was also given to CRF fellow John Tinsley's USGS research project on measuring earthquake wave strengths through analysis of broken speleothems.

Don Dunham measures guano in a cave in Ozark National Scenic Riverways. *Scott House*

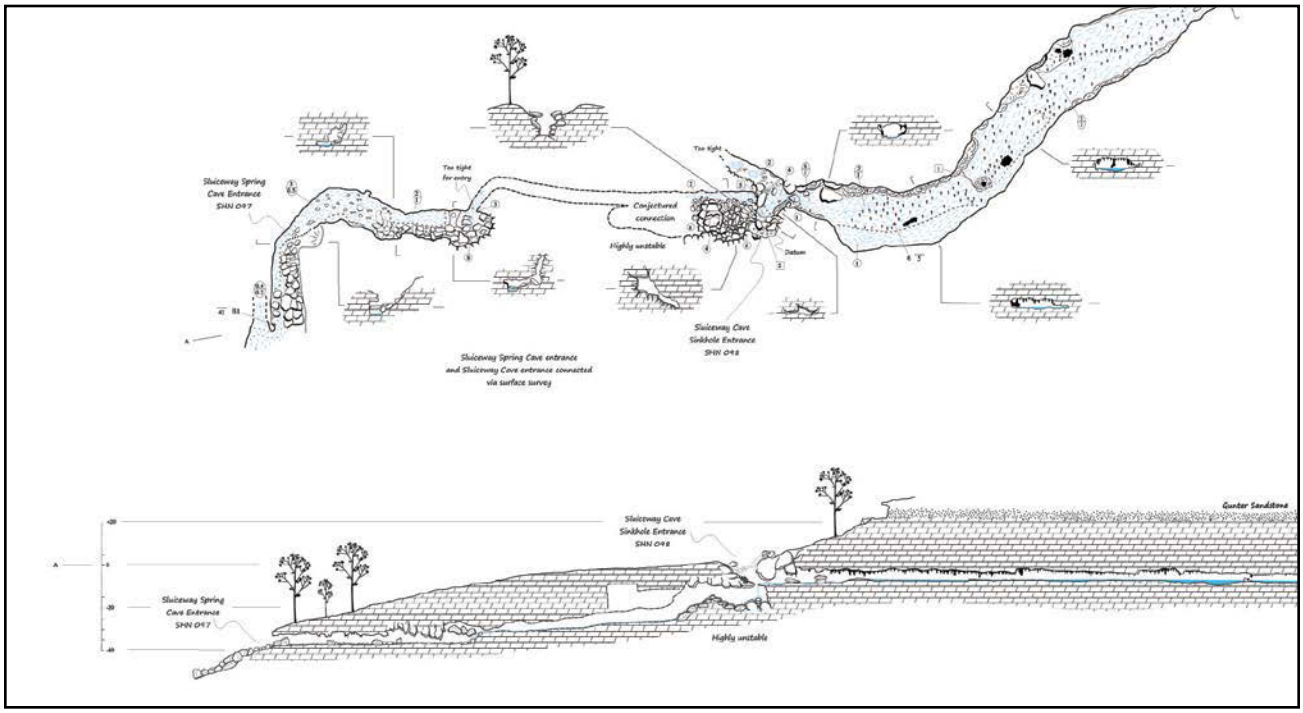
John Tinsley working on a flowstone fragment in an Ozark Riverways cave. *Scott House*

An invasive crayfish in Welch Spring Cave, Ozark Riverways. *Mike Tennant*

The Ozark Riverways/CRF cave office at Powder Mill Research Center. *Scott House*

Numerous monitoring trips counted cave fauna and analyzed human impacts to the caves. A special emphasis was given to examine bats closely to monitor the onset of the insidious White Nose Syndrome. Several days were spent on bat counts of priority hibernacula in cooperation with the Missouri Department of Conservation. One major monitoring effort was taken in Welch Spring Cave, a wet and muddy cave that has numerous records of rare species. One concern noted was that invasive crayfish have moved into the cave, replacing a cave-endemic species.

CRF also helps maintain the Powder Mill Research Center, a former visitor center converted to office, storage, and bunk space; we also keep our cave gating materials at that locale. NPS support includes the research center, office space, cave equipment, computers, and all utilities.



A detail from the Sluiceway Cave map. Cartography by Dan Lamping.

Wilsons Creek National Battlefield (NPS)

One trip was taken to five small caves on this Missouri battlefield in order to clarify names and locations. Some of these caves were new and will need to be mapped and inventoried at some point in the future.

Mark Twain National Forest

CRF operates on the Forest through a cooperative agreement. Much of the work focused on cave resources in the Eleven Point District. Numerous caves were monitored, especially in priority watershed areas. One big surprise came to a CRF monitoring crew when they encountered a bear in an Oregon County cave. After exiting, they screwed up their courage and reentered, managing to get a couple of quick photos of the ursine for verification.

Also in the Eleven Point, one trip was taken to Bat Cave, Oregon County, to assess it for an upcoming gating project. More trips were taken to the cave by Craig Williams and others of the cave archaeology group known as CAIRN, who mostly also belong to and work with CRF. CAIRN also assessed some smaller caves on the district as well. Float trips and extensive ridgewalking added to the number of caves that exist, and quite a few known caves were also monitored.

A major gating effort took place at Bat Cave in late September through early October of 2012. This involved numerous CRF volunteers, other volunteers, AmeriCorps members, and Jim Kennedy of Bat Conservation International. Coordinated by Jim Cooley, the large crew removed an old, inappropriate, gate and installed two gates on the two-entranced cave, including one with a chute to allow gray bat summer use.

In southwest Missouri, efforts also continued in the Ava District. The survey of wet Breezeway Cave in Christian County was completed after additional trips. Survey continued in the Robert L. Taylor Memorial Cave of Christian County and Cane Bluff Cave #2 in Taney County. Numerous monitoring trips and ridgewalking efforts added to the number of FS caves on the district. A group known as the Baldknobbers (basically vigilante-terrorists) that were active after the Civil War utilized caves from time to time, giving their name to a number of caves; two of these were surveyed in recent years by CRF members. CAIRN members visited several caves; one of these was to be gated and they performed an assessment of the resource. Another

CRF, BCI, and AmeriCorps workers at Bat Cave, USFS.

Bringing steel for a gate at McCormick Cave. *Jim Cooley*

archaeological assessment was done for a cave within an official roadless area.

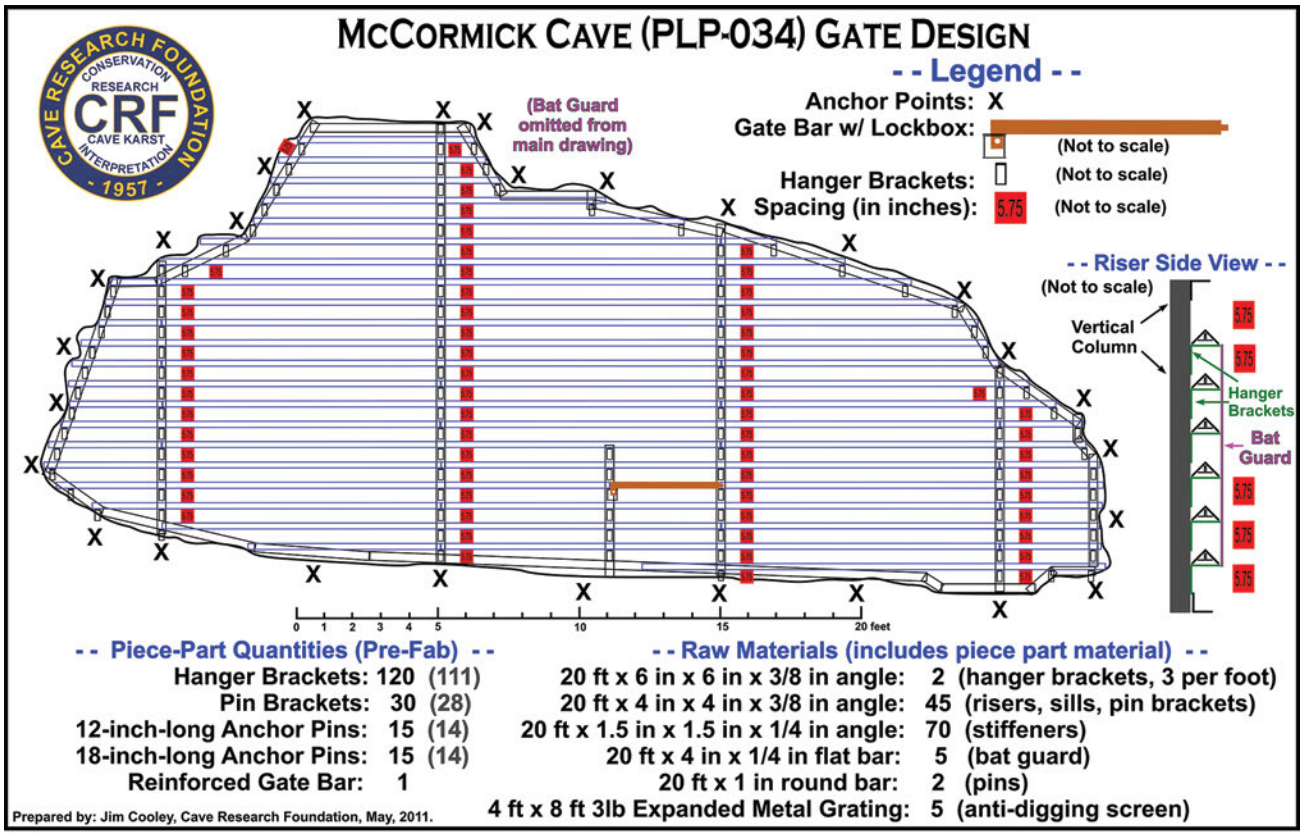
Rattlesnake Cave, also on the Ava, was gated by CRF in a well-planned effort. The weather did not cooperate, leaving some of the people working on the gate camping out in the snow.

On the Cassville Sub-District, a couple of smaller caves were surveyed and more were found as the result of some ridgewalking efforts.

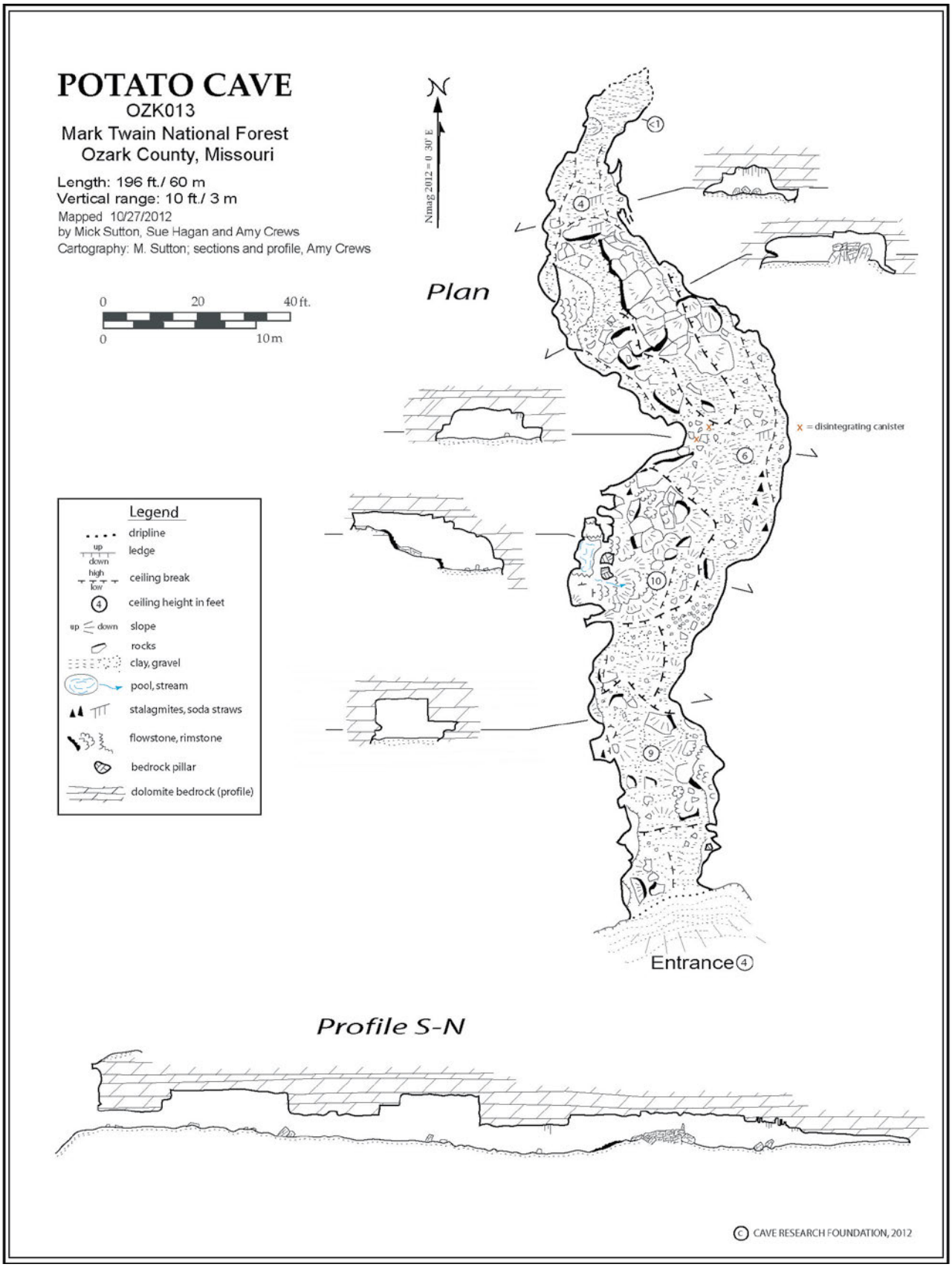
Additional cave maps and inventories were completed on the Willow Springs Sub-District, Potato Cave being one of the more important surveys finished.

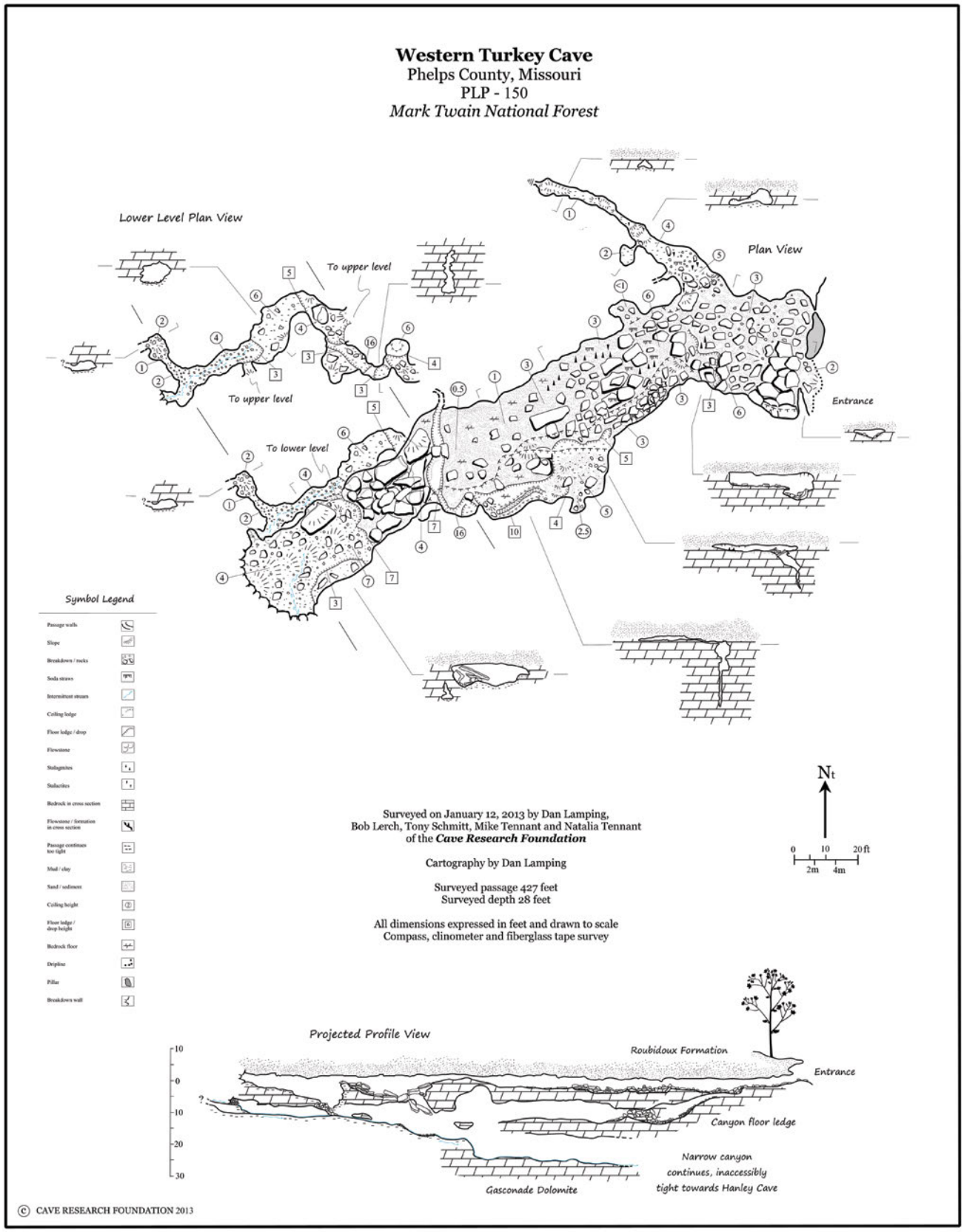
On the Houston-Rolla District, mapping was completed in Yancy Mills Cave. A major cave gating effort at McCormick Cave, led by Jim Cooley, resulted in the replacement of a cement block wall with a bat-friendly gate. This restored the entrance and twilight zones of the cave; it will be interesting to compare before and after biology counts in the cave over the next few years. Some of the same, large crew also fixed the gate on Onyx Cave while they were afield with plenty of equipment.

A long-missing cave, reported to have been bulldozed while under private landownership, was finally relocated although it remains un-enterable. A number of additional

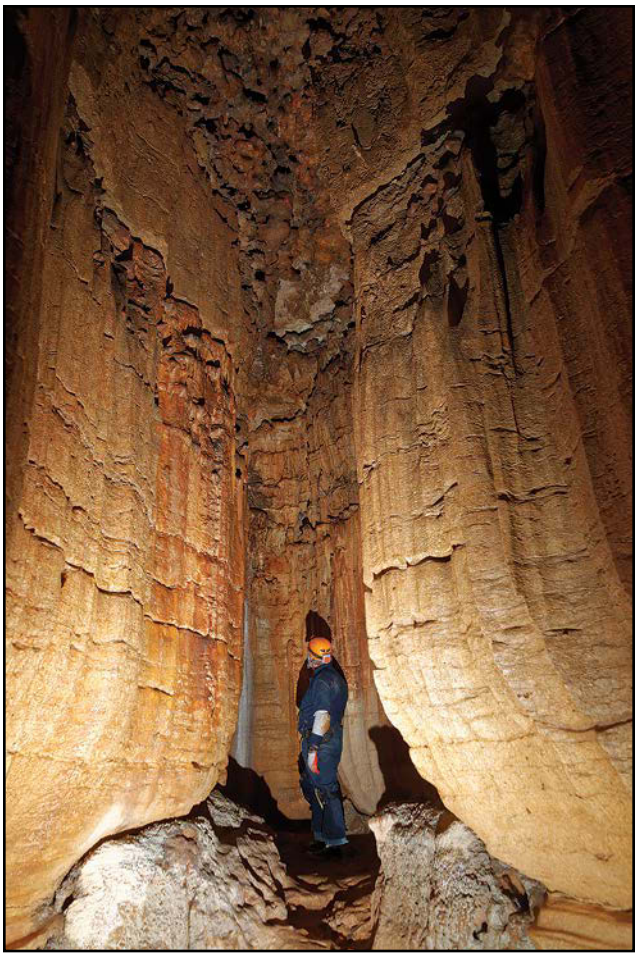


Gate design for McCormick Cave by Jim Cooley.


POTATO CAVE
OZK013
Mark Twain National Forest
Ozark County, Missouri
Length: 196 ft./ 60 m
Vertical range: 10 ft./ 3 m
Mapped 10/27/2012
by Mick Sutton, Sue Hagan and Amy Crews
Cartography: M. Sutton; sections and profile, Amy Crews
N
Nmag 2012 = 0° 30' E
0 20 40 ft.
0 10 m
Plan
x = disintegrating canister
Legend
dripline
ledge
ceiling break
ceiling height in feet
slope
rocks
clay, gravel
pool, stream
stalagmites, soda straws
flowstone, rimstone
bedrock pillar
dolomite bedrock (profile)
Entrance
Profile S-N
© CAVE RESEARCH FOUNDATION, 2012


Western Turkey Cave
Phelps County, Missouri
PLP - 150
Mark Twain National Forest
Lower Level Plan View
Plan View
To upper level
To upper level
To lower level
Entrance
Symbol Legend
Passage walls
Slope
Breakdown / rocks
Soda straws
Intermittent stream
Ceiling ledge
Floor ledge / drop
Flowstone
Stalagmites
Stalactites
Bedrock in cross section
Flowstone / formation in cross section
Passage continues too tight
Mud / clay
Sand / sediment
Ceiling height
Floor ledge / drop height
Bedrock floor
Dripline
Pillar
Breakdown wall
Surveyed on January 12, 2013 by Dan Lamping,
Bob Lerch, Tony Schmitt, Mike Tennant and Natalia Tennant
of the Cave Research Foundation
Cartography by Dan Lamping
Surveyed passage 427 feet
Surveyed depth 28 feet
All dimensions expressed in feet and drawn to scale
Compass, clinometer and fiberglass tape survey
Nt
0 10 20 ft
2m 4m
Projected Profile View
Roubidoux Formation
Entrance
Canyon floor ledge
Narrow canyon
continues, inaccessibly
tight towards Hanley Cave
Gasconade Dolomite
10
0
-10
-20
-30
© CAVE RESEARCH FOUNDATION 2013

Bright Hollow Blowing Cave, Mark Twain National Forest.
Matt Bumgardner



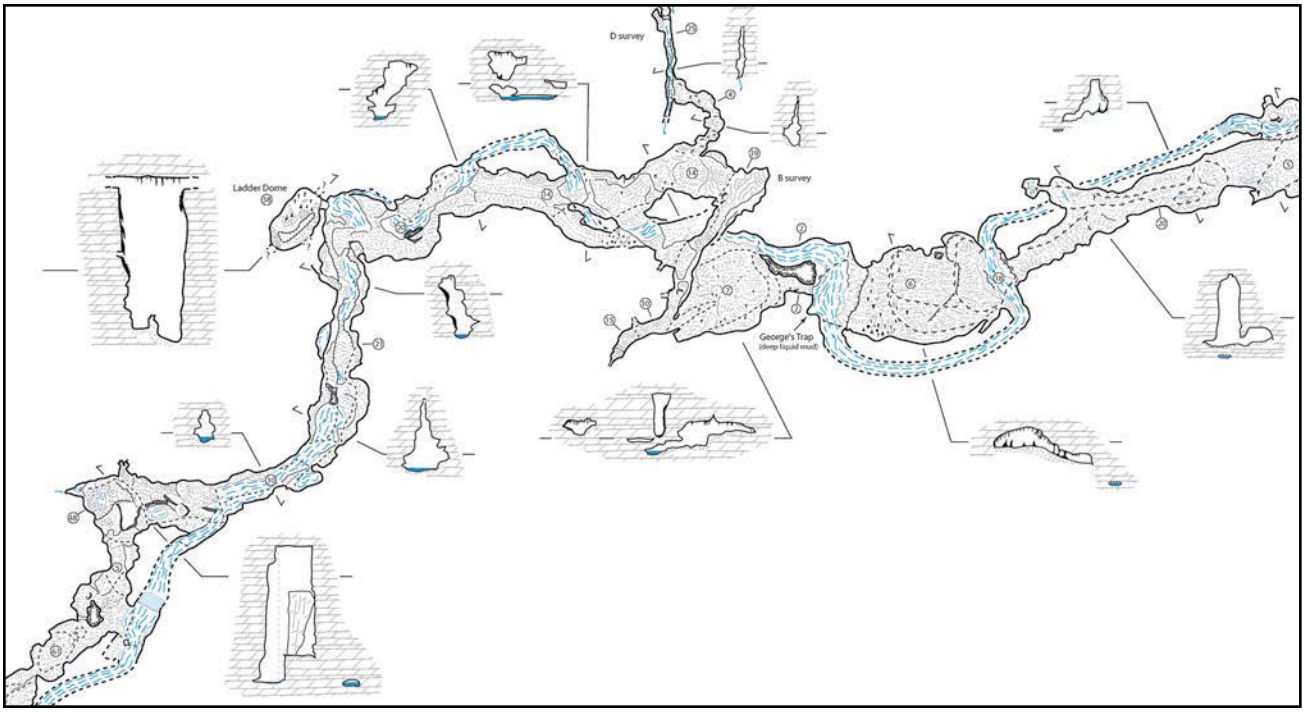
caves, including some important archaeological sites were monitored by a variety CRF members plus CRF-affiliated grotto cavers, from Rolla and St. Louis. A cave known as Western Turkey was surveyed; it lies above a previously known cave and is linked hydrologically. Another cave, located within a wilderness area, was monitored and turned out to be a major pipistrelle hibernaculum. Well-known, albeit short, Venable Cave was also surveyed.

One dive trip was taken to monitor visitation and life in Stone Mill Spring, Pulaski County.

Field work on the Fredericktown District included trips to plan the upcoming gating of several historic silver mines. And survey was renewed in a cave complex on the St. Francois River, nearly finishing that remote site which lies within a wilderness area.

In the Salem District, several important caves were monitored. After several additional trips, the mapping of Washington County's Chimney Cave was completed, led by Mick Sutton. Mick also led the survey of a cave complex on Sinking Creek; later another cave in the same area was also mapped. And a new map of Reno Cave was made, along with a resource inventory.

A detail from the Chimney Cave map. Cartography by Mick Sutton.



North of the Missouri River is one small chunk of the forest: the Cedar Creek Sub-District. A group of CRF-affiliated cavers from Chouteau Grotto monitored three caves on this interesting area.

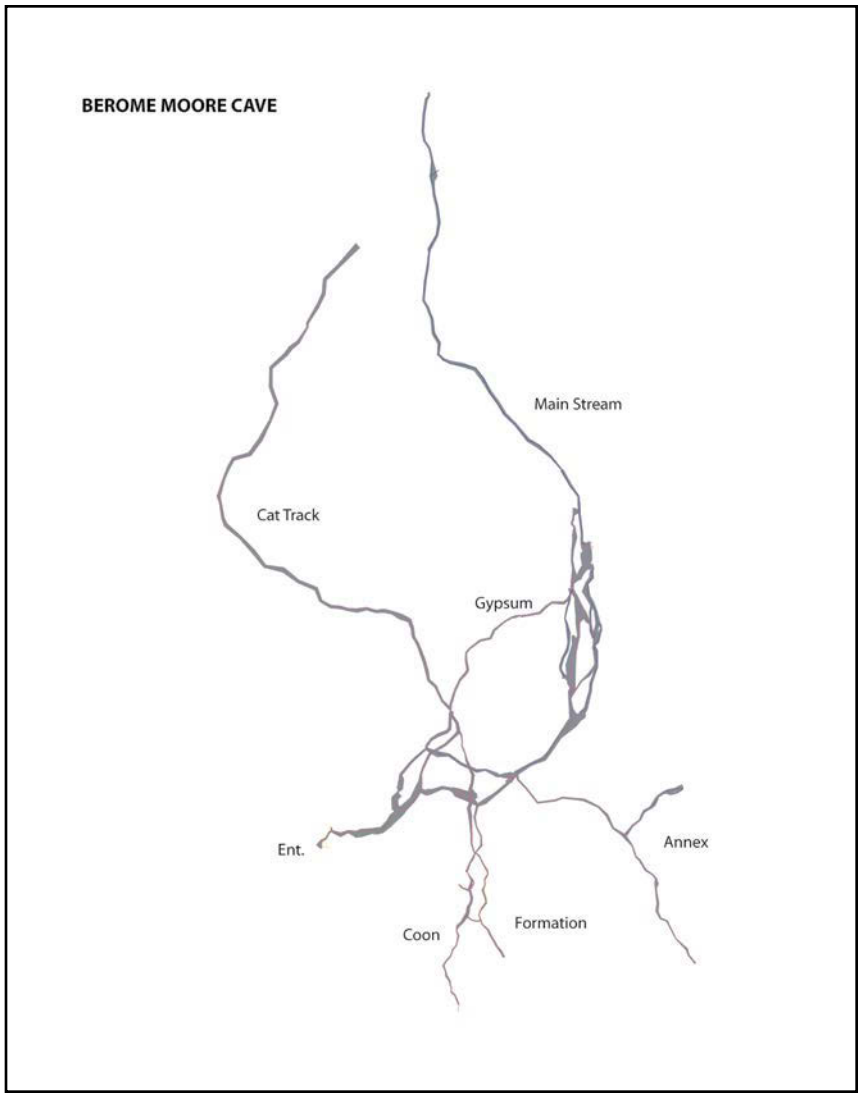
Berome Moore Cave

The Berome Moore Cave system is one of four large systems in Perry County, Missouri. The cave, which may be as long as twenty miles, was purchased by the Missouri Cave and Karst Conservancy and is managed by MMV Grotto of St. Louis. CRF is leading the resurvey effort of this large and important cave. During 2012–2013 more than thirty survey trips were taken. Sketchers include Scott House, Bob Osburn, Jon Beard, Dan Lamping, Paul Hauck, Andy Free, and Mike Tennant. Scott House is reducing the data, and Paul Hauck is drawing the map.

U.S. Fish and Wildlife Service

A large, hitherto unknown, hibernaculum was discovered by a caver who was checking an abandoned limestone mine for bats. Preliminary investigations revealed it to be a major colony. It soon became apparent that navigating the maze of the mine was not for the faint of heart. For this, and for reasons of plotting locations of bats, CRF was called into action to survey the mine. Funds were provided by USF&WS, through the Missouri Department of Conservation, and directly from the Cheyenne Mountain Zoo of Colorado; these funds covered new (i.e. clean) equipment, plus some salaries, travel, food, and housing expenses.

Thus began one of our most unusual field experiences in the summer



The maze of mine mapping.

Dan Lamping

of 2012. While mapping techniques were the same as cave mapping, stations had to be marked with spray paint, so as to be permanent and easily visible for recording purposes. Additionally, there was the problem of coordinating multiple parties working in the same mine so as to avoid duplication of survey. Amazingly, all went well, and after more than a week of surveying nearly eight miles was completed. Data reduction was done nightly in a motel room, with a bed serving as a drafting table to lay the sketches out as we figured out what had and had not been done.

The need for surveying was immediately obvious and overwhelming, as there were times when the survey party, returning the next day, took one or more wrong turns; a rule was quickly instituted that no one would travel alone!

Even an old mine can be beautiful. *Ed Klausner*

A section of the Mines of Moria.

Tony Schmitt afloat in a mine. *Dan Lamping*

Shauna Marquardt of U.S. Fish and Wildlife Service helps with mine survey. *Jim Cooley*

Finally, additional cavers were brought in, along with a canoe, to survey certain flooded portions of the mine.

The survey was drafted at 1:600 (1 inch = 50 feet) and was successfully used the following winter for a massive bat count. CRF surveyors served as guides and map readers for the six bat count parties. A follow-up trip the next spring added additional mileage in two areas.

Missouri Department of Conservation

An unfunded Missouri Department of Conservation project continued with the completion of the second of four sheets of Powder Mill Creek Cave map. Other projects on conservation areas and forests continue to be on hold during the period of figuring out what can or cannot be done in caves during the progression of WNS in the state. The Fish and Wildlife survey project described above was partially facilitated by MDC.

Missouri State Parks

Missouri State Parks are administered through the Department of Natural Resources; monitoring and survey efforts were supported by a grant. Continuing our tradition of working with the Missouri State Parks, several trips were taken to sort out caves in certain areas, map some un-surveyed caves, and perform biological inventory. Monitoring and survey trips were taken to Rockbridge Memorial State Park, Roaring River State Park, Lake of the Ozarks State Park, Onondaga Cave State Park, Johnson's Shut-Ins State Park, Bennett Springs State Park, and St. Francois State Park. One pit cave was mapped at Mastodon State Historic Site, and three caves at Bothwell Lodge State Historic Site were surveyed under the direction of Jim Cooley; here an early-20th century lodge was built on top of a cliff that housed caves below the lodge. Cooley also led a large volunteer crew that successfully re-gated the natural entrances of Onondaga and Cathedral Caves, both on Onondaga Cave State Park.

Pioneer Forest

Missouri's largest private landowner owns more than 150 caves. CRF has supported occasional survey and inventory in them, while providing cave management consultation. Work is usually coordinated by Dan Lamping, who led several field trips onto Forest lands during this reporting period. Some of the caves mapped or monitored within the Ozark Riverways are on land actually owned by the Forest. Highlights during this time period included the locating

and mapping of a long-rumored pit, a monitoring trip to a well-known cave, and the discovery and subsequent mapping of a cave near the Ozark Trail. Lastly one crew identified and mapped a small cave that appears to be an undisturbed archaeological site.

Alicia Wallace in front of new gate on Cathedral Cave. *Jim Cooley*

Elsewhere

One trip was taken to a private cave under development. Here CRF offered advice on mitigating biological impacts. In the St. Francois Mountains area two trips mapped caves on private property; one of these was quite historic and had been used for many years. Two educational restoration trips were taken to Cliff Cave, St. Louis County. These trips involved high school students fulfilling a service requirement in a useful manner; they cleaned non-historic graffiti and did general restoration. CRF members led this effort, which we supported with a financial contribution. And one trip was taken into St. Genevieve County to identify a new bat colony.

Missouri Cave Database

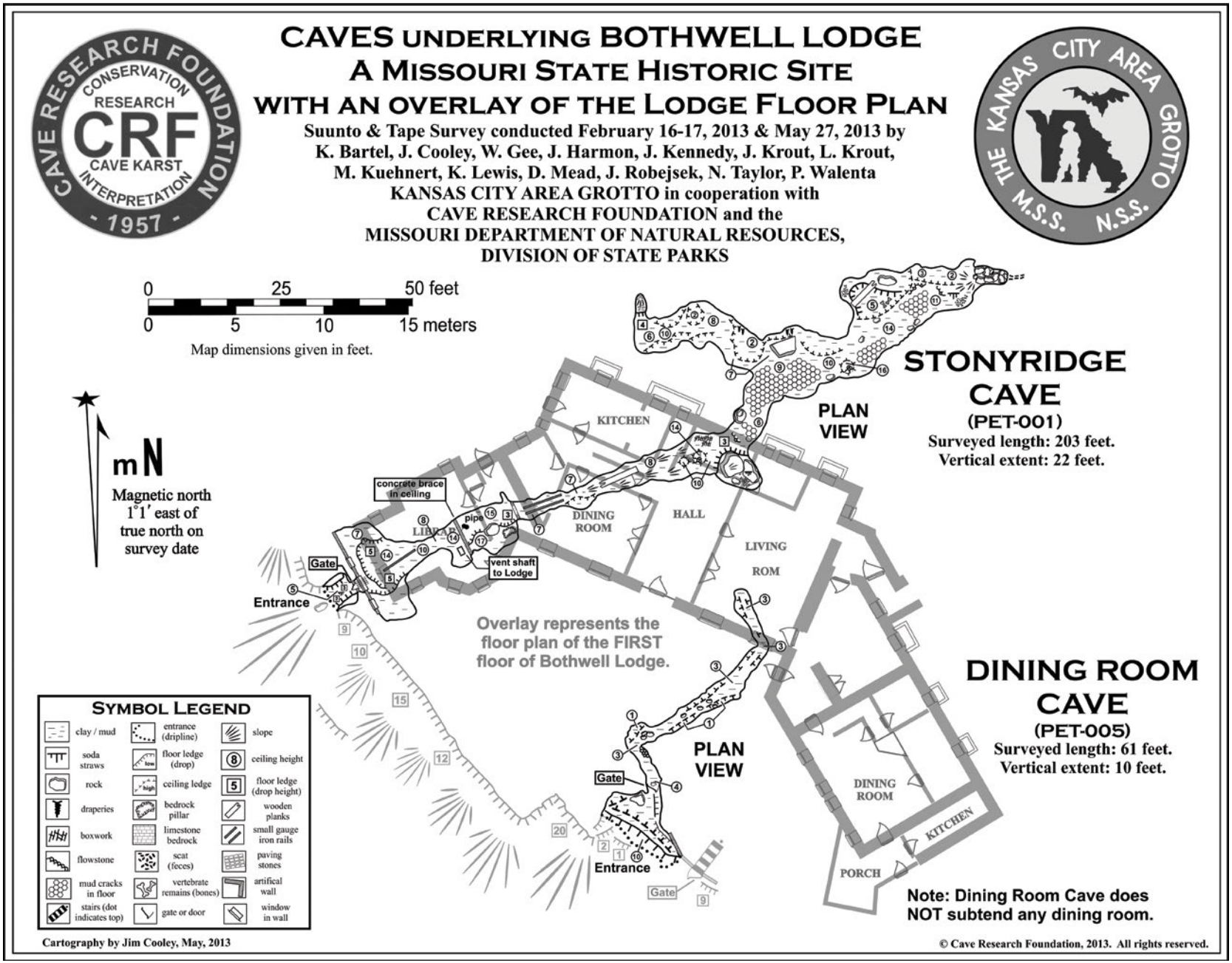
CRF continues to collaborate closely with the Missouri Speleological Survey (MSS) and with individual NSS grottos, especially with regard to additions and refinements to the cave files. Almost all Ozarks Operations work results in additions and corrections to the detailed cave records maintained by MSS, and Scott House continues to act as curator of those records on behalf of MSS.

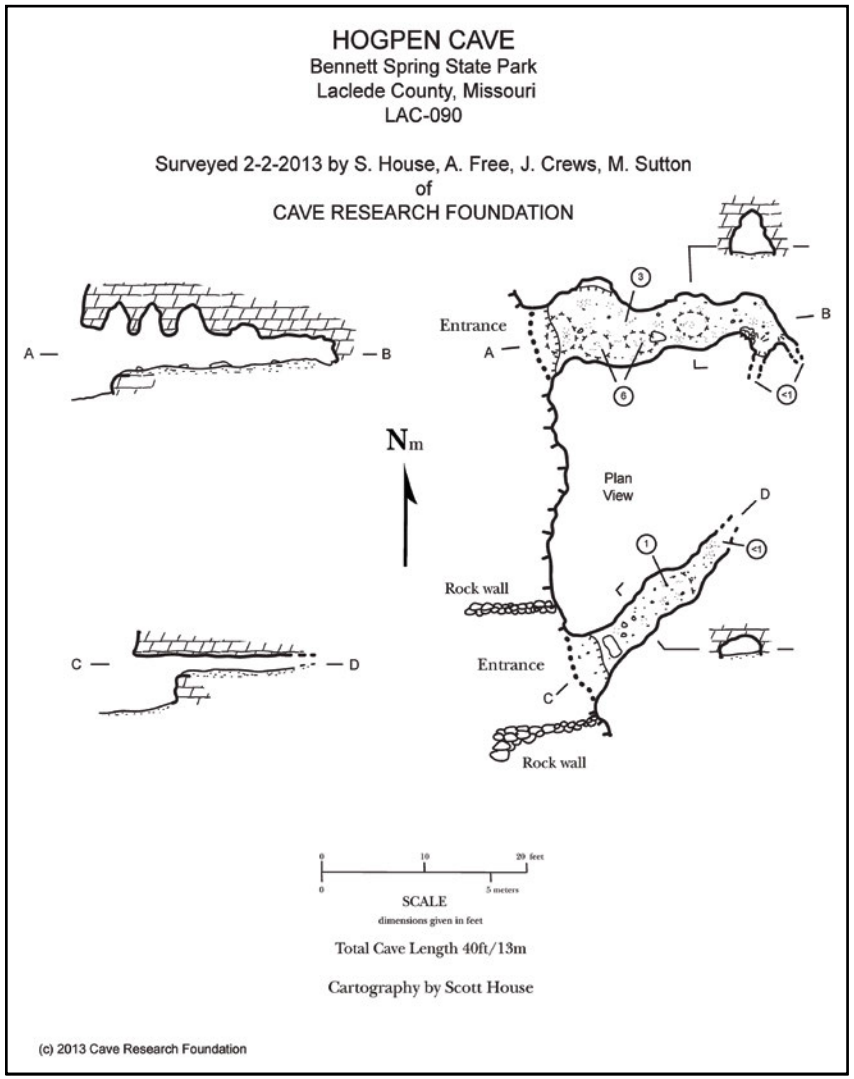
The MSS's Missouri Cave Database is a full-function relational database written in FileMaker Pro, a cross-platform program. The database currently has more than 6500 records including locations as well as descriptions and an index to mapped caves. Outputs are available in a variety of formats, allowing the data to be easily introduced into GIS or other programs.

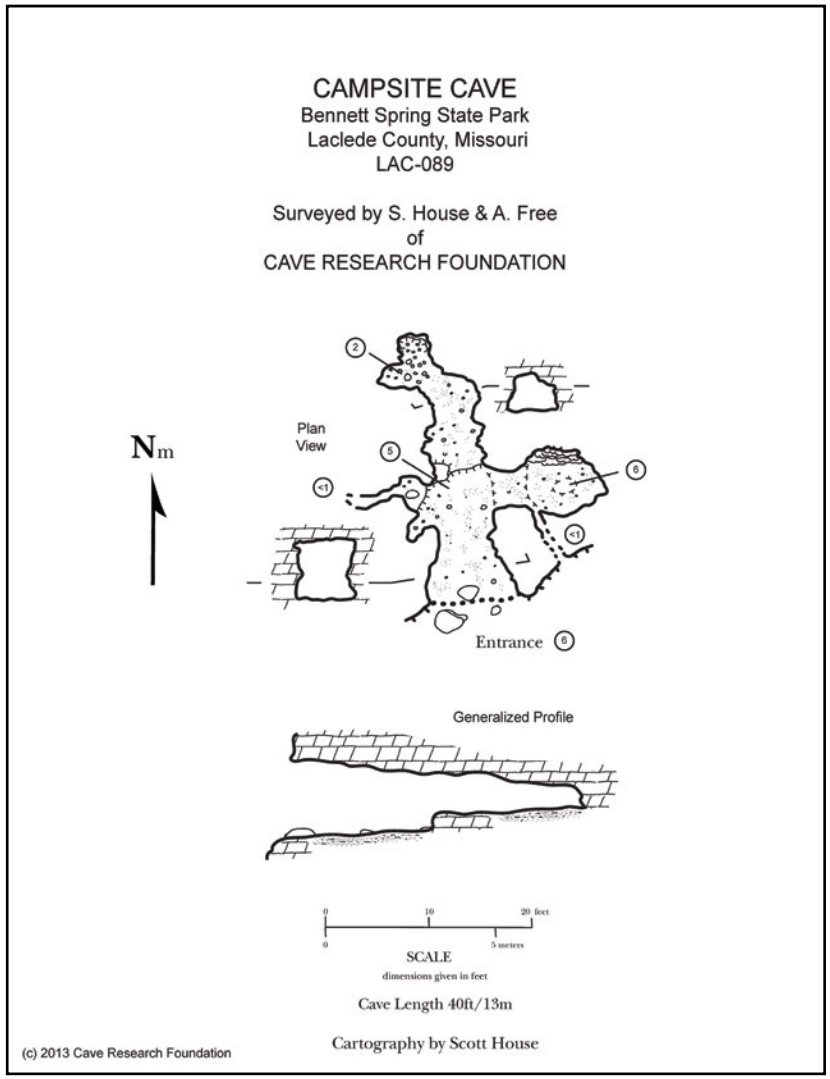
Cavers attend rescue training. *CRF photo*

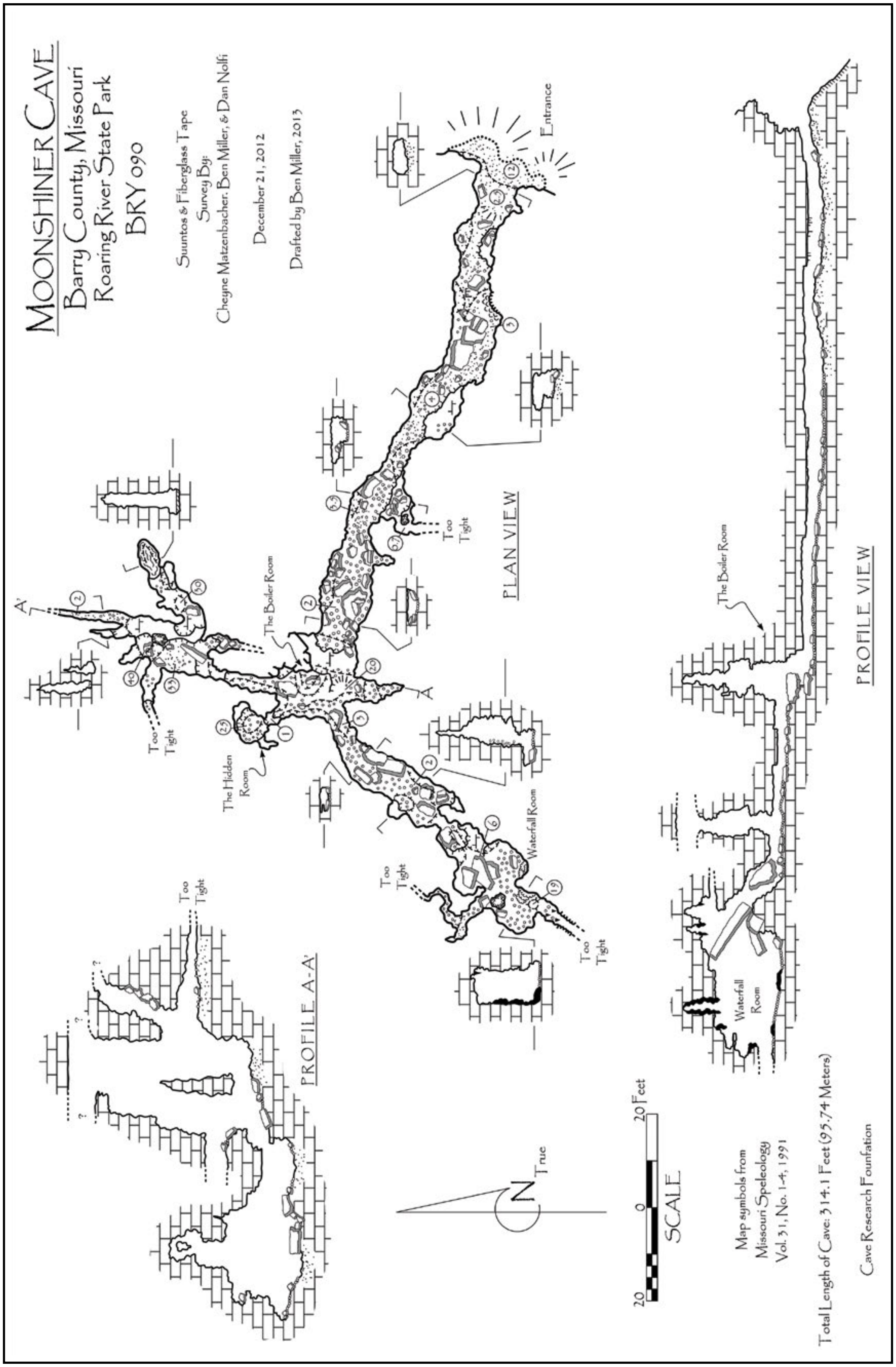
Training and Meetings

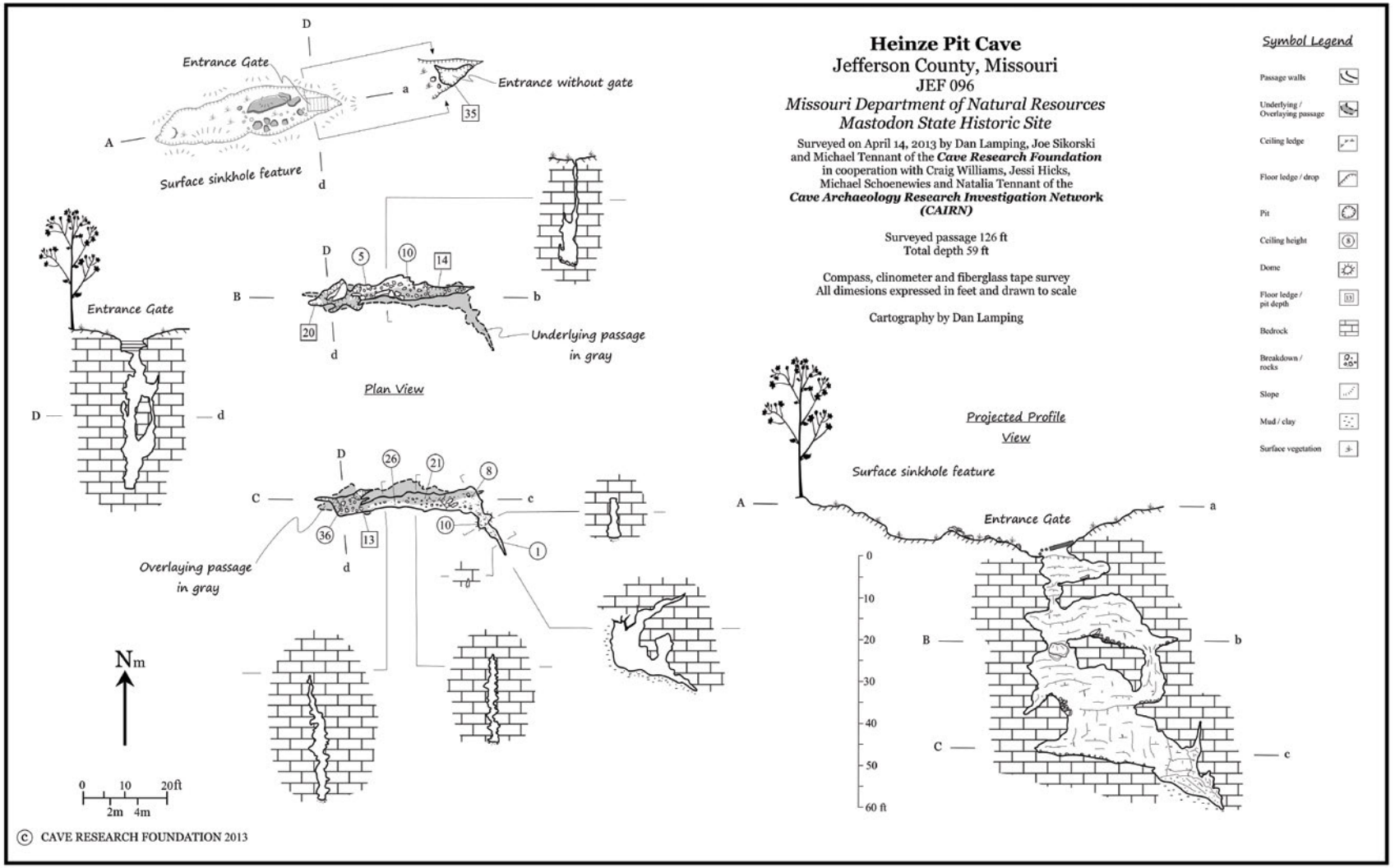
Numerous CRF personnel attended bat identification workshops in Cape Girardeau, St. Louis, Kansas City, and Springfield, MO that were put on by the Missouri Department of Conservation. CRF members also attended two bat coordination meetings to insure that efforts within Missouri were not duplicated. Mick Sutton and Scott House attended Missouri Natural Resource Conferences both years. Lastly, CRF members attended a cave rescue class to further our available skill levels.

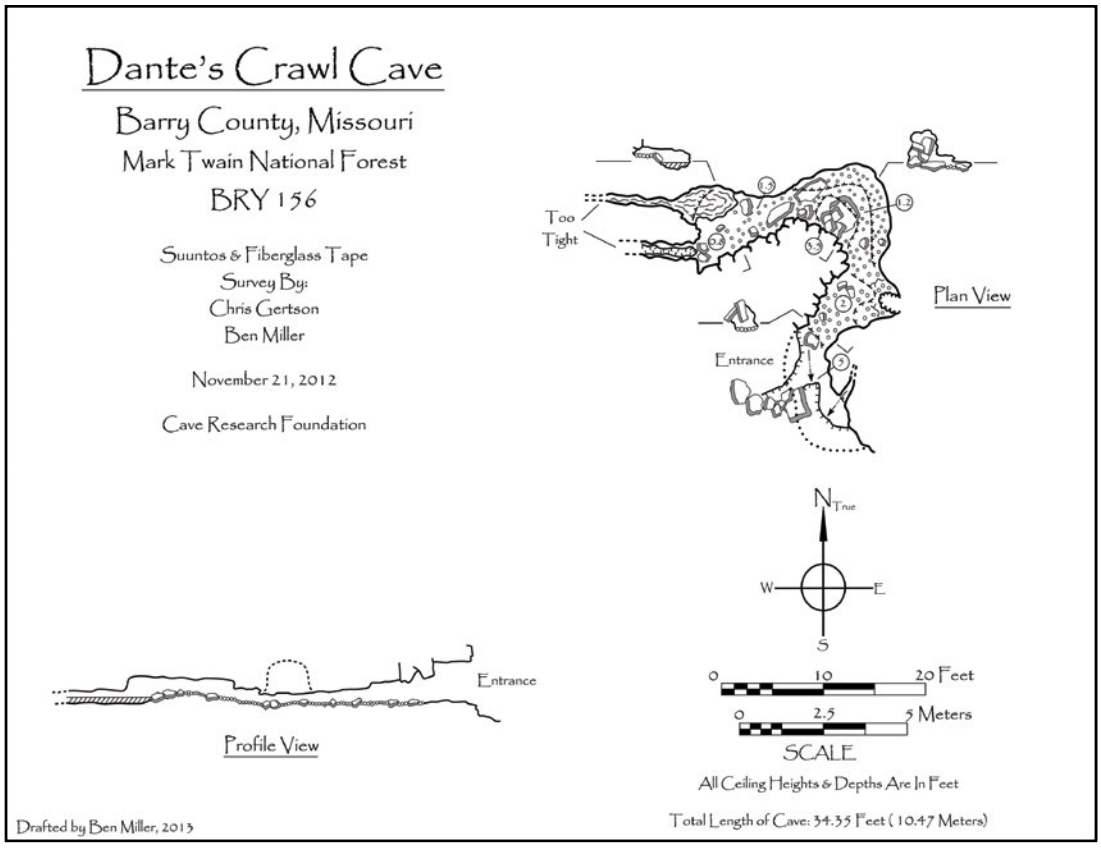

CAVES UNDERLYING BOTHWELL LODGE
A MISSOURI STATE HISTORIC SITE
WITH AN OVERLAY OF THE LODGE FLOOR PLAN
Suunto & Tape Survey conducted February 16-17, 2013 & May 27, 2013 by
K. Bartel, J. Cooley, W. Gee, J. Harmon, J. Kennedy, J. Krout, L. Krout,
M. Kuehnert, K. Lewis, D. Mead, J. Robejsek, N. Taylor, P. Walenta
KANSAS CITY AREA GROTTO in cooperation with
CAVE RESEARCH FOUNDATION and the
MISSOURI DEPARTMENT OF NATURAL RESOURCES,
DIVISION OF STATE PARKS
CAVE RESEARCH FOUNDATION
CONSERVATION RESEARCH CRF CAVE KARST INTERPRETATION
- 1957 -
THE KANSAS CITY AREA GROTTO
M.S.S. N.S.S.
0 25 50 feet
0 5 10 15 meters
Map dimensions given in feet.
mN
Magnetic north
1°1′ east of
true north on
survey date
STONYRIDGE CAVE
(PET-001)
Surveyed length: 203 feet.
Vertical extent: 22 feet.
PLAN VIEW
KITCHEN
DINING ROOM
HALL
LIVING ROM
concrete brace in ceiling
pipe
vent shaft to Lodge
Gate
Entrance
Overlay represents the floor plan of the FIRST floor of Bothwell Lodge.
DINING ROOM CAVE
(PET-005)
Surveyed length: 61 feet.
Vertical extent: 10 feet.
PLAN VIEW
Gate
Entrance
Gate
DINING ROOM
KITCHEN
PORCH
Note: Dining Room Cave does NOT subtend any dining room.
SYMBOL LEGEND
clay / mud
soda straws
rock
draperies
boxwork
flowstone
mud cracks in floor
stairs (dot indicates top)
entrance (dripline)
floor ledge (drop)
ceiling ledge
bedrock pillar
limestone bedrock
scat (feces)
vertebrate remains (bones)
gate or door
slope
ceiling height
floor ledge (drop height)
wooden planks
small gauge iron rails
paving stones
artifical wall
window in wall
Cartography by Jim Cooley, May, 2013
© Cave Research Foundation, 2013. All rights reserved.

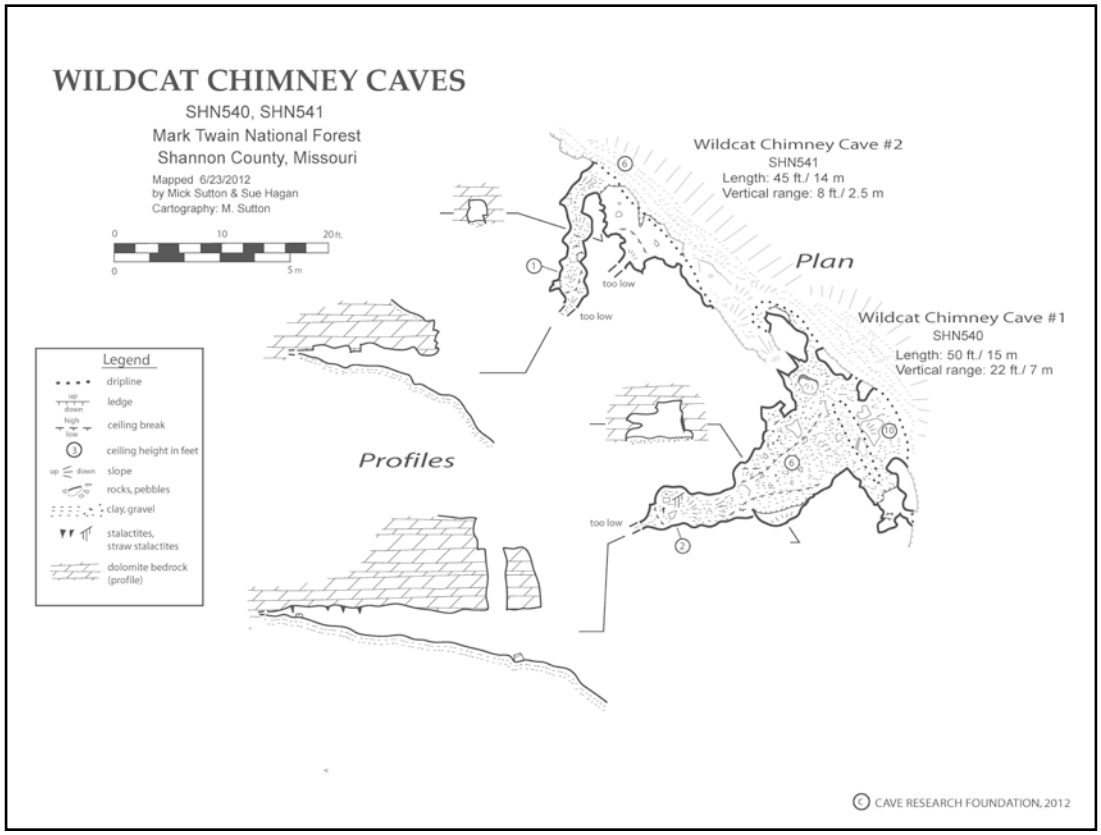

HOGPEN CAVE
Bennett Spring State Park
Laclede County, Missouri
LAC-090
Surveyed 2-2-2013 by S. House, A. Free, J. Crews, M. Sutton
of
CAVE RESEARCH FOUNDATION
A
B
C
D
Entrance
Plan
View
Rock wall
Entrance
Rock wall
Nm
3
6
1
<1
0
10
20 feet
0
5 meters
SCALE
dimensions given in feet
Total Cave Length 40ft/13m
Cartography by Scott House
(c) 2013 Cave Research Foundation

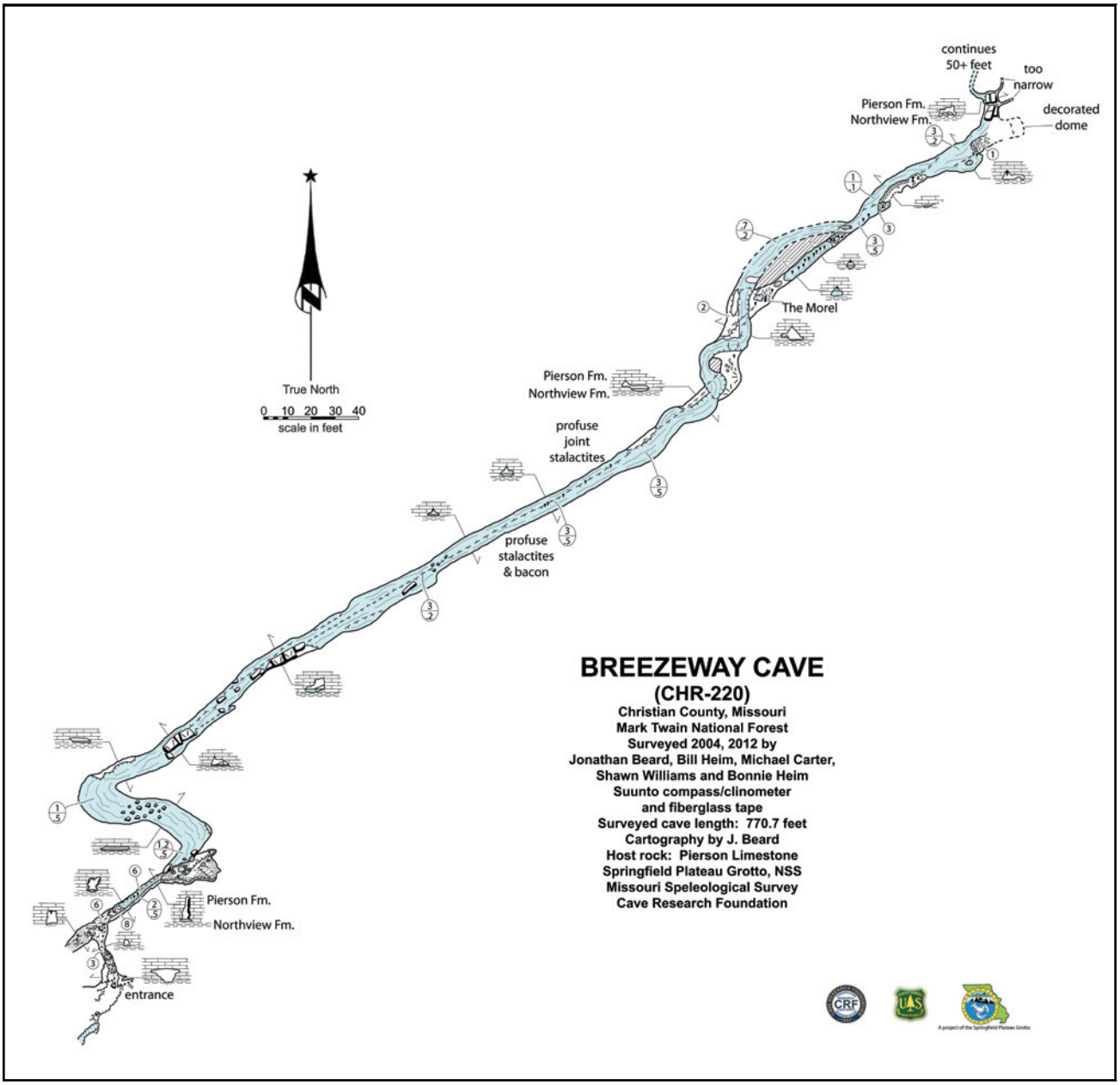

CAMPSITE CAVE
Bennett Spring State Park
Laclede County, Missouri
LAC-089
Surveyed by S. House & A. Free
of
CAVE RESEARCH FOUNDATION
Nm
Plan
View
2
5
<1
6
Entrance 6
Generalized Profile
0
10
20 feet
0
5 meters
SCALE
dimensions given in feet
Cave Length 40ft/13m
Cartography by Scott House
(c) 2013 Cave Research Foundation

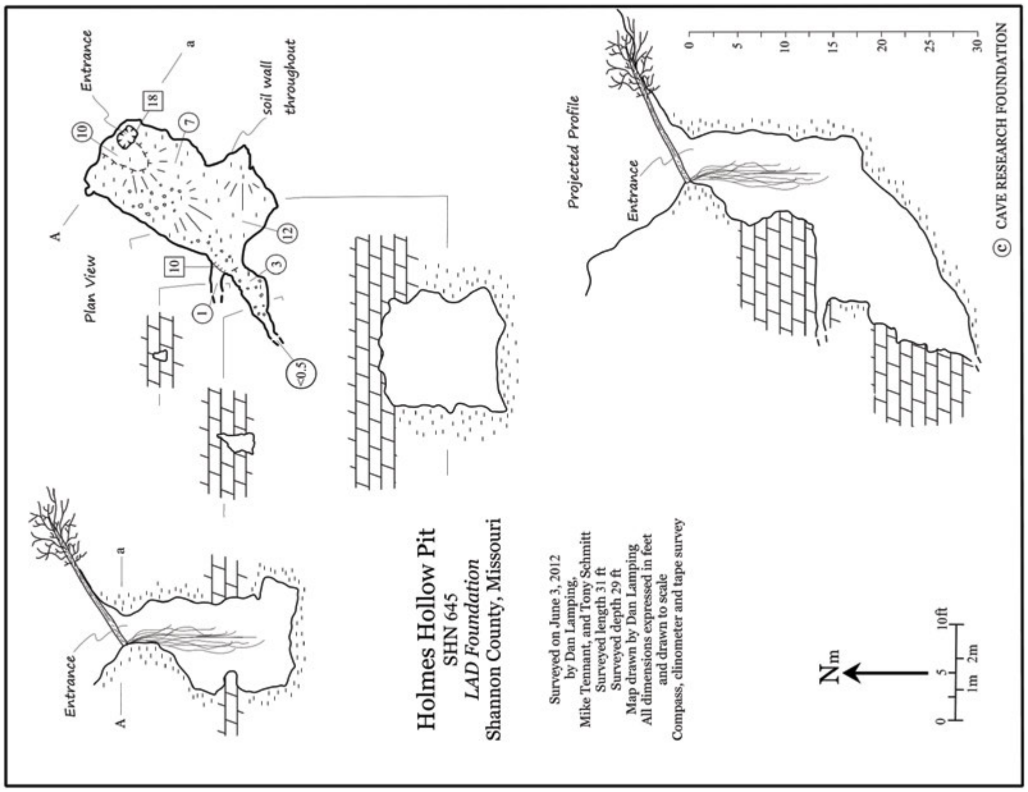

Moonshiner Cave
Barry County, Missouri
Roaring River State Park
BRY 090
Suuntos & Fiberglass Tape
Survey By:
Cheyne Matzenbacher, Ben Miller, & Dan Nolfi
December 21, 2012
Drafted by Ben Miller, 2013
Entrance
Too Tight
The Boiler Room
The Hidden Room
Waterfall Room
PLAN VIEW
PROFILE A-A'
PROFILE VIEW
The Boiler Room
Waterfall Room
True
N
20
0
20 Feet
SCALE
Map symbols from
Missouri Speleology
Vol. 31, No. 1-4, 1991
Total Length of Cave: 314.1 Feet (95.74 Meters)
Cave Research Founfation

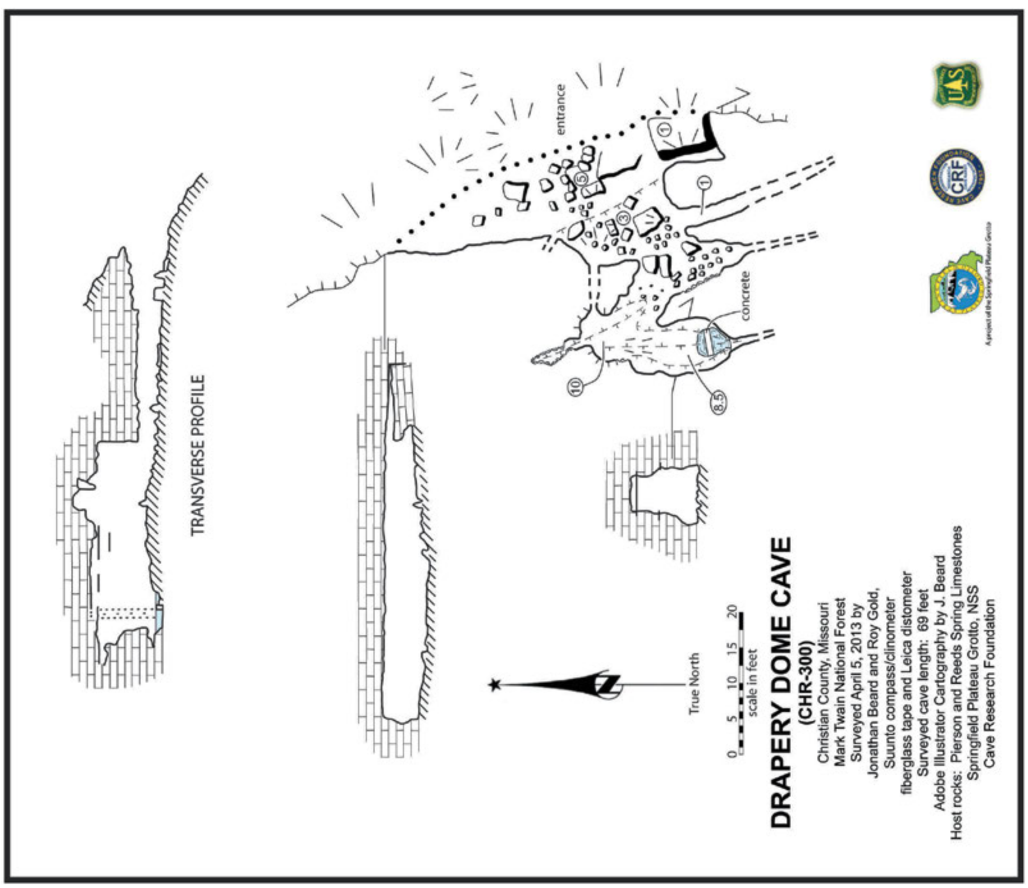

Heinze Pit Cave
Jefferson County, Missouri
JEF 096
Missouri Department of Natural Resources
Mastodon State Historic Site
Surveyed on April 14, 2013 by Dan Lamping, Joe Sikorski and Michael Tennant of the Cave Research Foundation in cooperation with Craig Williams, Jessi Hicks, Michael Schoenewies and Natalia Tennant of the Cave Archaeology Research Investigation Network (CAIRN)
Surveyed passage 126 ft
Total depth 59 ft
Compass, clinometer and fiberglass tape survey
All dimesions expressed in feet and drawn to scale
Cartography by Dan Lamping
Symbol Legend
Passage walls
Underlying / Overlaying passage
Ceiling ledge
Floor ledge / drop
Pit
Ceiling height
Dome
Floor ledge / pit depth
Bedrock
Breakdown / rocks
Slope
Mud / clay
Surface vegetation
Entrance Gate
Entrance without gate
Surface sinkhole feature
Plan View
Underlying passage in gray
Overlaying passage in gray
Projected Profile View
Nm
0 10 20ft
2m 4m
0 10 20 30 40 50 60 ft
© CAVE RESEARCH FOUNDATION 2013


Dante's Crawl Cave
Barry County, Missouri
Mark Twain National Forest
BRY 156
Suuntos & Fiberglass Tape
Survey By:
Chris Gertson
Ben Miller
November 21, 2012
Cave Research Foundation
Too Tight
Entrance
Plan View
N True
W
E
S
Entrance
Profile View
0 10 20 Feet
0 2.5 5 Meters
SCALE
All Ceiling Heights & Depths Are In Feet
Drafted by Ben Miller, 2013
Total Length of Cave: 34.35 Feet (10.47 Meters)

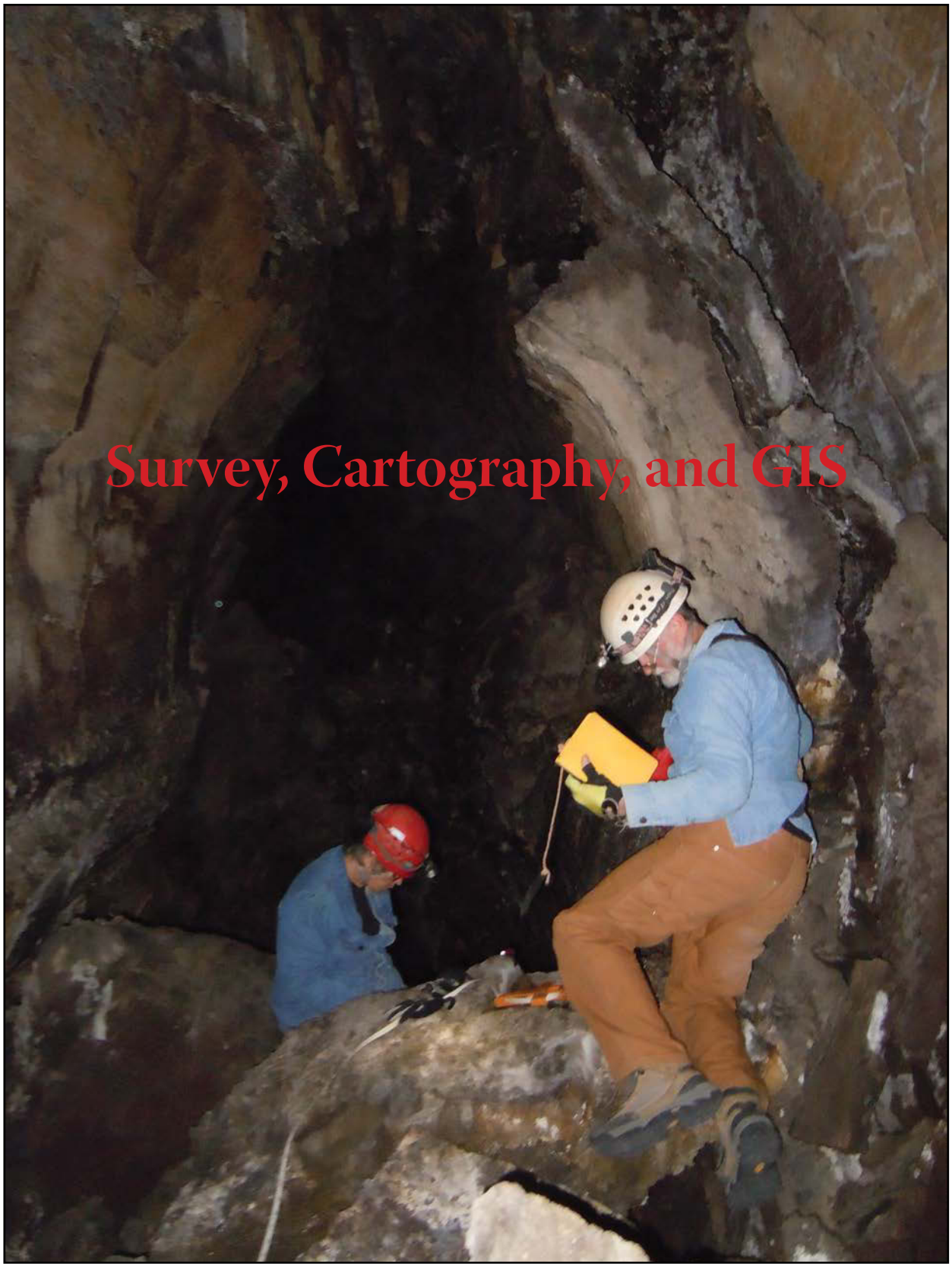

WILDCAT CHIMNEY CAVES
SHN540, SHN541
Mark Twain National Forest
Shannon County, Missouri
Mapped 6/23/2012
by Mick Sutton & Sue Hagan
Cartography: M. Sutton
0 10 20 ft.
0 5 m
Legend
dripline
ledge
ceiling break
ceiling height in feet
slope
rocks, pebbles
clay, gravel
stalactites, straw stalactites
dolomite bedrock (profile)
Wildcat Chimney Cave #2
SHN541
Length: 45 ft./ 14 m
Vertical range: 8 ft./ 2.5 m
Plan
too low
too low
Wildcat Chimney Cave #1
SHN540
Length: 50 ft./ 15 m
Vertical range: 22 ft./ 7 m
Profiles
too low
© CAVE RESEARCH FOUNDATION, 2012


continues
50+ feet
too
narrow
decorated
dome
Pierson Fm.
Northview Fm.
The Morel
True North
0 10 20 30 40
scale in feet
Pierson Fm.
Northview Fm.
profuse
joint
stalactites
profuse
stalactites
& bacon
BREEZEWAY CAVE
(CHR-220)
Christian County, Missouri
Mark Twain National Forest
Surveyed 2004, 2012 by
Jonathan Beard, Bill Heim, Michael Carter,
Shawn Williams and Bonnie Heim
Suunto compass/clinometer
and fiberglass tape
Surveyed cave length: 770.7 feet
Cartography by J. Beard
Host rock: Pierson Limestone
Springfield Plateau Grotto, NSS
Missouri Speleological Survey
Cave Research Foundation
Pierson Fm.
Northview Fm.
entrance


Entrance
soil wall throughout
Plan View
Projected Profile
Holmes Hollow Pit
SHN 645
LAD Foundation
Shannon County, Missouri
Surveyed on June 3, 2012
by Dan Lamping,
Mike Tennant, and Tony Schmitt
Surveyed length 31 ft
Surveyed depth 29 ft
Map drawn by Dan Lamping
All dimensions expressed in feet
and drawn to scale
Compass, clinometer and tape survey
© CAVE RESEARCH FOUNDATION


TRANSVERSE PROFILE
entrance
concrete
True North
scale in feet
DRAPERY DOME CAVE
(CHR-300)
Christian County, Missouri
Mark Twain National Forest
Surveyed April 5, 2013 by
Jonathan Beard and Roy Gold,
Suunto compass/clinometer
fiberglass tape and Leica distometer
Surveyed cave length: 69 feet
Adobe Illustrator Cartography by J. Beard
Host rocks: Pierson and Reeds Spring Limestones
Springfield Plateau Grotto, NSS
Cave Research Foundation

Survey, Cartography, and GIS



Mick Sutton and Sue Hagan surveying in Post Office Cave. *Ed Klausner*

Lava Beds National Monument Inventory and Monitoring

Ed Klausner

The Inventory and Monitoring Program (I & M) of the National Park Service was created to inventory the natural resources that they manage. They could then determine the condition of the resources as a baseline, and with periodic monitoring, determine if changes in policy are necessary to protect these resources.

The inventory of these resources is to be shared with other agencies to help foster cooperative arrangements with the goal of protecting these resources. Periodic monitoring tracks the changes (if any) of the resource over time. For caves, this includes animal usage of the caves, artifacts that may be damaged or stolen, and vandalism.

Maps of these caves are obviously a great resource for the monitors as they can note locations of animal occurrences on the map itself or use a data entry form with the survey station as the key for the specific location. In the same manner, graffiti, cultural artifacts, areas of animal use, and areas of damage can be noted, and possibly the location of a gate, if one becomes necessary.

In Lava Beds National Monument, caves are plentiful and finding a specific cave in a small area will be helped by having a cave map. All of these reasons prompted the monument to ask for a detailed map of each of their I & M caves. Over the course of several trips to the monument, we produced maps of Four Star Cave and Sentinel Annex Cave. Four Star Cave is in the Elmer's Trench section of the Mammoth Crater Flow and is 1121 feet long. There are two levels of passage with three walk-in entrances and two skylight entrances. Fifth Star Grotto is a small (46 foot) extension that was added to the map. Pearl Cave has a single entrance and is 401 feet long with a single passage. Pearl has a small connection to Four Star Cave, so it too was added to the map of Four Star Cave. Figure 1 shows

Joyce Hoffmaster surveying in Pearl Cave. *Ed Klausner*

Elizabeth Miller at the entrance to Pearl Cave in Elmer's Trench. *Ed Klausner*

Shawn Thomas and two interns at Four Star Cave to monitor the cave. *Ed Klausner*

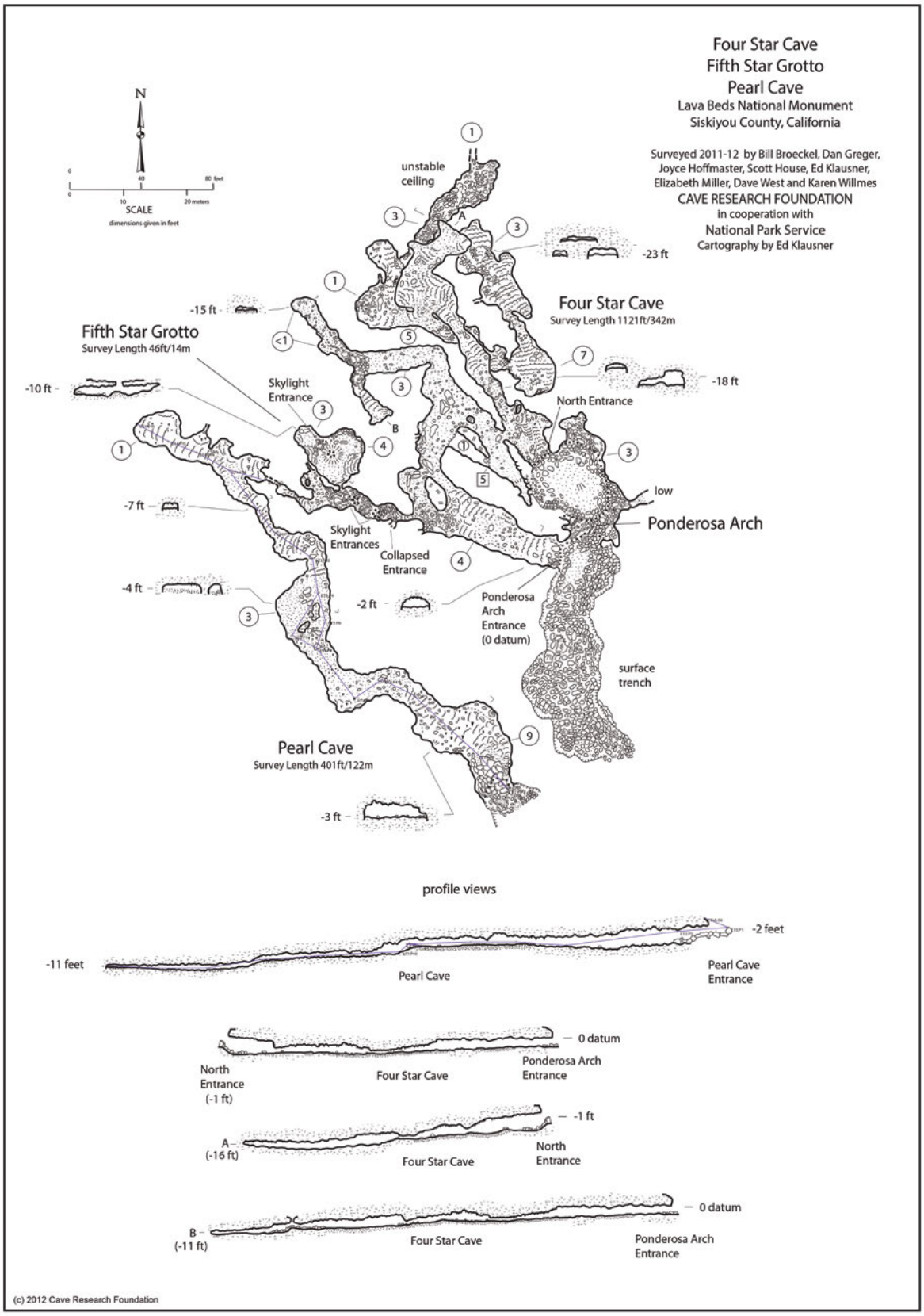


Figure 1. Four Star Cave, Fifth Star Grotto, and Pearl Cave.

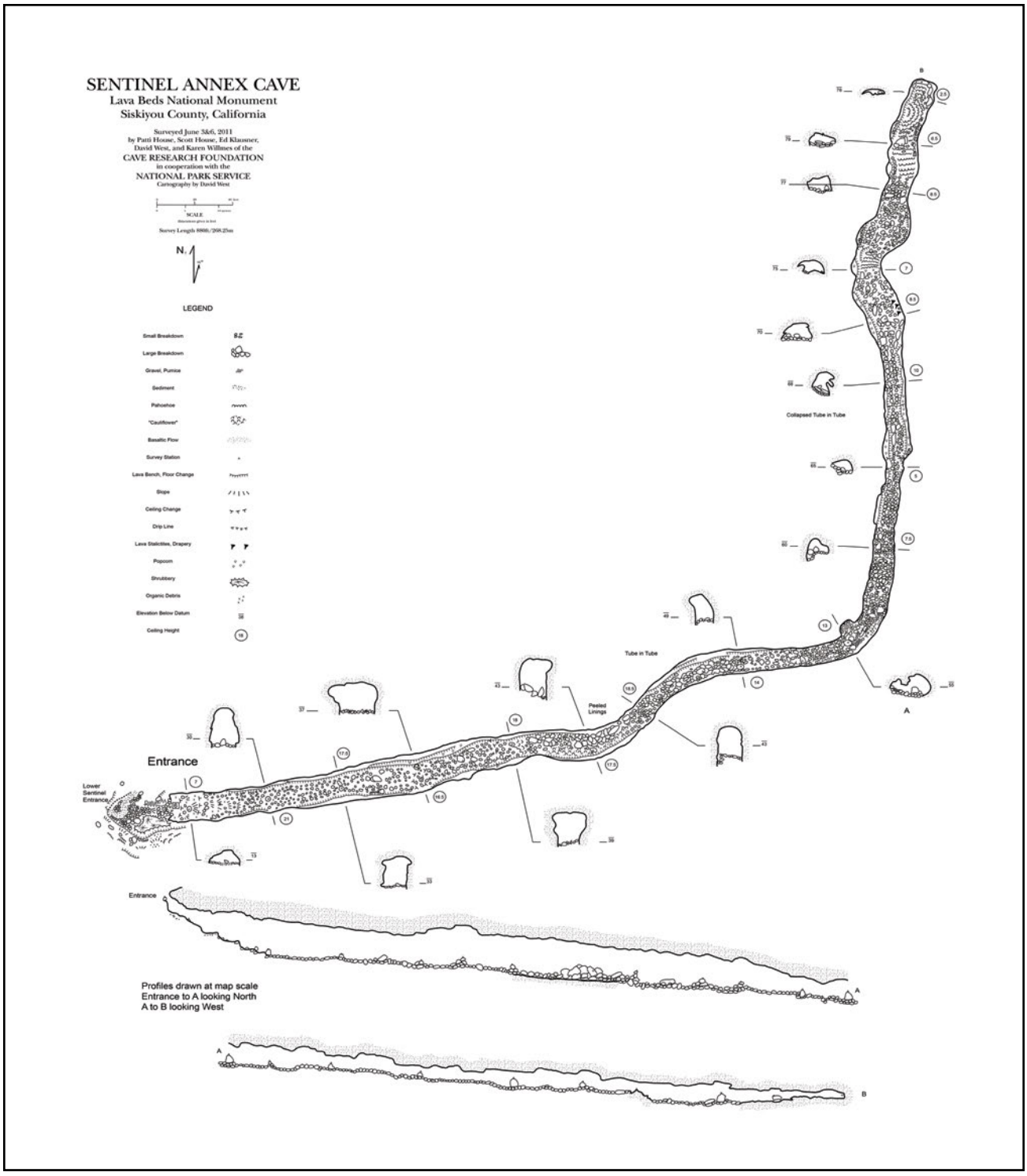


Figure 2. Sentinel Annex Cave.

the three caves along with the surface trench.

Sentinel Annex Cave is on the Cave Loop near the Visitors Center. It is 880 feet in length and drops 78 feet from the entrance to its terminal end. One note is that is both a tube within a tube and a collapsed tube within a tube. See Figure 2 for the map. Liz Wolff has a project to resurvey the rest of the caves along the Cave Loop. This will be very useful for the monument and the visitors.

Valentine Cave is a 2135-foot cave that has a parking lot for visitors. There was an existing map, but it lacked some features, so the park also had us survey Valentine Cave to make a new map. Since this is a popular cave that is easily available to park visitors, it was also easy for us to survey in the evening after we surveyed during the day in more remote locations. Valentine Cave has lava pools, benches, cascades along with many ceiling formations. See Figure 3 for the map of Valentine Cave.

Elizabeth Miller at the upflow entrance culvert to Post Office Cave. *Ed Klausner*

Scott House and Don Dunham surveyed Upper Cavern, an I & M cave in the Balcony/ Boulevard area. They completed the survey in two trips, one in September and one in October of 2013. Figure 4 shows the cave plus Balcony Cave.

One other cave that is on the I & M list is Post Office Cave. This cave is more challenging as it is multilevel, and the bottom level is fairly cold. This is said to be the most complex and challenging cave in the monument. We started the survey in 2012 and had a trip planned for 2013, but the government shutdown in October forced us to cancel our trip. We plan on continuing the survey in 2014.

Elizabeth Miller and Jim Wolff at the upflow entrance to Post Office Cave. *Ed Klausner*

Elizabeth Miller surveying in Post Office Cave. *Ed Klausner*

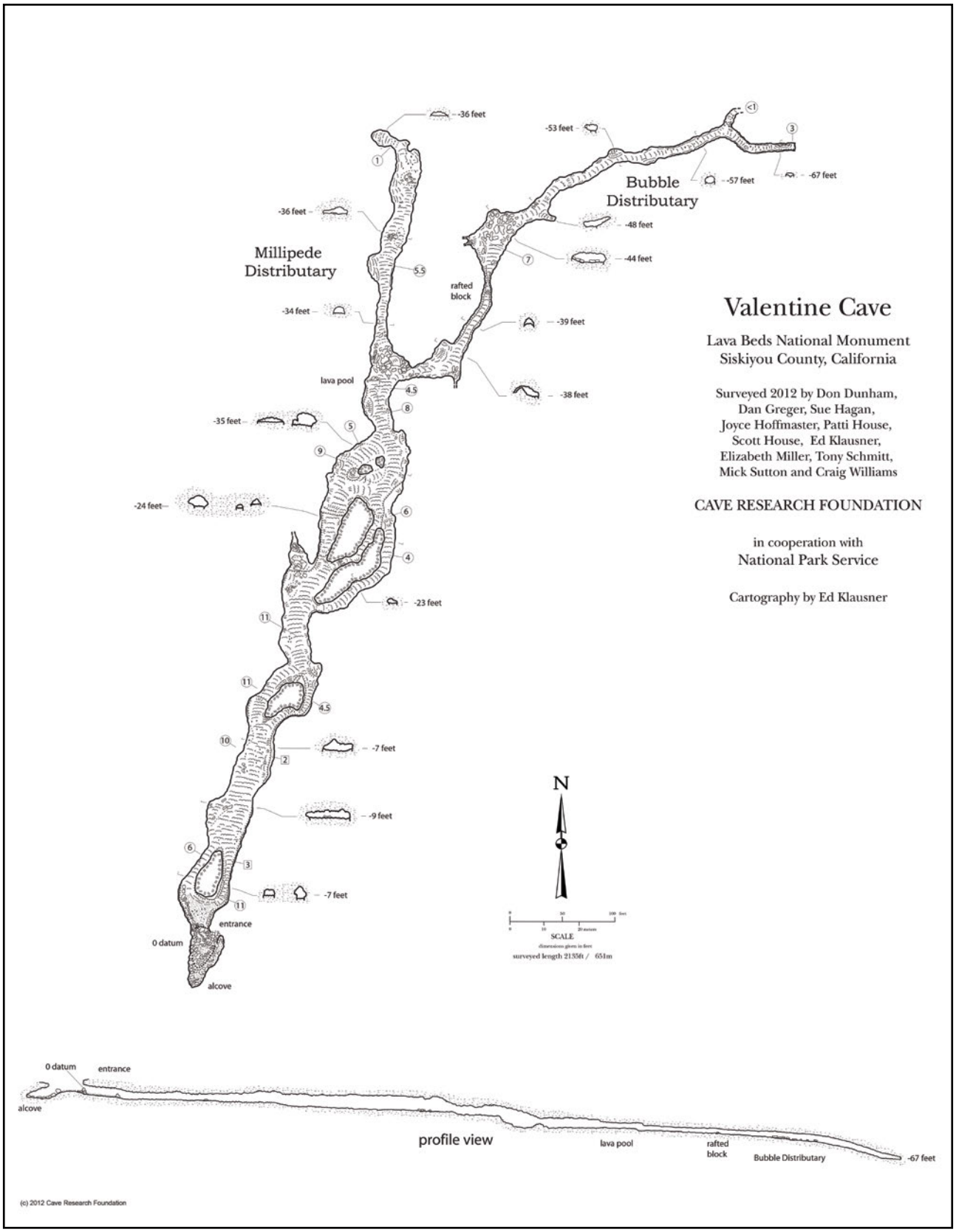


Figure 3. Valentine Cave.

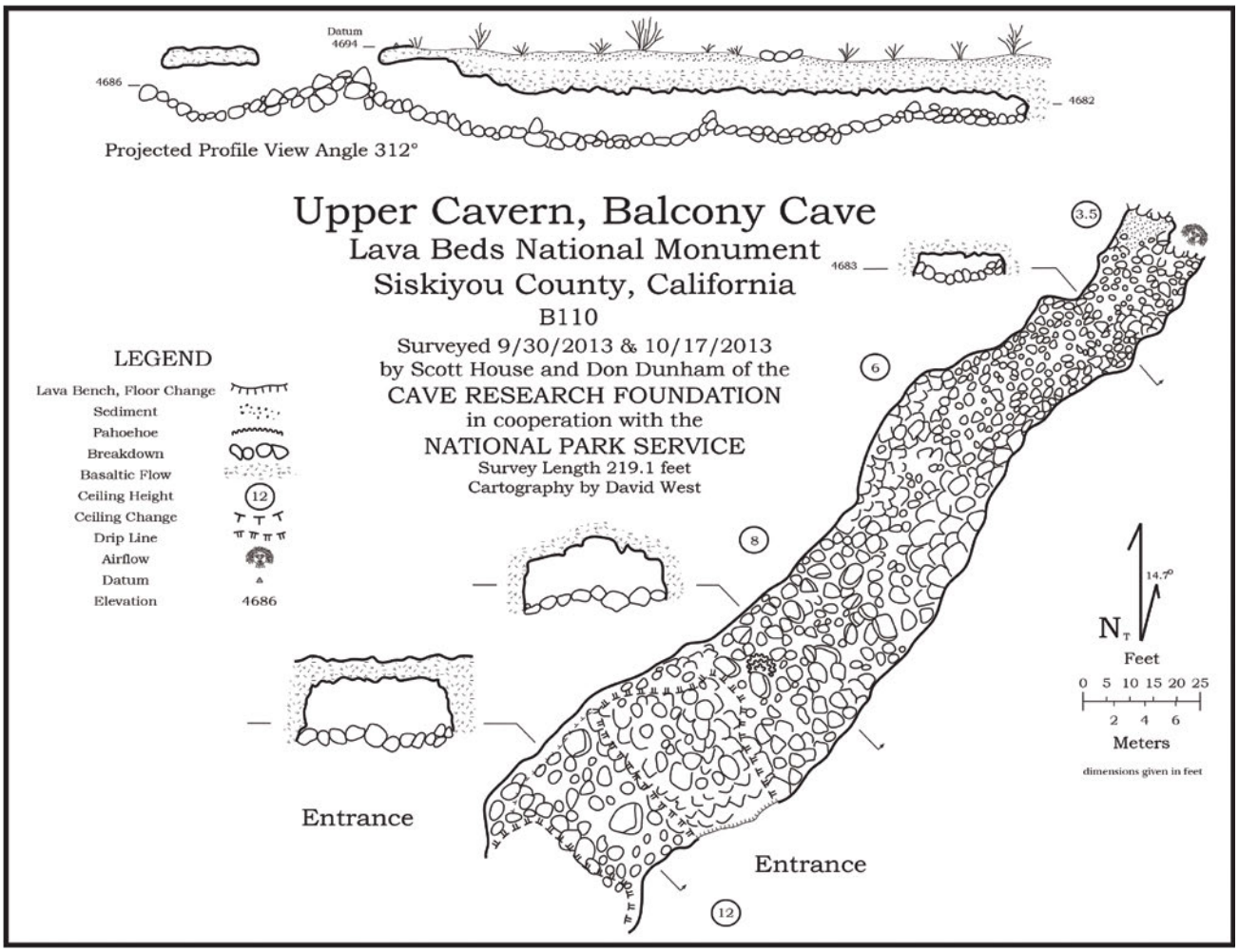


Figure 4. Upper Cavern, Balcony.

Carlsbad Caverns Cartography

Big Room, Middle Earth, Spirit World, Lower Cave

Ed Klausner

The Big Room area of Carlsbad Cavern in Carlsbad Caverns National Park is multileveled and difficult to represent on a two-dimensional map. The Resource Office of the Park wanted a detailed map of the visitor's trail along with the rest of the Big Room, Middle Earth (below the south east part of the Big Room), Spirit World (above the Big Room and Middle Earth), and Lower Cave (below much of the Big Room). Figure 1 is an overview showing this relationship.

After many trials and input from Stan Allison and Shawn Thomas (employees of the Cave Resource Office

Figure 1. Overview of the Big Room, Middle Earth, Spirit World and Lower Cave.

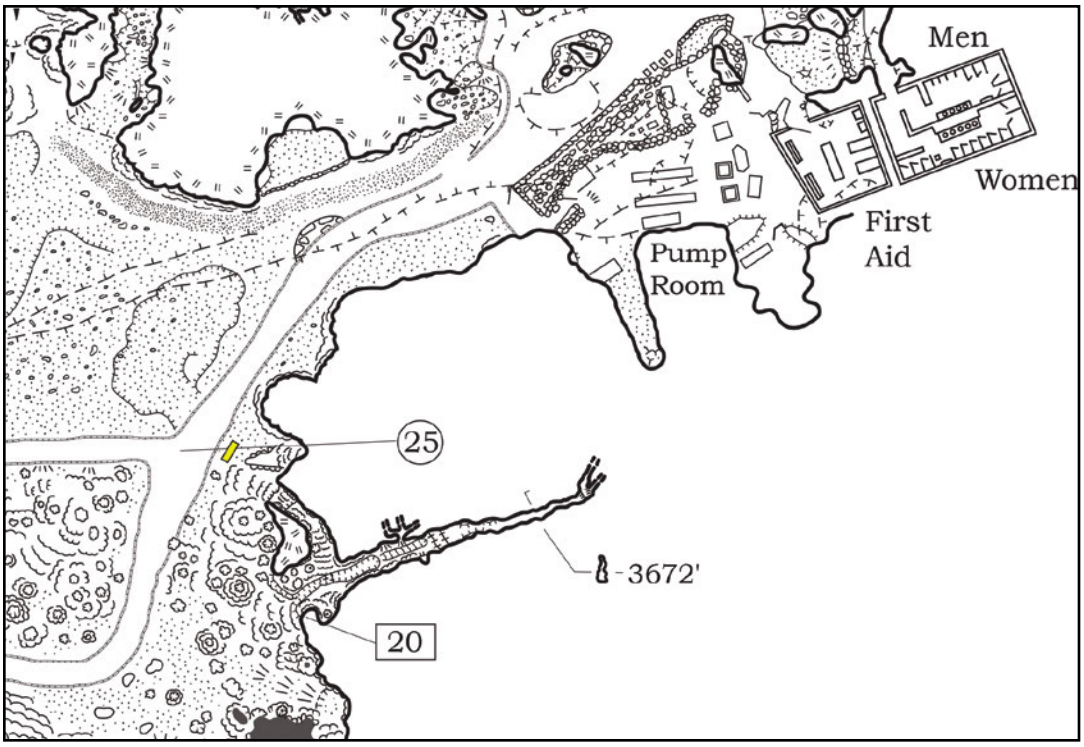


Figure 2. Passage above the Big Room south of the Pump Room.

of Carlsbad Caverns National Park in addition to being cave cartographers themselves), we developed a plan for the map that would show the Big Room in detail with Middle Earth and Spirit World as offsets as well as show their actual position in relation to the Big Room as a shaded area. Lower Cave would be shown as a shaded area as well, but the actual map of Lower Cave would be separate for a number of reasons. To begin with, Lower Cave has different boundaries than the Big Room so the frame of the map had to be different. Second, Lower Cave itself is multilevel and requires its own shading to show upper levels such as Talcum Passage and Mabel's Room.

Fortunately, the map was drafted using Adobe Illustrator, and one electronic map could be used to produce separate paper maps by the use of layers in Illustrator. That way, the exact shape and location of Lower Cave, for example, could be correctly shaded and placed in the map of the Big Room.

The CRF folio map of 1988 was used to locate areas that were not resurveyed. For example, there is a passage very close to the Lunch Room that is about 20 feet up and requires a ladder to reach. The Cave Resource Office helped find a ladder and with the help of Shawn Thomas, Derek Bristol and Karen Willmes, we cushioned the top section, so it would not damage the flowstone lip of the passage, and put the ladder in place to allow us to complete the survey. See figure 2 for this passage.

Scott House sketches in Carlsbad. *Mark Jones*

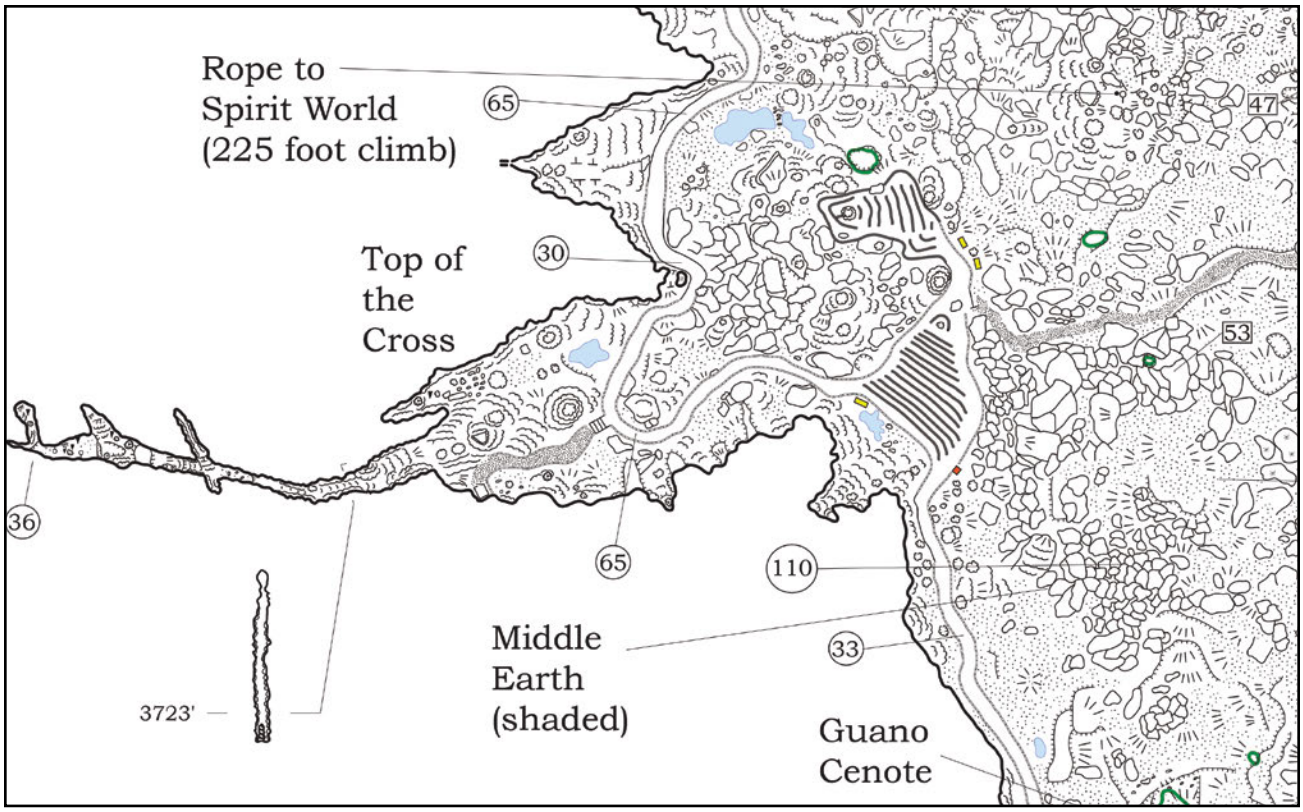


Figure 3. Passage west of the Top of the Cross.

Figure 3 shows a passage to the west of Top of the Cross, which was shown in the CRF folio map but not resurveyed. This, along with the passage behind the ladders leading to Lower Cave (Figure 4), were surveyed and added to the map.

Middle Earth was sketched by Kathy Lankford from 1999 to 2003, and drafted by Stan Allison. His map was incorporated into the map of the Big Room, and two trips were taken to check leads as there were still some left to complete. One short section was surveyed, and several leads noted that were unstable or required more rope than was taken on the trip. The work in Middle Earth will continue as well in 2014. Figure 5 shows the plan detail of Middle Earth as on offset to the Big Room with shading used to show its location under the Big Room.

Spirit World had two leads that Derek Bristol volunteered to check (and resurvey the rest of Spirit World.) Over the course of several trips, a new rope location was identified by Derek's crew and then placed by the Cave Resource Office. This new location avoids the traverse that was problematic. The first lead turned out not to go, but one lead that was deemed unlikely to do anything was finally checked by Derek and Shawn on Halloween, 2013. After a climb of 83 feet, they broke into Halloween Hall, a 100 by 100 foot room that was 20 feet tall—with leads. Work will continue here in 2014. See Figure 6 for the plan view as an offset to the Big Room and shading indicating its location above the Big Room.

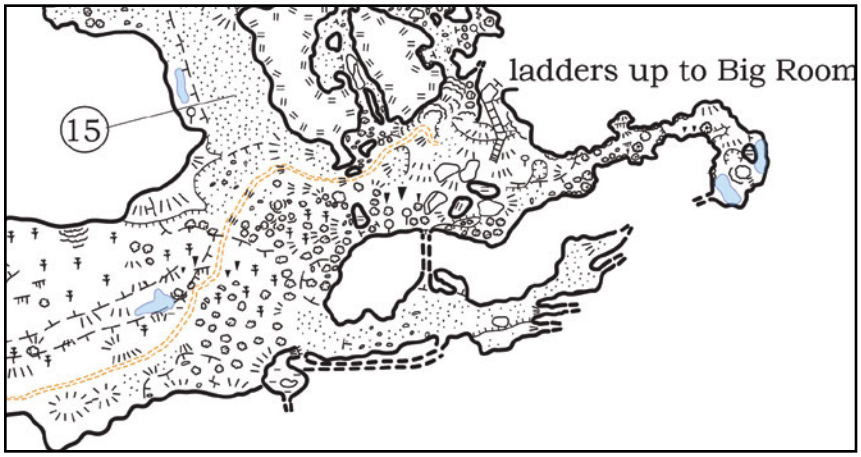


Figure 4. Passage behind the ladders to Lower Cave.

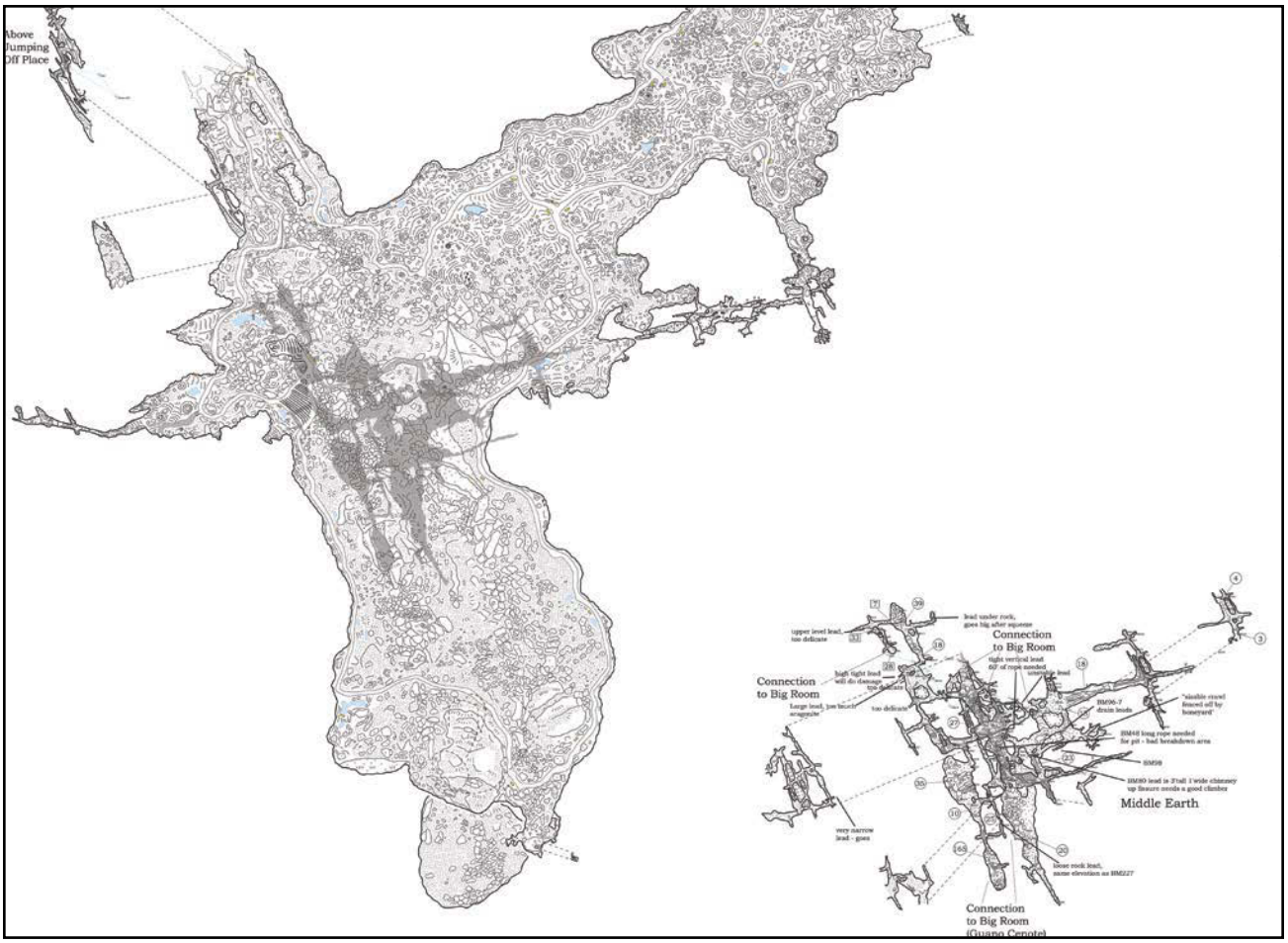


Figure 5. Middle Earth.

Figure 6. Spirit World.

An alcove to the southeast of Crystal Springs Dome had a small hole leading to more passage. This was surveyed by Aaron Addison (two trips in 1998) and Joel Despain (one trip in 1998). They noted leads. These leads were surveyed in two trips in 2013 making a connection to Crystal Springs Dome. See figure 7.

Figure 8 shows part of Talcum Passage that can be seen from the Jumping Off Place above Lower Cave. This section of Talcum Passage forms a balcony and survey was started by Kevin Glover in 2006. The survey of the balcony was completed in 2013, but it still needs to be tied to the rest of Talcum Passage.

Much work remains in Lower Cave, and there are several trips planned to check the rest of the leads. Thanks to all the surveyors for your work over the years.

Don Dunham in Carlsbad Caverns. *Scott House*

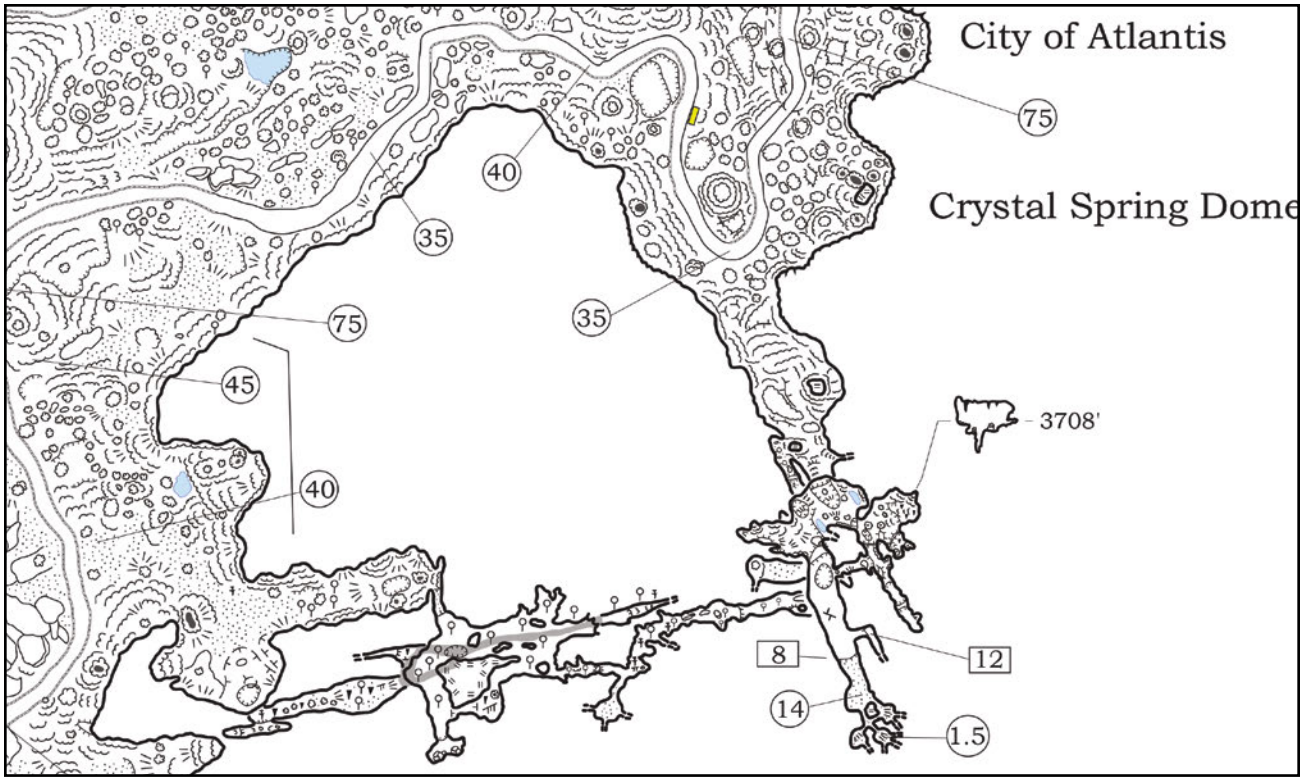


Figure 7. Passage connecting an alcove near Cave Man Junction with Crystal Spring Dome.

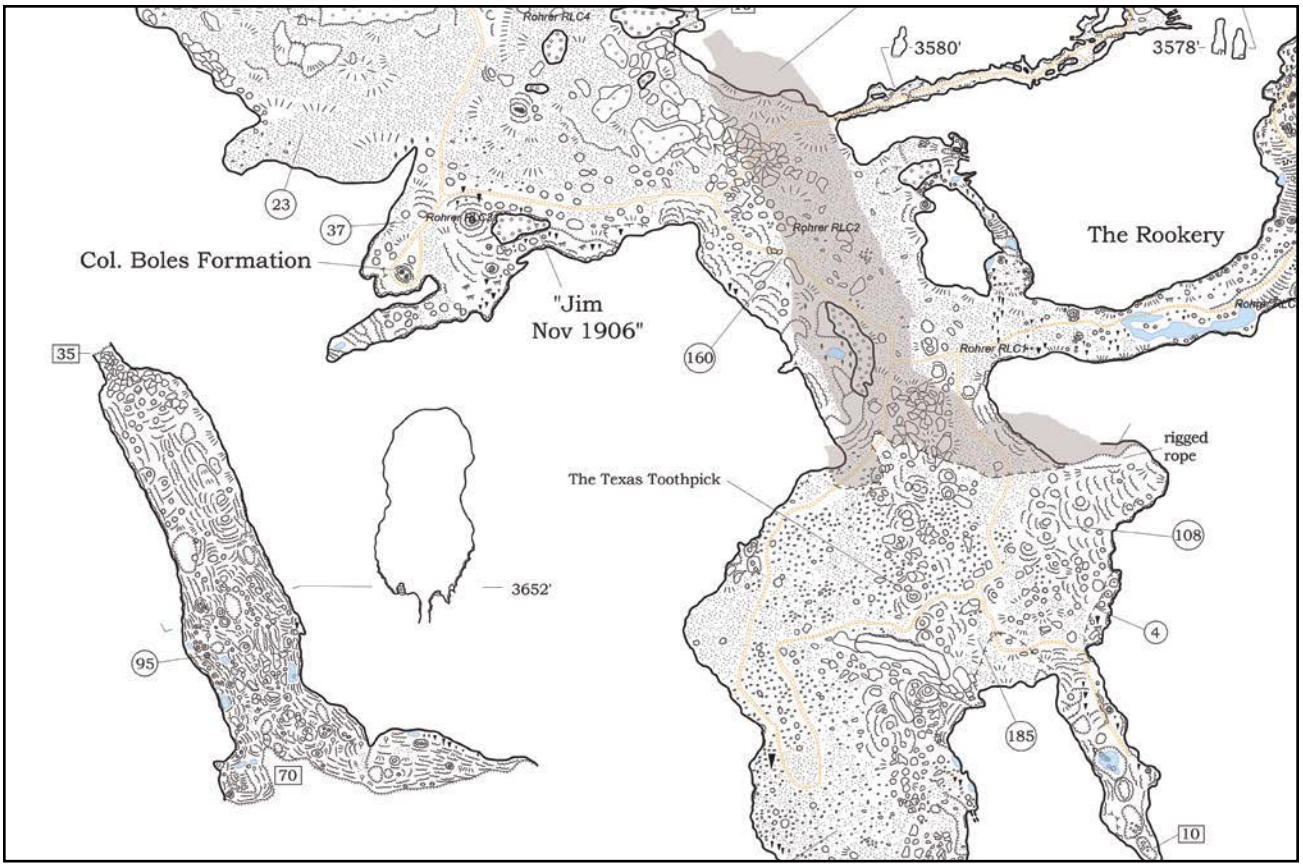


Figure 8. A section of Talcum Passage in Lower Cave.

Slaughter Canyon Cave, Carlsbad Caverns National Park, 2013

Dave West

Back in 2008, a number of CRF personnel, myself included, assisted with mapping Slaughter Canyon Cave in Carlsbad Canyon National Park. Slaughter Canyon Cave, formerly called New Cave, is one of the Park's tour caves, with ranger-led flashlight tours available seasonally. A pencil draft based largely upon the sketches from the survey had been produced but did not adhere well to the line plot of the survey. The Park wished to have a more finished and accurate map that adhered well to the survey, and during the October 2012 trip to Carlsbad with Scott House and Ed Klausner, it was suggested that I might be willing to draw it up. I agreed and took home a copy of the data and scans of the surveys. I quickly determined that the survey contained four bad loops that would need correcting before drafting could begin. The majority of the sketches were quite usable, but a few were simply going to require resurvey.

Our first trip to the cave for this effort was in late February 2013 and loop repair was the initial focus. Six days of survey succeeded in repairing three of the four loops, and some areas that needed resurvey were also addressed. A profile down the main passage was accomplished as well. Photos for the map were also obtained, as the cave has some well-known formations, such as the Clansman and the Christmas Tree, that I felt should be on the map. On the return home, drafting was begun, and additional resurvey requirements were identified.

We returned to the Park in late October for another four days of work. The last loop was finally repaired, with a Universal Variance Estimate (UVE) of less than one for both horizontal and vertical aspects of the survey. Some of the needed resurvey was also accomplished. Detail for profiles and cross sections were also obtained.

Much work remains to produce a truly finished map, and we have yet to start surveying leftover leads. Work will continue in 2014.

February 2013 participants—Dave West, Karen Willmes, Mark Jones, Don Dunham, Ed Klausner, Elizabeth Miller, Rick Olson, Joyce Hoffmaster, Dan Greger, and Garret Jorgensen. October 2013 participants—Dave West, Karen Willmes, Joyce Hoffmaster, Dan Greger, Charles Fox.

The Clansman. *Rick Olson*

Elizabeth Miller and Ed Klausner admire the Leaning Tower of Pisa. *Rick Olson*

Various biologists counting bats. *Scott House*

Cave Research Foundation Graduate Student Research Grant Program

George Crothers

Grant Program Chair

The 2012 and 2013 grant programs were very successful with many high quality proposals being submitted for funding. In 2012, thirteen applications were submitted and six were selected for funding at a total of $11,900. In 2013, eleven applications were submitted, and five were selected for funding at a total of $9,800. Abstracts of all of the funded projects are provided below.

Of the eleven funded proposals, we received nine reports after completion of their fieldwork, including an extensive summary of Patricia Kambesis' major work in Quintana Roo, Mexico. Congratulations to all of the recipients. We look forward to seeing their contributions to cave and karst science for many years to come.

2012 Grant Recipients

Chelsie Dugan ($2,100)

Department of Geological Sciences
Ball State University

Investigating Vadose-Zone Hydrology in Karst Aquifers using Quantitative Groundwater Tracing Methods: Timpanogos Cave National Monument, Utah

Abstract—During the spring and summer of 2012, I will undertake water-tracing and groundwater investigations at Timpanogos Cave National Monument (TICA) to help National Park Service resource managers understand the scope and characteristics of the watershed that contributes to the many cave pools in this important tourist destination in the American Fork Canyon near Provo, Utah. More specifically, I propose a series of dye trace experiments, geochemistry studies, and water isotope investigations to assess the water quality and hydrologic function of the contributing watershed to TICA, which is hypothesized to extend into adjacent United States Forest Service (USFS) lands. These USFS lands above the American Fork River and on the slopes of Mount Timpanogos are subjected to recreational off-road vehicle use, snowmobiling, commercial ranching, and mining. Each of these activities presents a potential source of contamination to surface waters that may enter the cave ecosystem. TICA managers are particularly concerned with potential contamination derived from recreational activities on these USFS lands.

Brett R. Gerard ($1,600)

Department of Biology, Aquatic Resources Program
Texas State University-San Marcos

Modeling Precipitation Thresholds Required for Recharge into a Central Texas Karst Aquifer and the Influence of Barometric Pressure on Cave Drip Rates

Abstract—Karst aquifers supply water for many aquatic ecosystems and an estimated 20 percent of the world's population (Ford and Williams 2007). Growing populations in karst regions place increasing demands on water in these systems, and to sustain the ecosystems and communities that rely on them, better management strategies are needed.

My research objectives are twofold. First, I plan to quantify the complex effects of antecedent hydrologic and environmental conditions on precipitation thresholds that must be exceeded in order for diffuse and direct recharge to occur in karstic aquifers in the Edwards Plateau, Central Texas, USA. To do this, I will use precipitation, environmental and in-cave drip and stream-discharge data to examine the complex relationship between precipitation and recharge. I will also use continuous and periodic geochemical and stable isotope data to develop hydrograph separation curves for responses under variable hydrologic and environmental conditions.

Secondly, I will examine the relationship between cave speleothem drip rates and barometric pressure. To do this, I will use the same in-cave drip data used in objective one along with surface and in-cave atmospheric pressure data. Preliminary data show a strong anti-correlation between barometric pressure and cave drip rate consistent with the findings of Genty and Deflandre (1998). Preliminary data also show a strong anti-correlation between barometric pressure and drip water specific conductance, a trend not observed by Genty and Deflandre (1998). Ultimately, the results of my research will provide information required for developing better recharge models, which are necessary for groundwater modeling and environmental management strategies.

Patricia Kambesis ($3,000)

Department of Geoscience
Mississippi State University

Speleogenetic Mechanisms in the Eastern Yucatan Peninsula, Quintana Roo, Mexico

Abstract—Carbonate islands and continental coastlines share a unique regional hydrology where cave development results from the interaction of a freshwater lens and marine waters. The regional hydrology is a function of catchment size and type of recharge. Hydrology is affected by eustatic sea-level changes and/or tectonics and can result in polygenetic caves that develop at different elevations and are overprinted with features associated with diffuse and/or turbulent flow. It has been suggested that island size controls the nature of cave development. Small islands have large perimeter-to-area ratios, and meteoric catchment can easily be discharged to the sea as diffuse flow, creating classic flank margin cave conditions. As islands grow larger, area increases by the square, but perimeter increases linearly. Because meteoric catchment increases faster than the available discharge perimeter, diffuse flow paths become longer. Under these conditions, conduit flow becomes sustainable, and cave development makes a switch to integrated turbulent flow systems. Just as with islands, cave development on continental carbonate coastlines is also a function of catchment and recharge on a regional scale. The Yucatan Peninsula exemplifies complex regional coastal hydrology that has been subject to eustatic sea-level changes. In the Yucatan, these conditions are expressed as different types of caves, from vast underwater cave systems to flank margin caves as end members. The purpose of this study is to determine the speleogenetic mechanisms that have resulted in the formation of a spectrum of caves types in close geographic proximity that range from turbulent flow to diffuse-flow systems.

Amy R. Michael ($1,700)

Department of Anthropology
Michigan State University

The Use of Dental Microscopy in the Investigation of Social Experience and Status of Non-Elites in Ancient Maya Cave and Rockshelter Mortuary Sites: Interpreting Health Differences in Disparate Social Groups in the Caves Branch River Valley, Belize

Abstract—The ancient Maya subscribed to an ideological system that was deeply entrenched in the assignation of supernatural powers to earthly features. Caves figure prominently in Mayan ritual beliefs, a notion reflected by the burial of the dead in these environments. Although archaeologists have long known of the presence of human remains in caves, explanations for these interments vary from evidence for human sacrifice, to ancestor worship to expedient disposal of the dead.

The aim of this project is to use standardized scanning electron microscopy methods to analyze the dental microstructure of individuals buried in caves and rockshelters in order to assess health quality and to infer social experience, especially that of the non-elite population. Biological data (to investigate health) and archaeological data (to investigate use of cave and rockshelter mortuary space) are employed to determine if there is validity to the hypothesis that caves were restricted zones reserved for elites, while rockshelters were openly accessed repositories for non-elites.

A binary model of health stress (elites did not suffer, while non-elites suffered greatly) likely does not encapsulate the experience of either group and does not explain the subtle, graded stratifications within the overarching social hierarchy. Analysis of these mortuary environments will reveal information on Maya lifeways and death rituals, leading to a better understanding of the importance and use of caves in ancient burial programs. This project combines the disciplines of archaeology, physical anthropology, and geochemistry to analyze mortuary data and to make inferences about prehistoric ritual behavior.

Gilman Ouellette ($1,500)

Department of Geography and Geology
Western Kentucky University

Paleohydrology and Climate Change in the Eastern Caribbean from Barbadian Speleothems

Abstract—Ground water resources on island nations such as Barbados are highly sensitive to changes in precipitation regimes. To understand and manage water resources most effectively, a strong understanding of the geographically unique climate/ground water interactions is necessary. To this end, a high-resolution reconstruction of late Holocene precipitation on the island of Barbados will be reconstructed from multiple speleothem stable oxygen isotope records. The reconstructed paleoprecipitation patterns will be analyzed using time series analysis, elucidating the role major climate influences play in modulating water availability throughout the Late Holocene. This research will provide insight into how the climate of the Eastern Caribbean (and thus groundwater resources) has changed in the past several thousand years as well as the causal mechanisms affecting these changes. This information is vital in understanding regional and global climate change, as well as managing the limited groundwater resources of Barbados and nearby islands in the face of future climate change scenarios.

Kendra L. Phelps ($2,000)

Department of Biological Sciences
Texas Tech University

Conserving Cave Bats in the Philippines: Assessing the Impact of Cave Disturbance on Bat Communities

Abstract—The Philippines harbor a vast diversity of bat species, many of which are unique to the tropical archipelago. Nearly half of these bat species are dependent upon caves as roosting sites for rearing young and shelter from weather. Tragically, cave-dependent bats in the Philippines are threatened by human activities; this is particularly so on Bohol Island. Human pressures on cave bats are occurring at multiple scales on Bohol Island, including widespread landscape disturbances from illegal logging that results in the loss of foraging sites. Localized disturbances from residents, including hunting, cave tourism, and guano mining, add additional pressures. Such threats jeopardize the viability of cave-dependent bats. My study aims to compare cave-dependent bat communities among caves experiencing differing levels of human disturbance on Bohol Island to: i) assess the status of cave bats in an increasingly human-dominated landscape in order to identify priority caves; and ii) pinpoint threats that have the greatest impact on cave-dependent bats. Specifically, this study will quantify disturbance levels at 60 caves on Bohol Island using a modified karst disturbance index, and compare with species diversity and composition of cave bat communities documented over two consecutive nights. Results will be used to evaluate the significance of individual caves for maintaining viable populations of cave-dependent bats, identified as a priority under the Philippine National Caves and Cave Resources Management and Protection Act. Furthermore, assessing threats to cave-dependent bats allows for identification of the most detrimental forms of human activities, critical information for developing effective management strategies.

2013 Grant Recipients

David D. Decker ($3,000)

Department of Earth and Planetary Sciences
University of New Mexico, Albuquerque

Effects of Landscape Evolution on the Growth of Sub-aqueous Speleothems—Rise of the Guadalupe Mountains

Abstract—The timing of the rise of the Guadalupe Mountains is in dispute. One model suggests they didn't reach their present height until recently, during the Rio Grande rifting. A second model suggests that the Laramide orogeny was the culprit for the major uplift. I suspect there were three instances of mountain building, and a combination of the three led to the present 2 km+ height of the Guadalupe Mountains.

A new technique that will better constrain the orogenic episodes will be tested in the Guadalupe Mountains to evaluate its effectiveness in determining the timing and magnitude of the uplift events. By correlating the growth of speleothems (specifically scalenohedral dog tooth spar) both temporally and spatially with the injection of basalt dikes in the region, we can develop a proxy for the timing and uplift of the mountains. Using radiogenic isotopes (U, Th, and Pb) to determine the age of the cave formations, and stable isotope analysis of fluid inclusions to gain information on temperature of formation and formation waters as well as chemical signatures of the intrusive igneous rocks in the region, we can develop a method for correlating the growth of the sub-aqueous speleothems with the igneous intrusions and from there determine the processes that may have been occurring at the surface during the growth of the spar as well as the timing of these processes.

This method may be expanded by use of vein filling and nail head spar and will be a valuable process for determining landscape evolution in other areas of the country, specifically the Colorado Plateau, the Ozark Mountains, and the Black Hills.

John DeDecker ($1,500)

Department of Geological Sciences
University of North Carolina at Chapel Hill

Correlating Lava Tube Morphology with the Petrologic and Petrographic Characteristics of the Host Rock

Abstract—There is an inverse relation between length and viscosity in the Hagen-Poiseuille equation used to model tube confined flow. Lava viscosity is related to the compositional and textural properties of the lava. Lava viscosities can be estimated from subsolidus basalts using the compositional and petrographic properties of the rock and methods developed by Marsh (1981), McBirney and Murase (1984), Ishibashi and Sato (2007), Giordano et al. (2008).

According to the Hagen-Poiseuille equation, there should be a correlation between lava tube morphology (length in particular) and the petrographic and petrologic characteristics of the lava that solidified at the time of tube formation. This study seeks to determine whether such a correlation exists by estimating the viscosity of the lava using compositional and textural data acquired from samples collected from lava tubes, and by constructing 3-D maps to constrain the length, radius, and slope of sampled lava tubes. It is expected that longer lava tubes will be correlated with rock compositions and petrographic textures indicative of lower viscosity lavas, and shorter lava tubes will be correlated with compositions and textures indicative of higher viscosity lavas.

Chris Myers ($2,800)

Department of Earth and Environmental Sciences
Vanderbilt University

Paleoseismology of the Shillong Plateau, India: Constraints from U/Th Dating of Tectonically Broken Cave Deposits

Abstract—Recent uplift of the Shillong Plateau in northeast India has produced numerous mega earthquakes such as the estimated 8.7 magnitude Great Assam Earthquake of 1897[1]. Previous paleoseismic research of Shillong Plateau has relied upon radiocarbon techniques to date organic material found in liquefaction features created by large seismic events [2]. A lack of observable surface ruptures on the plateau, 50,000-yr-dating limit, and large age uncertainties (~150 yrs) limits the accuracy as well as the temporal (~2,000 yrs) and spatial span of this paleoseismic approach [2]. Broken cave deposits (speleothems) can experience various forms of breakdown during seismic events such as sub-horizontal fracturing and collapse of stalagmites as well as fracturing of thin soda straw stalactites. U-series dating of carbonates such as speleothems allows breakage events to be dated more accurately over longer time scales (500,000 yrs) than previously possible with radiocarbon techniques. An initial U-series analysis has produced errors of ± 65 years for a 15,000-year-old aragonite stalagmite from the plateau suggesting that speleothems from this region can be dated with high precision. Using broken speleothems as paleoseismic archives allows for a more precise way to date paleoseismic events and estimate reoccurrence intervals more accurately. I propose to constrain speleothem breakage events caused by mega earthquakes on the Shillong plateau using U-series dating techniques. If successful, my proposed research would greatly increase the current record of seismic events in northeast India, and provide invaluable risk assessment information for the people of northeast India and Bangladesh.

Daniel Nedvidek ($1,500)

Department of Geography and Geology
Western Kentucky University

Evaluating the Impact of Injection Wells and the Effectiveness of Regulatory Sampling Protocols for Stormwater on Groundwater Quality in Karst Regions

Abstract—The City of Bowling Green (CoBG) is situated on a karst landscape, typified by a lack of surface streams, numerous sinkholes and thin soils. The lack of surface streams in the Bowling Green area, combined with thin soils, makes the cave systems in the area natural candidates for storm water runoff control through the use of injection wells, which direct water into underground streams and aquifer systems. Understanding the impacts of Class V injection wells on groundwater is necessary, as these unfiltered, uncased wells are allowable under EPA regulation as long as they do not impair underground sources of drinking water (USDW), including those sources currently under use and those that could be used in the future (US EPA 40CRF 144.3). Although the CoBG primarily obtains its drinking water from the Barren River, which has significant karst spring inputs, the entire watershed is impacted by urban and agricultural land use both upstream and down. Under the Safe Drinking Water Act and the Federal Underground Injection Control Program, preventing the contamination of the CoBG's groundwater is important for regulatory compliance, and also for downstream users and the overall health of the ecosystem. While results from previous studies suggest that the harmful storm water runoff and the use of injection wells to control that runoff are mitigated by dilution provided by the Lost River, we expect to show that expanding population and changing land use make storm water runoff a much more credible threat to groundwater quality than it has been in the past.

Nicole M Ridlen ($1,000)

Department of Geosciences
Mississippi State University

Speleothem Strontium Concentrations as a Function of Aragonite/Calcite Inversion

Abstract—The presence of strontium (Sr) in carbonate rocks has been documented and has been recognized as a contributor to the trace element content of speleothems used for paleoclimate reconstruction. The Sr in speleothems can originate from multiple sources although the majority of Sr analysis in speleothems has been assumed to be infiltrated from a surface. The aragonite crystal structure allows for a greater amount of Sr to exist in the bedrock. It is hypothesized that younger carbonates, such as those in the Caribbean, can contain more Sr than older carbonates that have already inverted to calcite prior to cave formation. Island carbonates, such as the carbonate units deposited as aragonite on Curaçao, are terraced where the oldest unit is on top and inland, and the youngest on the bottom and seaward. Samples from Bahamian caves of similar age should provide a comparison with a climatic variant.

Three questions are to be asked during this research. 1) Does the primary aragonite content of the young carbonate host rock register as the Sr content of Caribbean speleothems and have a direct relationship with the age of the host rock at the time of precipitation? 2) Do older speleothem layers contain less Sr than younger speleothem layers in the same climatic setting from young carbonate host rock with the same initial primary aragonite content? 3) Is there a variation in the primary aragonite content, and hence Sr content of speleothems in young carbonates of the same age but from different climates?

Modeling Precipitation Thresholds Required for Recharge into a Central Texas Karst Aquifer and the Influence of Barometric Pressure on Cave Drip Rates

Brett R. Gerard[1]

Texas State University, Department of Biology, 601 University Drive, San Marcos, TX 78666

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Research Summary

A better understanding of controls on karst recharge processes is essential for developing improved resource management strategies in regions where populations rely on karstic groundwater (Jones et al. 2000). Water management is of particular concern to many users and managers of karstic groundwater systems of central Texas, which are experiencing greater stress due to increased pumping and recurring drought. This project was a direct response to the need for an improved understanding of these systems. We quantified infiltration and recharge at a site in the karstic Trinity Aquifer of central Texas, one of the most utilized aquifers in the state (George, Mace, and Petrossian 2011). The objectives of this study were: 1) to use multi-year cave drip monitoring coupled with environmental data to create predictive models for recharge to the system; 2) provide new estimates of recharge rates to the system; 3) examine recharge composition from storm events of varying environmental conditions; 4) propose a new mechanism for "noise" observed in speleothem drip data during inter-rainfall periods.

To address these objectives data was collected from Cave Without a Name (CWAN), located ~35 km northwest of San Antonio, Texas. CWAN is formed in the Middle Trinity Aquifer, a subdivision of the Trinity Aquifer that supplies water to ~85% of the wells in the Hill Country (Jennings et al. 2001). Six in-cave sites were instrumented to record a number of hydrologic and geochemical parameters. Above the cave, soil moisture was logged, a weather station recorded a suite of environmental parameters, and precipitation samples were regularly collected. Precipitation and water samples collected from in-cave sites (collected weekly to monthly) were analyzed for liquid water stable isotopes, anions, and cations.

Utilizing time series data from CWAN, mixed effect logistic models were analyzed to explore the importance of environmental variables, rainfall characteristics, and antecedent moisture conditions in predicting recharge responses at in-cave monitoring sites. Results of this analysis indicated that a model including the event rainfall sum, antecedent soil moisture, and the sum of potential evapotranspiration (PET) over the previous twelve weeks is best at predicting a recharge response (prediction success of 88.7%). For cross-validation of the model, randomly selected calibration and validation datasets were used. Analysis of the calibration dataset indicated that a model including the rainfall sum, antecedent soil moisture, and the sum of PET over the previous fourteen weeks is best (prediction success of 87.7% for calibration dataset and 91.4% for validation dataset). A linear regression analysis was also performed to investigate the importance of these variables on predicting response magnitude at an in-cave stream, the most integrative site in the system as it includes contributions from at least 4.5 km of mapped conduits that collect, transport, and integrate diffuse and direct recharge from various sources. Results indicated that event rainfall

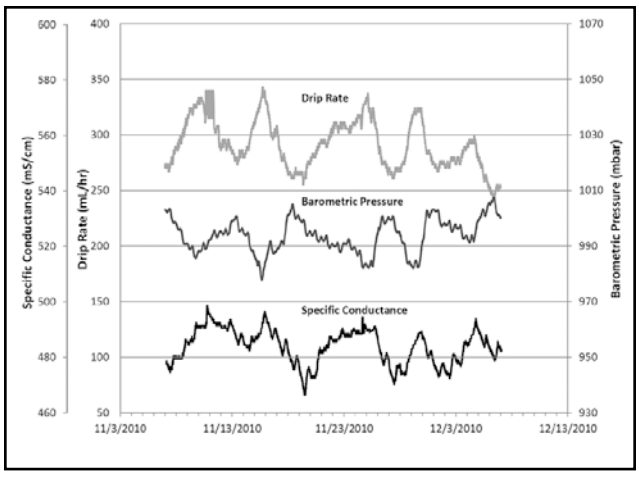

Figure 1: A segment of a speleothems drip time series illustrating the negative correlation between barometric pressure and drip rate as well as the negative correlation between barometric pressure and specific conductivity.

From Schwartz et al. (2013)

sum and the sum of PET over the previous ten weeks is best at predicting response magnitude. Cumulatively these results demonstrate the importance of antecedent conditions in controlling how connected epikarst flow paths are, and how and when the epikarst transmits recharge to the groundwater system. Furthermore, the combination of these models allow for the prediction of recharge occurrence and magnitude in this system.

Using deuterium ratios of precipitation and in-cave samples collected at frequent intervals (hourly to daily) before, during, and after recharge responses from a late summer rainfall in 2010 and a late winter rainfall in 2012, we examined and compared recharge response composition using a two end-member mixing model (EMMA). Event water response contributions to in-cave sites were quantified, revealing complexities in recharge composition due to antecedent conditions, rainfall characteristics, and site specific conditions. These factors were shown to strongly influence response magnitude and the event water contributions, while site characteristics heavily influenced response dynamics.

Recharge estimates for the Middle Trinity Aquifer were calculated using a chloride mass balance method. Our estimates ranged from 4.3% to 11.1% of total precipitation, which is consistent with previous studies (Ashworth 1983; Bluntzer 1992; Kuniansky and Holligan 1994; Kuniansky 1989; Mace et al. 2000). As a further check of our estimates, a basin size was calculated for the in-cave stream which runs the length of CWAN. This resulted in a basin size of ~27 km^2, which is realistic given the extent of the cave system and the local geology.

We additionally examined the cause of fluctuations at speleothem drip sites during baseflow conditions (Figure 1), which was found to be negatively correlated with barometric pressure. To our knowledge, few previous studies have examined this mechanism and/

Table 1: Regression analysis of the selected logistic mixed effect models (the full dataset and the randomly selected test dataset) and the selected linear regression model for the response magnitude data set for the in-cave stream, and the prediction success of the logistic mixed effect models.

Logistic Mixed Effect Model (Full Dataset)

Variables in Selected Model

Coefficient	Estimate	Standard Error	Wald	P-Value
Intercept	-5.20	2.09	-2.49	0.01
Precipitation Amout (P_s)	0.18	0.04	4.34	< 0.01
Soil Moisture (θ)	0.19	0.06	3.29	< 0.01
12-Week PET (PET_{12})	-0.01	0.00	-3.41	< 0.01

Classification Table

	Predicted		
Observed	No Response	Response	% Correct
No Response	81	4	95.29%
Response	9	21	70.00%
Overall % Correct			88.70%

Logistic Mixed Effects (Cross-validation)

Variables in Selected Model (Calibration Dataset)

Coefficient	Estimate	Standard Error	Wald	P-Value
Intercept	-3.86	2.89	-1.34	0.18
Precipitation Amout (P_s)	0.22	0.07	3.31	< 0.01
Soil Moisture (θ)	0.20	0.08	2.38	0.02
14-Week PET (PET_{14})	-0.01	0.00	-2.80	0.01

Classification Table (Calibration Dataset)

	Predicted		
Observed	No Response	Response	% Correct
No Response	39	1	97.50%
Response	6	11	64.71%
Overall % Correct			87.72%

Classification Table (Test Dataset)

	Predicted		
Observed	No Response	Response	% Correct
No Response	42	3	93.33%
Response	2	11	84.62%
Overall % Correct			91.38%

In-Cave Stream Linear Regression

Variables in Selected Model

Coefficients	Estimate	Standard Error	t-value	P-Value
Intercept	104.04	68.64	1.52	0.16
Precipitation Amout (P_s)	6.21	0.76	8.19	< 0.01
10-Week PET (PET_{10})	-0.53	0.21	-2.52	0.03

or proposed a mechanism driving this correlation (Genty and Deflandre 1998). We have proposed a new mechanism (Schwartz 2013). As the epikarst transitions from wet to drier conditions, large pores and poorly connected fissures drain slowly and become air-filled. During the next wetting/recharge event, air bubbles or pockets are trapped as these sites are partially filled. As barometric pressure decreases, these bubbles/pockets expand and force water into larger flow paths, increasing head and discharge at the drip site. Geochemical time series data provide evidence supporting this concept (Figure 1); an anti-correlation between drip water specific conductance and barometric pressure. As proposed, when barometric pressure decreases, expanding bubbles/pockets force water out of fissures. This would, as observed, result in an increase in the conductivity of drip water because water forced out of the fissure and into the flow path of the drip will be more chemically saturated due to a longer period of water-rock interaction.

The results of this research present a strong and quantifiable relationship between recharge and antecedent moisture, environmental parameters, and rainfall characteristics. This relationship was shown to exist through the use of stable isotope mixing models and regression analyses. Recharge estimates made using the chloride mass balance method closely match previous estimates for the region and further validate these estimates. This project is also the first in the region and one of few worldwide to look at the effect barometric pressure fluctuations have on infiltrating epikarstic waters. We have proposed a new hypothesis for the mechanism driving this relationship and have provided supporting evidence.

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The Geologic Controls on the Development of Caves within the Phreatic, Epiphreatic, and Vadose Zones on the Northeast Coast of Quintana Roo, Mexico

Patricia Kambesis

a. Introduction

The northeast coast of the Yucatan peninsula within the state of Quintana Roo, Mexico, is an example of a carbonate coastline with a complex regional hydrology that has resulted in the formation of an extensive, density stratified, conduit-drained aquifer. Exploration and mapping of the extensive conduits (underwater cave systems) have been ongoing since the mid-1980s, and there is a large dataset that describes their character and extent. All caves in the region are not submerged and some occur in the vadose-epiphreatic zone of the aquifer. Exploration and documentation of the vadose and epiphreatic-zone caves are still in early stages, so there is a considerable amount of exploration bias in the existing data. This research compared the features and characteristics of the underwater caves with those caves located within the vadose-epiphreatic zone. Though there are a few striking exceptions, both groups of caves displayed two different morphologies: inland cave passages follow a northwest trend and form linear, anastomosing conduits that are perpendicular to the coast. Cave passages at or near the coast and within beach ridges consist of rectilinear mazes that parallel the coast and/or the beach ridges. Analyses of cave data and maps indicate that cave system configuration and passage morphology are influenced by regional and local structures as well as stratigraphy. Passage morphologies are also influenced by local conditions such as ceiling collapse or speleothem development both which may result in stream diversion. Comparison and analyses of the underwater caves with the vadose-epiphreatic zone caves of the region indicated that they share the same characteristics with the exception of elevation and location with respect to the coast. The vadose-epiphreatic zone caves occur at slightly higher elevations than the submerged caves and are absent in areas less than a kilometer from the coast. The very similar morphologies of both groups of caves indicate that the vadose-epiphreatic zone caves formed from the same processes as the underwater caves, i.e., mixing-zone corrosion. This strongly suggests that the vadose-epiphreatic zone caves formed when sea level was higher during MIS5e and became stranded in the vadose zone when sea levels subsequently dropped. A more comprehensive understanding of cave development was accomplished by the study of all caves in the region regardless of their position with respect to sea level.

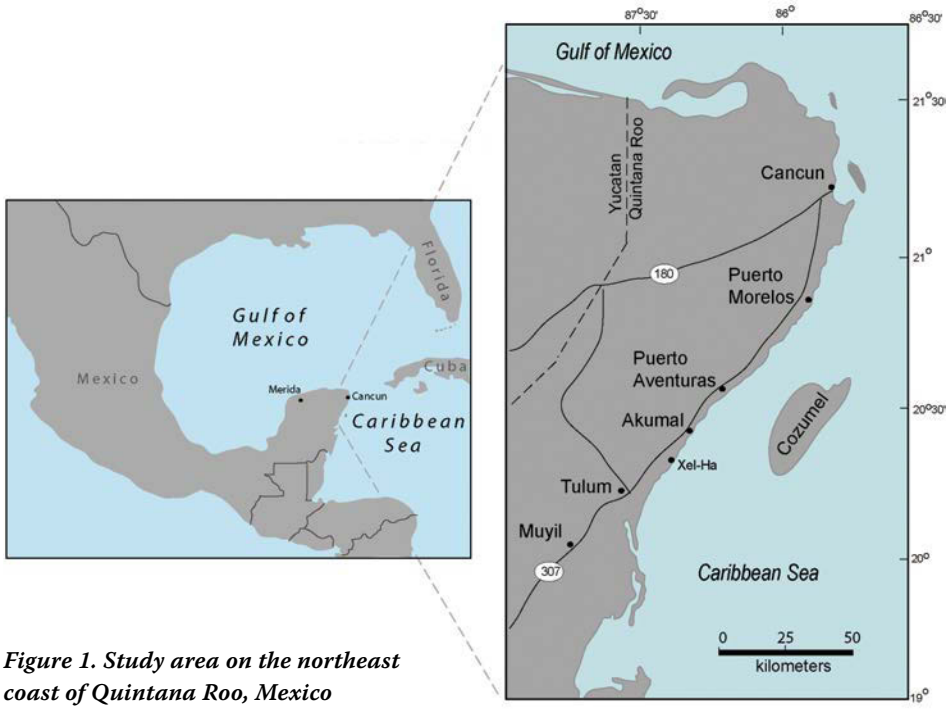


Figure 1. Study area on the northeast coast of Quintana Roo, Mexico

b. Study site overview

The state of Quintana Roo, Mexico, located along the northeast coast of the Yucatan peninsula (Figure 1), consists of an eogenetic carbonate coast whose complex regional hydrology has resulted in the formation of an extensive conduit-drained aquifer (Beddows 2004, Smart et al. 2006). On the Caribbean coast of Quintana Roo between Puerto Morelos and Muyil, over 1309 km of submerged cave passages within 337 cave systems have been documented (QRSS 2015). In addition to the underwater cave systems

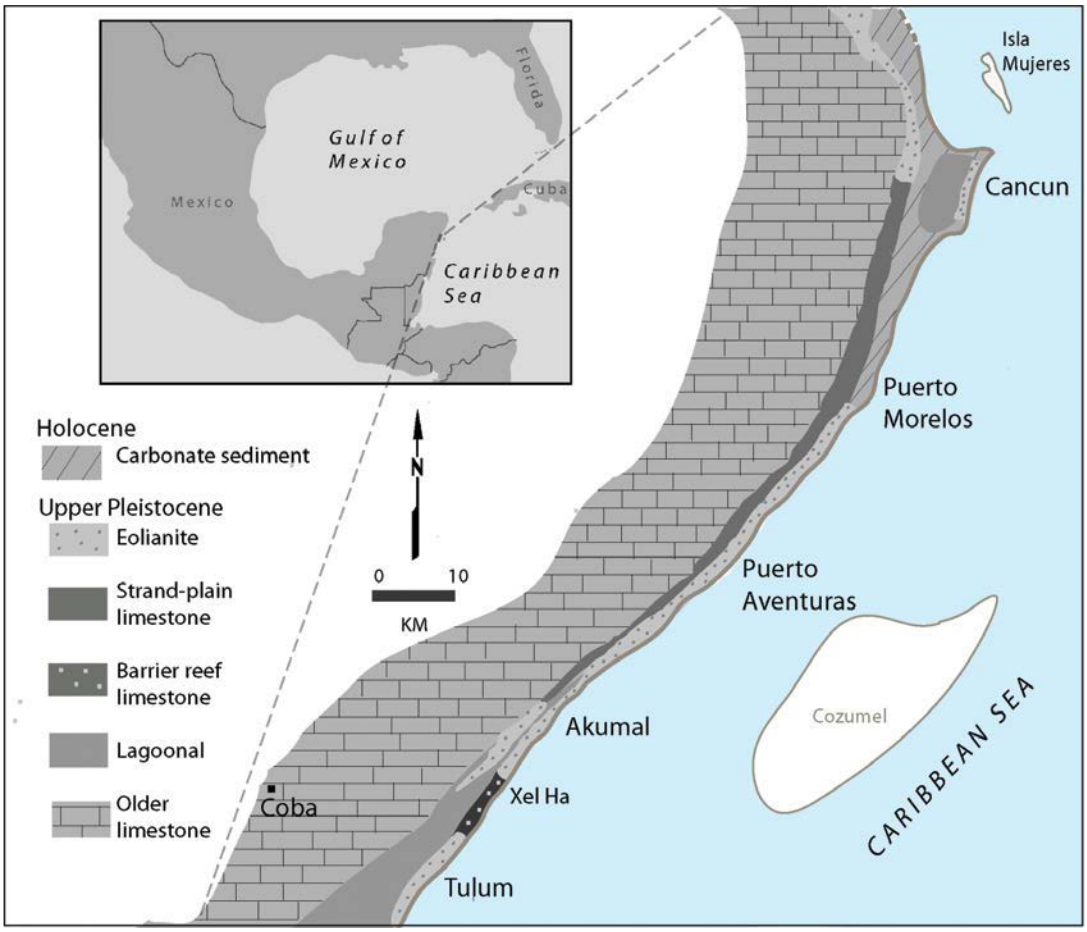


Figure 2. Stratigraphy of the northeast coast of Quintana Roo, Mexico *Modified from Ward 1985*

are caves that currently reside in the vadose-epiphreatic zone of the aquifer as well as flank margin caves located in eolianites along the coast near Tulum (Kelly et al. 2006). So far 315 km of passages within the vadose zone have been documented. North, south and west of this extensive block of cave development, the density of cave passages appears to notably decrease.

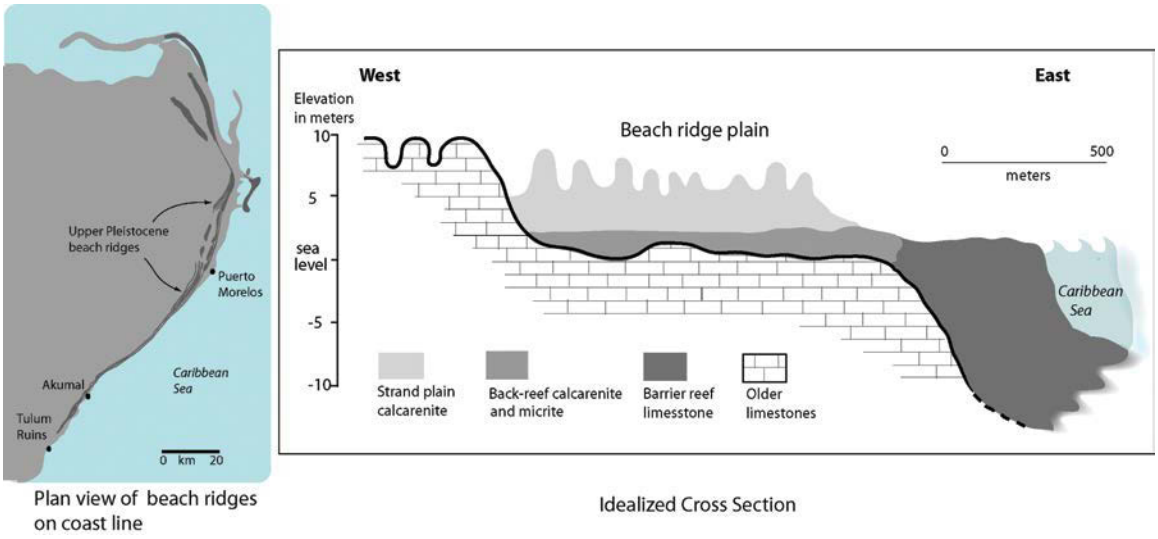
The climate of the Yucatan peninsula is tropical with distinct wet and dry seasons (Kottek et al. 2006). The average annual temperature is 26°C, with a range in monthly averages between 23 and 29°C (Beddows 2004). May to September is the hot, rainy season and October to April is the relatively cooler, dry season. There is a significant east–west precipitation gradient across the peninsula (Neuman and Rahbek 2007). The Caribbean coast is the wettest side with >1500 mm of precipitation per year (Gonzalez-Herrera 2002).

The stratigraphy of the study area is summarized in Figure 2. A narrow ridge and swale plain of Upper Pleistocene limestone located five to ten meters above present sea level, characterizes the northeast coast of Quintana Roo between Cancun and Tulum (Ward and Brady 1979) (Figure 3). Ridge crests are one to five meters above the swales and are spaced 50 to 200 meters apart, paralleling the modern coastline (Ward 2003). There are as many as 20 ridges at the widest part of the plain, but they all coalesce south of Akumal (Beddows 2003). The Middle Pleistocene unit, which is 150 km long, up to 4 km wide and 3–10 m thick, underlies the beach-ridge plain, and is exposed at the surface as a low-relief karst plain due west of it (Ward 2003). East of the beach-ridge plain are Upper Pleistocene barrier-reef limestones.

Quintana Roo is within the Eastern Block-Fault district that extends from Cape Catouche on the northeast coast, to the Yucatan's border with Belize. The two main faults/lineaments in Quintana Roo are the Holbox Lineament Zone and the Rio Hondo Fault Zone. The structure of the study area is shown in Figure 4.

The coastal karst aquifer of Quintana Roo is unconfined and recharged by precipitation from extensive inland areas north of Akumal for cave systems north of that area and from the west near Muyil for the underwater cave systems

Figure 3. Ridge and swale plane of the northeast coast of Quintana Roo, Mexico *Modified from Ward 1985*



in the vicinity of Tulum (Kambesis and Coke 2013). The aquifer responds to short term conditions such as heavy rains, barometric pressure, tides, and ocean density, which supports the hypothesis that base flow originates far inland from the coast (Neuman and Rahbek 2007).

The karst aquifer is density-stratified where a thin meteoric-derived freshwater lens floats on the denser saline water (Lesser 1980). Separating the fresh from saline water is the halocline, which is a density and temperature transition zone that serves as a hydrochemical mixing zone. Freshwater and saltwater flow is decoupled at the halocline that is thickest near the coast but decreases inland to a sharply defined boundary (Beddows 2003, 2004). The mixing zone responds to several factors including conduit cross section, turbulence from conduit discharge, and tidal pumping, although the effects of the latter diminish inland (Beddows 2004).

Aquifer discharge of groundwater to the Caribbean Sea is via a network mesh of conduits of varying size from tens of millimeters in width to humanly enterable passages, which can range up to 80 meters in width (QRSS 2013). Beddows (2004) gave a crude estimate of coastal discharge within the 80 km section of Caribbean Yucatan coast in her study area to be 2.3 x 10^7 m^3/year per kilometer of coast.

Though there is an absence of flow indicators (scallops) in the underwater caves of the region, cave divers report strong water flow within many of the underwater passages and the observed occurrence of dunes of white silt along the perimeter of cave passages, indicating turbulent flow (Coke personal communication 2013).

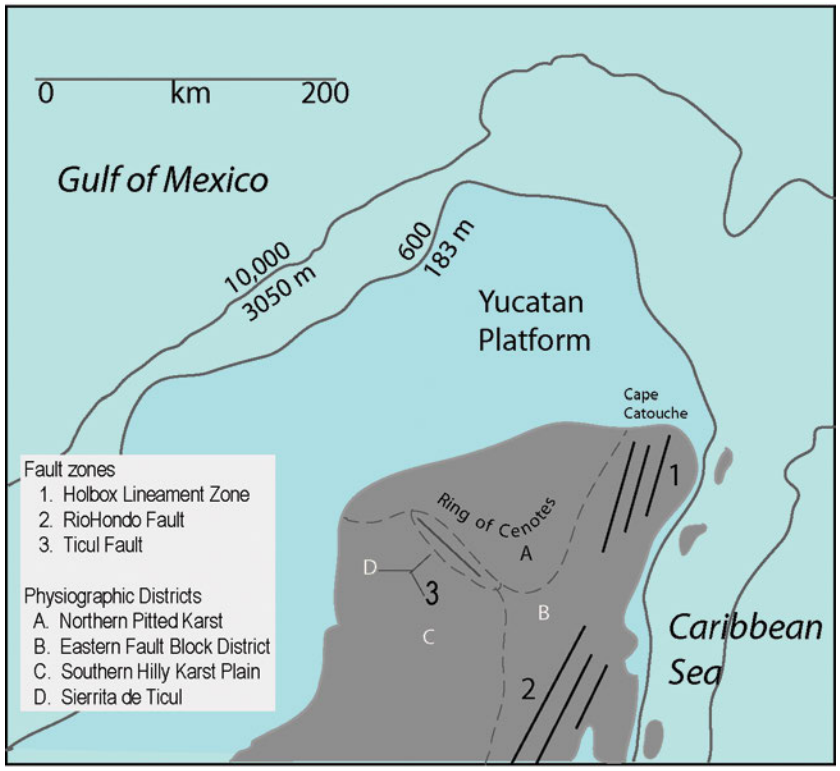


Figure 4. Structural features of the Yucatan peninsula
Modified from Beddows 2003

Precise vertical control is lacking on the peninsula overall but elevation in Quintana Roo is about 30 m or less above sea level with local relief of 5 m but rarely exceeding 10 m. Lack of surface drainage features coupled with minimal vertical control make it impossible to identify individual drainages basins (Beddows 2004). Instead, sub-regional distinctions have been made based on fault zones and subtle variations in surface topography (Lesser and Weidie 1988).

Surficial karst features characteristic of the study area are collapse cenotes that form by mechanical collapse of the ceilings of shallow phreatic cave systems when buoyant support is lost as a result of low sea levels (Beddows et al. 2007b). Cenote density above the extensive underwater cave systems of Quintana Roo is about one cenote for every 300 meters of cave passage (Neuman and Rahbet 2007).

Dry sinkholes are extremely common in the high density cave block between Puerto Morelos and Muyil. These features have the same origin as the collapse cenotes that serve as portals to underwater cave systems. The dry sinkholes access cave passages currently within the vadose zone.

Significant groundwater discharge to the Caribbean Sea occurs via springs and small discharge vents associated with submerged phreatic conduits. An inventory of coastal discharge feature for this study documented 20 coastal springs and numerous small outflows and seeps. Coastal inlets (or lagoons), called caletas, are narrow coves that extend inland for up to several hundred meters and are associated with larger coastal springs (Back et al. 1979: Figure 1.7). Caletas form where discharging freshwater conduits mix with saltwater at their seaward margins causing an increase in local dissolution and inducing conduit collapse that migrates inland to form a cove (Beddows 2004). As dissolution continues to act on the caleta limestone and weakening it by solution channels, they become more vulnerable to mechanical erosion by wave action (Back et al. 1979). As the inlet opening widens, waves have greater access to the caleta walls, which eventually erode to form a crescent-shaped beach (Back et al. 1979). Caletas and crescent-shaped beaches are an example of coastal reentrants produced by dissolution that characterize some carbonate coasts (e.g., Stafford et al. 2004, Kambesis et al. 2012).

Since the 1980s, the Caribbean coast of Quintana Roo, Mexico has been the focus of intense underwater cave exploration. Cave divers have documented an extensive series of linear, phreatic interlinked and anastomosing conduits within a 132 km^2 block of coastline that extends from Puerto Morelos south to Muyil on the northern boundary of the Sian Ka'an Biosphere Reserve, and inland from eight to twelve km from the coast, which is near the eastern boundary of the Holbox Lineament Zone (Smart et al. 2006). This zone of cave development corresponds to the 10–12 km band of Pleistocene carbonates that rim the Caribbean Yucatan coast from Cancun to Tulum and beyond. In addition to the underwater caves systems are caves that currently reside in the vadose-epiphreatic zone of the aquifer as well as flank margin caves located in eolianites along the coast near Tulum (Kelly et al. 2006). North, south and west of this extensive block of cave development, the density of cave passages appears to notably decrease.

c. Methods

Field work for the vadose zone caves of the study area consisted of mapping, inventorying and geo-locating caves and karst related features. Data were transformed to digital cave maps volumetric plots, and shapefiles for morphometric analysis. Existing maps were scanned in order to be included in the analyses.

Caves were mapped using Suunto compass/clinometer, and laser-range finders (with fiberglass tape backup). Garmin GPSMAP CSX 60 hand held GPS units were used for geo-referencing cave entrance locations, sinkhole collapses and coastal discharge features (datum to NAD 83 UTM) that were added to a karst feature inventory of the area. Each location was recorded to a 3-meter radius using the unit's location averaging function. Coastal features that could not be accessed in the field were assessed via remote sensing applications.

WALLS V2-B8 by David McKenzie, a freeware cave data reduction/plotting program distributed by the Texas Speleological Survey, was used to reduce and plot survey data to scalable vector format (SVG) for analysis and map production and to export shapefiles for use in ArcGIS™. Survey notes were scanned, and along with SVG line plots, imported into Adobe Illustrator® for manuscript map production.

Digital data sets from underwater and vadose zone caves were used to generate a series of rose diagrams for passage azimuth and inclination. Frequency plots made from the vertical component of the survey datasets were made to show cave passage development with respect to current sea level.

Cave maps and cave-feature locational data were projected on satellite imagery in order to quantify distribution and density of cave passages and cave features.

Morphometric comparisons of underwater and vadose zone caves at the system and passage level were conducted by direct comparisons of cave maps and from calculating fractal dimension, which measured passage complexity.

A significant number of maps of vadose-zone caves were available for use in this research. Though 1309 km of survey has been conducted in the underwater caves of the study area, most remain as line plots with no passage detail. This reflects the difficulty in detailed data collection during the

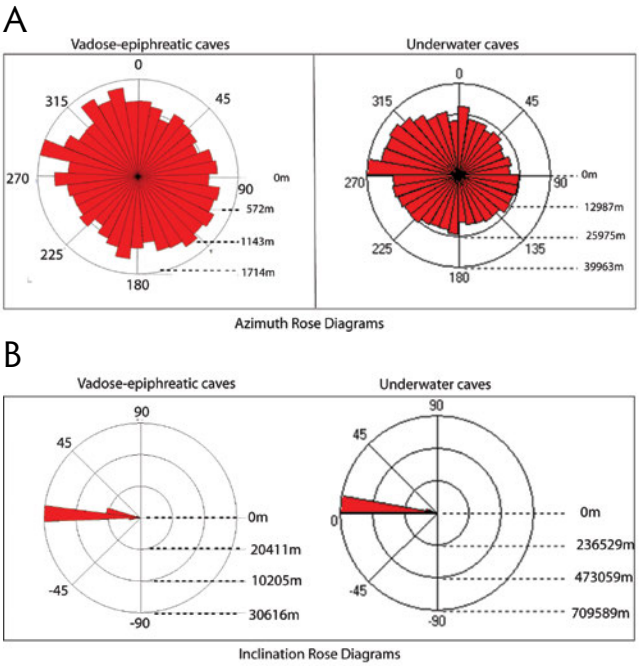


Figure 5.* (A) *azimuth rose diagrams from regional cave data;* (B) *rose diagrams on inclination.

From regional cave survey data of vadose-epiphreatic zone and underwater caves. Data for underwater caves: QRSS 2013

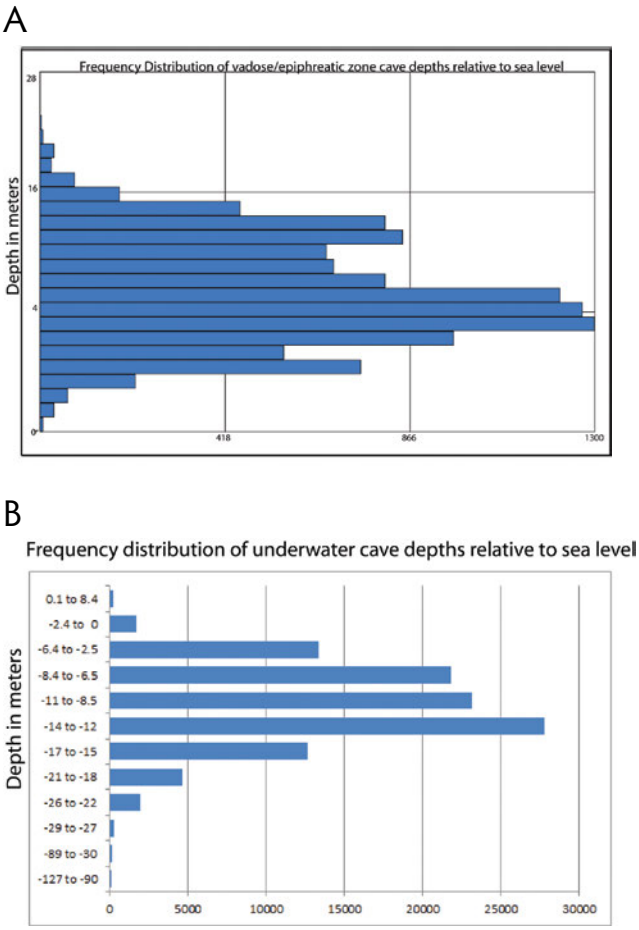


Figure 6.* (A) *frequency distribution on depth for vadose zone caves relative to modern sea level;* (B) *frequency distribution of underwater cave depths relative to modern sea level.

Data source: QRSS 2013

high-risk activity of cave diving. A small portion of the data is detailed enough and has been transformed to data-rich cave maps. Sistema Sac Actun, which is the longest cave in Mexico and second longest in the world, does have maps detailed enough for morphometric analysis. Because of its great extent, it served as a type example of underwater caves with which to make comparisons for this study.

d. Results

Separate sets of rose diagrams for azimuth and inclination, based on regional survey data for the vadose zone and underwater caves were generated for structural analysis. The azimuth diagrams (Figure 5a) for vadose zone and underwater based on regional data display a strong northwest–southeast component to cave passage development though there appears to be a stronger east–west component in the underwater caves. The inclination rose diagrams (Figure 5b) are very similar for both data sets.

Frequency distribution graphs were generated to display regional vertical development with respect to sea level. The vadose zone caves (Figure 6a) obviously show vertical development above sea level; three dominant elevation zones are 2, 4 and 8 meter above sea level. The underwater caves (Figure 6b) show predominant vertical development at the following depths: -15m to -21m, -11m to -14m, and at -6m to -8m. In the underwater cave dataset, three sections of significantly deep cave development have been documented by cave divers at Hoyo Negro, Aktun Hu (-60m), Blue Abyss, Nohoch Nah Chich (-70m), and The Pit–Dos Ojos (-119m). Significant cave depth has also been documented in submerged cave passages located less than 200 meters from the coast (Bordignon personal communication 2014).

There is some passage development noted above sea level for the underwater caves at elevations 0–8 m and this area is located within Sistema Sac Actun. It is not certain if the tendency for minimal vadose zone passages above underwater caves is a typical characteristic of underwater caves in general or if it is an expression of exploration bias that favors the documentation of underwater caves over dry cave.

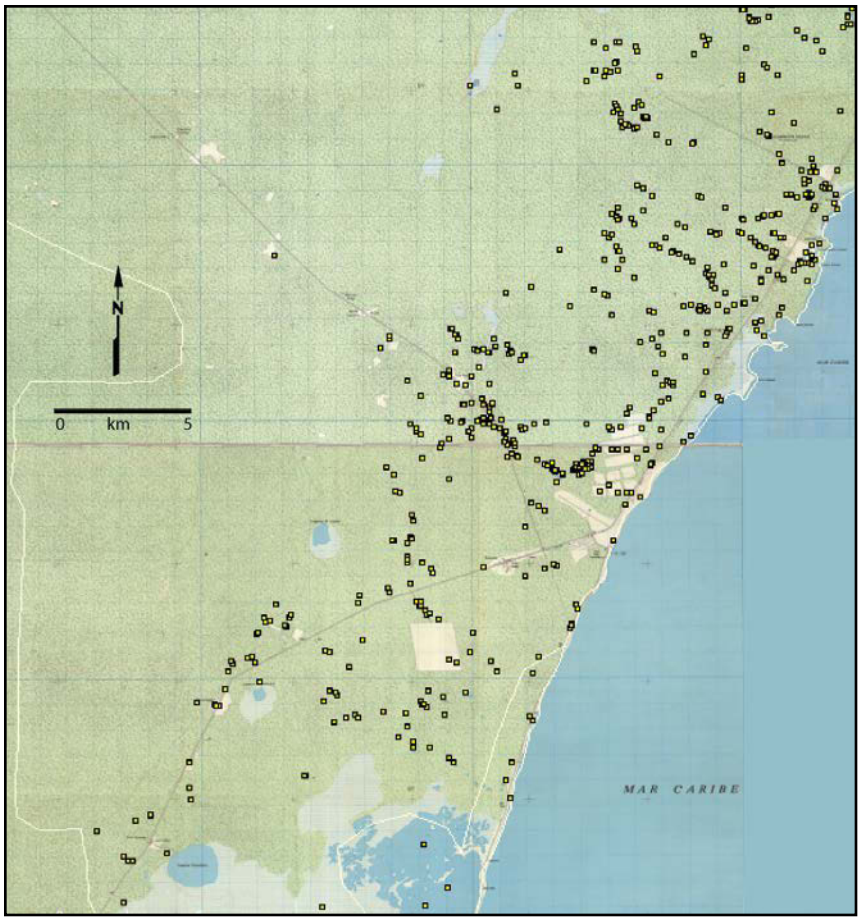


Figure 7. Cenote distribution from Sian Ka'an Reserve to Akumal

i. Collapse feature distribution (cenotes and dry sinkholes)

The karst feature inventory shows the distribution of cenotes (water filled collapsed sinkholes) and dry collapsed sinks leading to vadose zone cave passages. Sub-sections of the inventory are displayed in Figures 7 and 8 and show the distribution of cenotes and dry sinkholes in the Tulum and Playa del Carmen areas are synonymous with cave entrances in the region.

ii. Springs and related discharge features

Coastal discharge vents (springs) are displayed in Figure 9. A total of 20 springs has been documented in the area but numerous smaller vents that are currently undocumented discharge offshore. Crescent-shaped beaches, which are features associated with caletas, were also documented and analyzed.

iii. Cave distribution and density

Cave passage development on the northeast coast of Quintana Roo occurs between Muyil and Puerto Morelos and up to 12 km inland (Figure

Figure 8. Cenote distribution in Playa del Carmen area

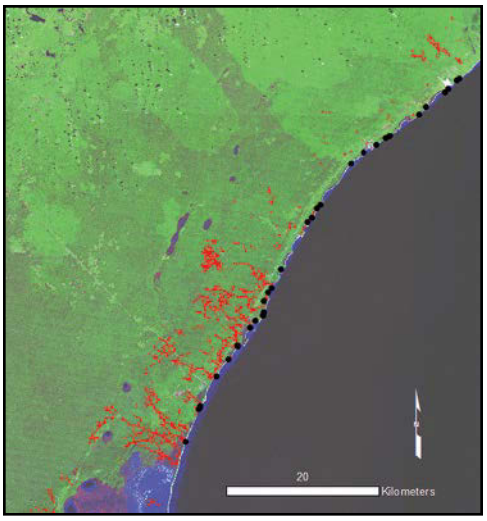


Figure 9. Distribution of coastal springs of northeast Quintana Roo. Black dots are costal springs; red lines are cave systems.

Cave data source: QRSS 2013

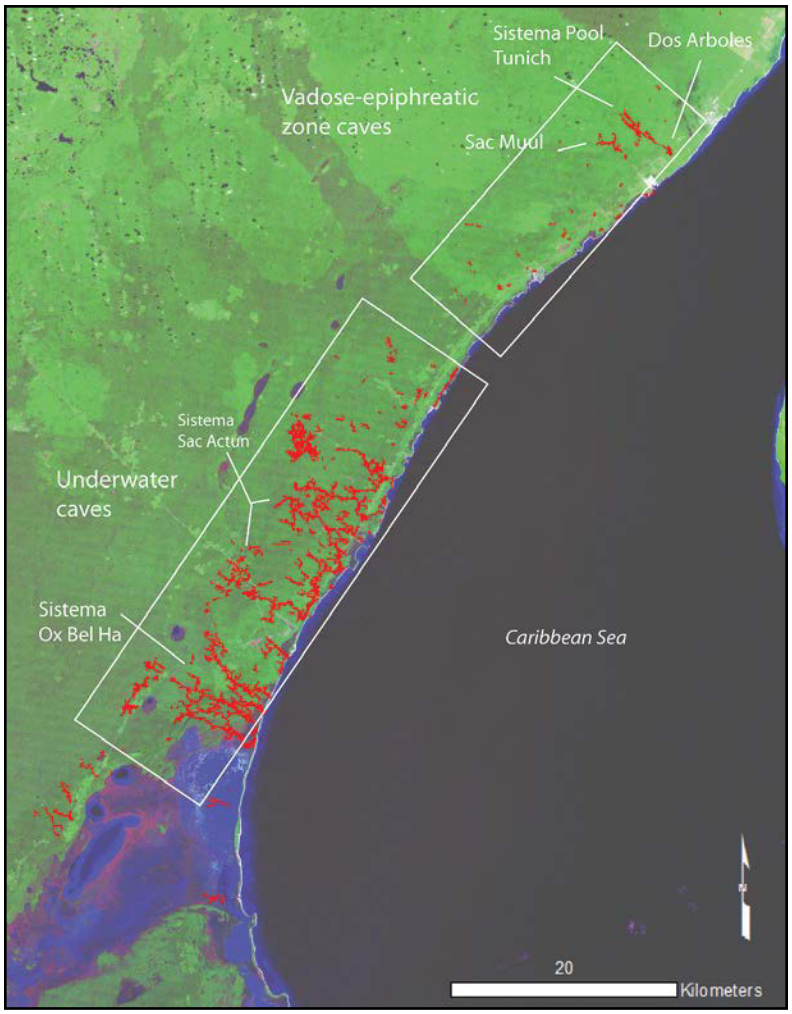


Figure 10. Cave distribution and density of underwater and vadose zone caves

10). Within this area, 1309 km of underwater passages have been documented in 337 discrete caves. Of those, 8% contain sections in the vadose zone. The highest density of underwater cave occurs between Muyil and Akumal, and cave density within this 430 km^2 area is 2.7km/km^2. Cave density in the 45 km^2 block containing Ox Bel Ha is 5.2 km/km^2. The cave density of Sistemas Sac Actun and Dos Ojos which occur within a 108 km^2 block is 2.9km/km^2. These particular cave systems have an inland extent of up to 9 kilometers and continuous passages have been documented to connect to coastal discharge points.

The greatest concentration of caves located within the vadose-epiphreatic zone occurs in the area between Akumal and Playa del Carmen and extending 7 km inland (Figure 10). Over 315 km of cave passages have been surveyed in 250 cave systems and 4% of those caves contain epiphreatic passages. Within this 234 km^2 area, cave density is 0.5 km/km^2. Sistema Pool Tunich is the most extensive at 38 km, followed by Sistema Sac Muul (11 km) and Sistema Dos Arboles (8 km) (QRSS 1013).

iv. Cave morphology analysis

Cave maps revealed that there are two types of cave passage morphologies in the region. Caves that are less than a kilometer from the coast display high-density rectilinear mazes that parallel the coast on a northeast–southwest trend. The cave passages that make up the mazes are low and horizontal, almost canyon-shaped in places, and are interspersed with fissure-controlled chambers. They are devoid of speleothems, and coated with clay-like silt. The limestone is very friable and in places can be unstable. Passages in the Cenote Abejas section of Sistema Sac Actun display this morphology (Figure 11). Exploration was very difficult in this section of cave due to the unstable nature of the bedrock and silt, which compromises visibility (Coke personal communication 2013). There are currently no vadose zone caves within 500 meters of the coast; however, there are vadose zone caves with the near-coast morphology. Cueva Camaras (Figure 12) is a vadose zone maze cave located in a beach ridge less than two kilometers from the coast. A notable exception to the coastal passage morphology "rule" is Sistema Ox Bel Ha; the inland trend of large, linear anastomotic passages continues all the way to the coast.

The other type of passage morphology characteristic in the region occurs in caves or cave segments located

Table 1. Fractal dimension for a selection of underwater and vadose zone caves

Underwater	Fractal Dimension	Vadose-Epiphreatic	Fractal Dimension
Sistema Sac Actun	2.5083	Sistema Pool Tunich	2.3953
Sistema Ox Bel Ha	2.6049	Sistema Sac Muul	2.3668
Dos Pisos	2.3781	Dos Arboles	2.3901
Sand Crack	2.3579	Fallen Fig	2.2973
Sistema Camilo	2.3727	Cueva Camaras	2.3876

a kilometer or more from the coast. These caves display a distinct linear pattern and elliptical passage morphology. Passages tend to average up to 10 meters in width though they can be of greater size. They are anastomotic in configuration and run perpendicular to the coast on a northwest–southeast trend. Speleothems are common in both the underwater and vadose-epiphreatic zone caves. Sistema Dos Arboles (Figure 13a), a vadose-epiphreatic zone cave and Maya Blue, part of Sistema Ox Bel Ha (Figure 13b), exemplify this type of passage development.

Cave maps show the anastomotic mazes to occur near entrances and in association with upper level passages. Cenote Balancanche, an underwater cave (Figure 14a), has 10 collapse cenotes located within a 0.6 km^2 zone of anastomosing passages. Sistema Pool Tunich (Figure 14b), a vadose zone cave, also shows anastomotic development near cenote entrances.

Some sections of maps that appear to show anastomotic passage development but are showing two levels of passage that overlie each other. The Hell's Gate section (Figure 15) in the Nohoch Nah Chich region of Sac Actun shows overlying upper level passages that appear to be part of the same maze, but in actuality exist on two levels. There are no upper level passages in the vadose-epiphreatic caves of the region.

Fractal dimension was calculated for the cave footprints of a selection of underwater and vadose zone caves and are summarized in Table 1. The fractal dimension values fall between those characteristic of the higher range of values for flank margin caves and the mid-range values for hypogenic maze caves.

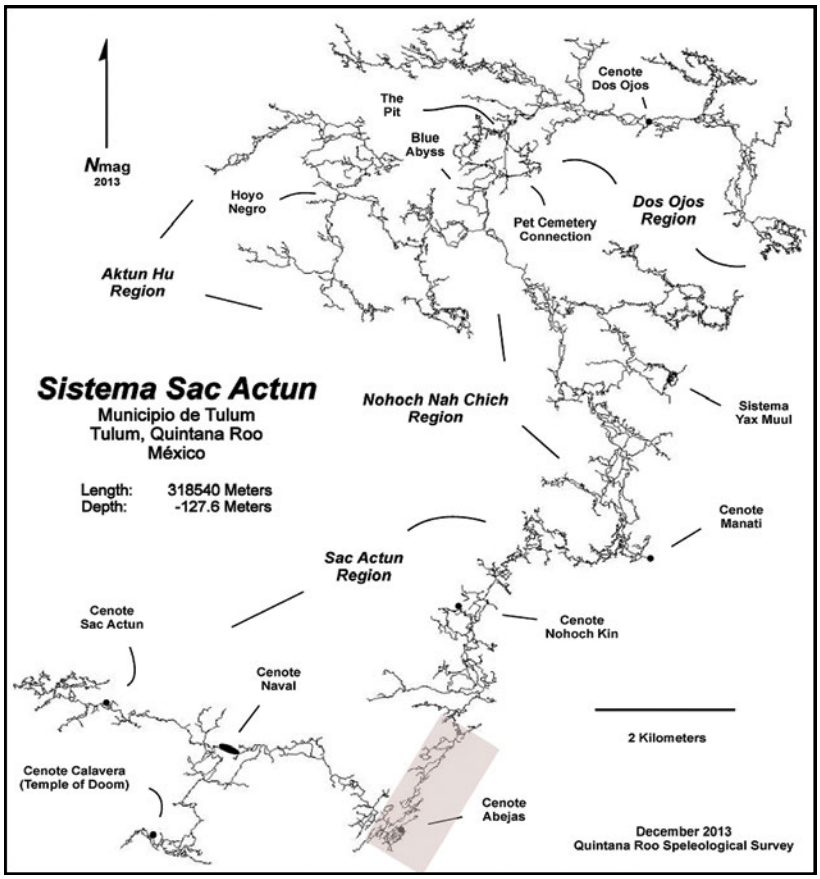


Figure 11. Coastal maze passages of Cenote Abejas section of Sistema Sac Actun. Highlighted area shows the northeast trending maze passages of the Cenote Abejas section—Sistema Sac Actun, the second longest cave in the world and longest cave in Mexico. The passages of this section of cave parallel the coast. Northwest trending passages are fracture controlled, anastomozing in configuration and located perpendicular to the coast. *QRSS 2013*

v. Hydrologic observations

Many of the caves located in the vadose zone are completely dry. Cueva Camaras (Figure 12) is an example of a cave within a beach ridge, which is located 2 kilometers from the coast at an elevation of 10 meters above sea level. Cave development within the ridge occurs at approximately 6 meters above sea level. Vadose zone caves that are located a kilometer or more from the coast contain epiphreatic sections that can contain pools of water or may be inundated wall-to-wall with water, both which respond to daily tidal pulses. Grotte Aluxes (Figure 16) is an example of a near-coast beach ridge cave (l km from the coast; cave developed at 0–1 meter above sea level) and contains shallow and epiphreatic zones that respond to tidal pulses. The vertical extent of Sistema Pool Tunich ranges from 6–8 meters above sea level through below sea level. The cave, which ranges up to 7 km inland, contains dry, epiphreatic, and phreatic sections.

Though there is an absence of flow indicators (scallops) in the underwater caves of the region, cave divers report strong water flow within many of the underwater passages and the observed occurrence of dunes of white silt along the perimeter of cave passages, indicating turbulent flow (Coke personal communication 2013) (Figure 17a). The northern sections of Sistema Pool Tunich located 7 km from the coast (Figure 17b) contain areas where turbulent flow is documented in sections of cave passages that extend to the local water table. Daily tidal pulses have been observed in vadose-epiphreatic zone caves along the coast such as Grotte Aluxes.

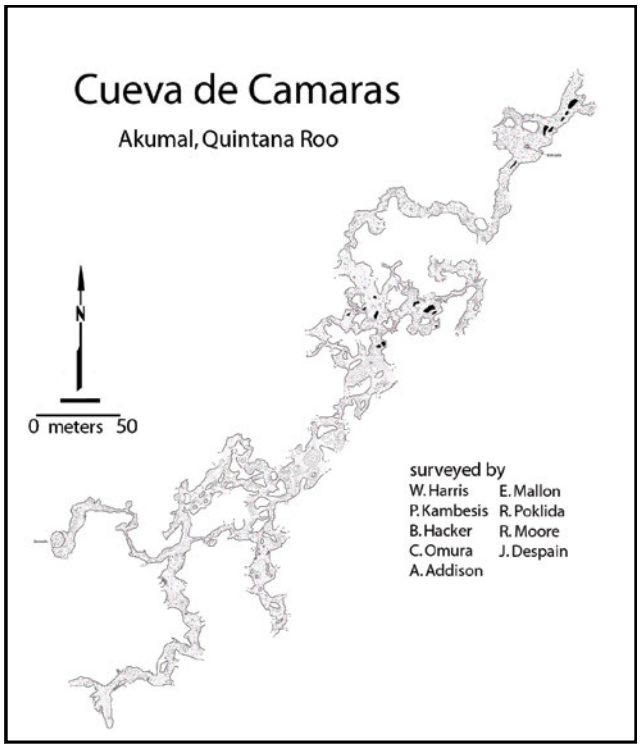


Figure 12. Map of Cueva Camaras. This cave is a rectilinear maze cave formed within a beach ridge located 2.5 km from the coast. *Cartography: Aaron Addison*

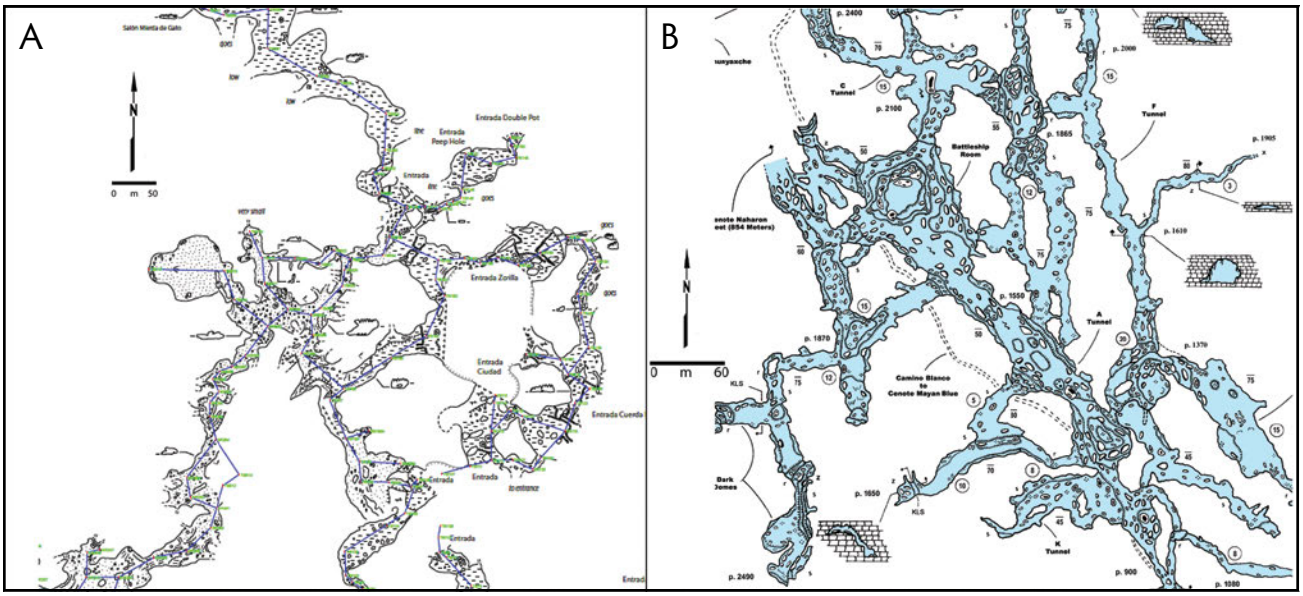
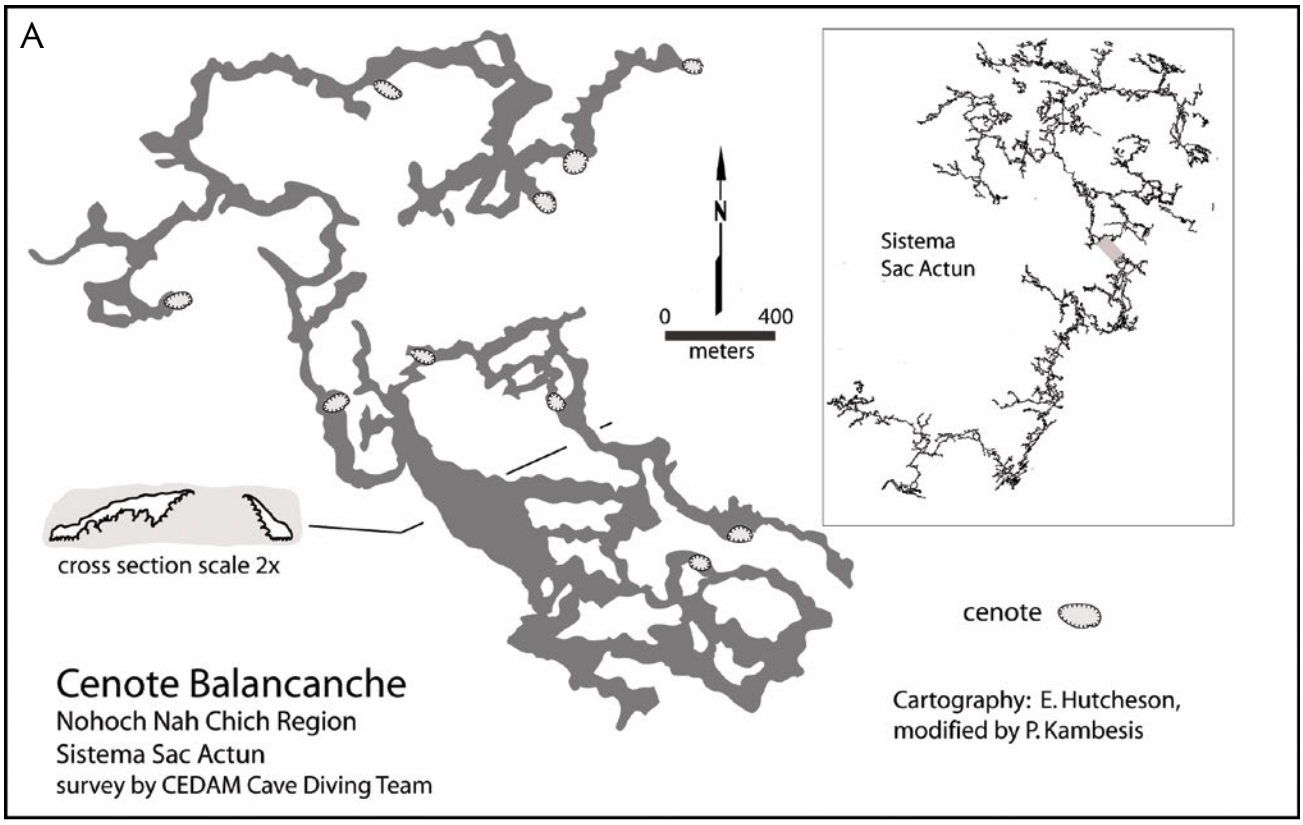


Figure 13. Anastomotic cave passage development. **(A)** ***Segment of Dos Arboles (located in vadose zone);*** **(B)** ***section of Sistema Ox Bel Ha (underwater) that display northwest trending anastomotic passages.***

Cartography: Dos Arboles, Sprouse and Kambesis; Ox Bel Ha, James G. Coke IV



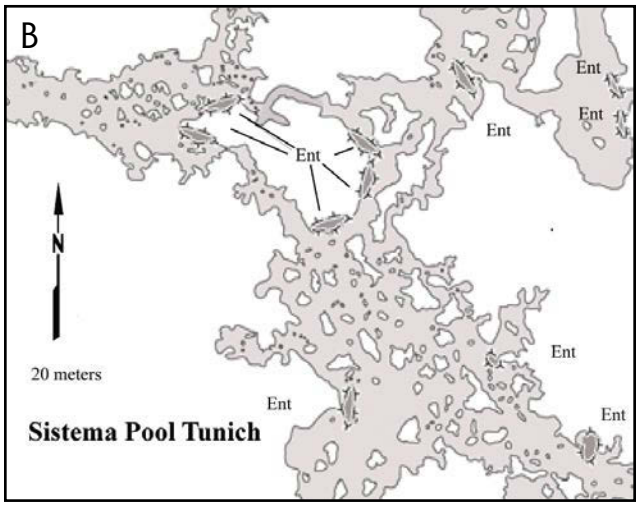


Figure 14. Complex mazes associated with cenotes. **(A)** ***Cenote Balancanche section of Sistema Sac Actun (underwater);*** **(B)** ***section in the northern reaches of Sistema Pool Tunich (vadose-epiphreatic) showing multiple entrances (labelled) within a complex maze.***

Cartography: Cenote Balancanche, E. Hutcheson, modified by P. Kambesis; Sistema Pool Tunich, P. Sprouse and P. Kambesis.

e. Discussion

Exploration bias has to be considered when making comparisons between the underwater and vadose zone caves of Quintana Roo. This concern is most evident in Figure 10, which shows the distribution of underwater versus vadose zone caves. What is not immediately obvious from this graphic is that exploration and documentation of underwater caves has been ongoing since mid-1980, whereas exploration and detailed documentation of equal focus did not begin in the vadose zone caves until 2008. The underwater caves and vadose-epiphreatic zone caves of northeast Quintana Roo share many characteristics though there are some subtle differences which do not detract from the relationship of the two cave types but rather support it.

i. Cave passage orientation and distribution

The major structural orientation and inclination of the underwater and vadose-epiphreatic zone caves are very similar though the underwater caves seem to have more E-W development. This may be an artifact of comparing 1309 km versus 215 km of cave survey rather than any real differences in orientation or it may be related to topography as the dry caves are restricted to high ground areas whereas the flooded caves are not.

Tułaczyk et al. (1993) suggested that fissure or joint controlled networks were the initial precursors to the dissolutional conduits that currently drain to the coast. Due to the limited lateral extent of fissure controlled passages (Kambesis and Coke 2013), it is also possible that there is no structural control on incipient passages but rather that coastward hydraulic gradient resulted in the development of sub parallel passages that randomly intersected. This bears some similarity to the development of flank margin caves as random dissolutional voids that randomly connected to form larger voids (Labourdette et al. 2007). However, cave passages with a strong linear N30°E trend and located less than 200 meters from the coast, have recently been discovered. The passages parallel the coast with a lateral extent of 4 km (personal communication Bordignon 2014) and may be related to the extensive horst and graben fault block system located off of the coast of Quintana Roo that was described by Weidie (1985). This suggests that initial conduit development did occur along regional joint and/or fault trends and that the anastomotic pattern of passage development is a secondary imprint due to local geological conditions.

There are no significant vadose zone caves located less than a kilometer from the coast though small flank margin caves are found in eolianites located on the coast in the Tulum area (Kelly et al. 2006) (Figure 18). Because of the small size of the Quintana Roo flank margin caves, they do not display the typical morphology of more extensive flank margin caves, e.g. ramiform or spongework with cross-linked chambers. However, they do display the large width to low height ratio of chambers that reflect the form of the distal margin of a freshwater lens. The elevation of the Tulum flank margin caves and breakdown at their entrance areas suggest that the caves initially formed without entrances and were ultimately exposed by erosion and coastline retreat.

There is major underwater cave development near the coast and cave divers report the zone to be devoid of speleothems, with friable and unstable walls, and a lot of sediment. These are all the symptoms of very young limestone units. Beddows et al. (2007a) identified the near-coast environment as the active mixing zone and location of the youngest Pleistocene limestones, with the least overprinting by other processes.

Significant vadose zone cave development occurred in the beach ridges of the study area and the cave passages in those areas are characterized by low, rectilinear mazes, similar to passages actively forming at the coast today (Figure 18). Based on the flank margin caves that have been documented in the coastal area at Tulum (Kelley et al. 2006), it is possible that the caves in the beach ridges may have initiated as flank margin caves but became incorporated in the regional hydrology when sea levels rose.

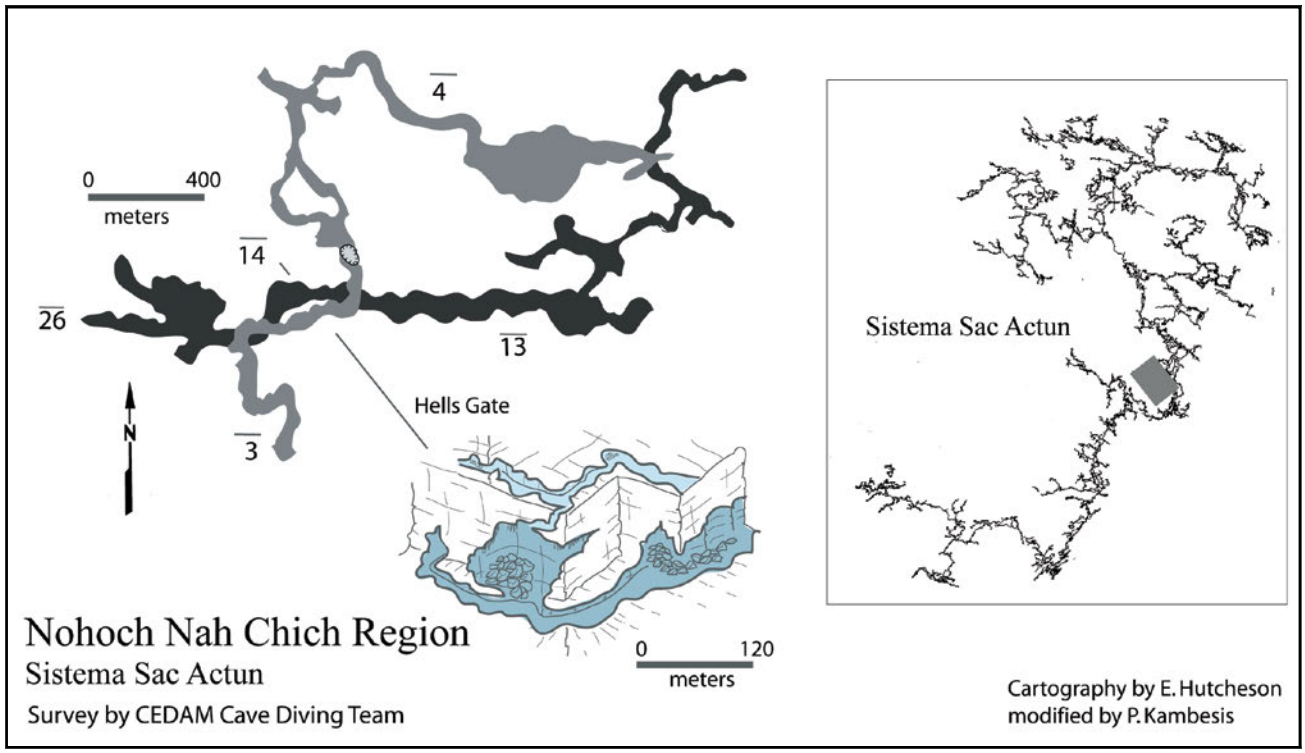


Figure 15. Map of Hell's Gate Section of Sistema Sac Actun. Superposition of upper and lower level passage development.
Cartography: E. Hutcheson, modified by P. Kambesis

The distribution of underwater versus vadose zone cave passages as presented in Figure 19 needs to consider the distorting perspective of exploration bias. As vadose zone cave exploration continues, more vadose zone caves will be found though their extent may not compare to that of the underwater caves. Connections are also likely between the vadose zone and underwater caves via the epiphreatic sections.

ii. Cave passage morphology

There are two types of cave passage morphologies in the region. Cave that are less than a kilometer from the coast display northeast–southwest trending high-density rectilinear mazes that parallel the coast. These passages can have either elliptical or fissure dominated cross sections. Cave passages located greater than a kilometer from the coast display a northwest–southeast trending linear pattern with predominantly elliptical cross sections. The morphological differences of cave passages from coastal to inland configuration may in part be caused by changes in lithology where Holocene to Pleistocene age carbonates transition to older, more consolidated ones and cave passages are contained within more massive and stable bedrock. For example, at distances of 3 to 6 km from the coast, the southern and northern arms of Sistema Sac Actun at Naval and Nohoch Nah Chich respectively encounter Neogene rocks (Coke 2009). Lateral branching of passages still occurs but the number of passages is limited to just one or two primary discharge tunnels; secondary passages are small in dimension and length and typically end in impassible tubes or cracks that discharge freshwater (Coke 2009).

An exception to the near-coast morphology of many of the caves along the coast is observed in Sistema Ox Bel Ha, which displays the passage characteristics of an inland cave in its sections all the way to the coast (Coke 2009). The spring vents of Sistema Ox Bel Ha appear to be located in an older paleo-coastline section than caves to the northeast. The distribution of caletas, which are common northeast

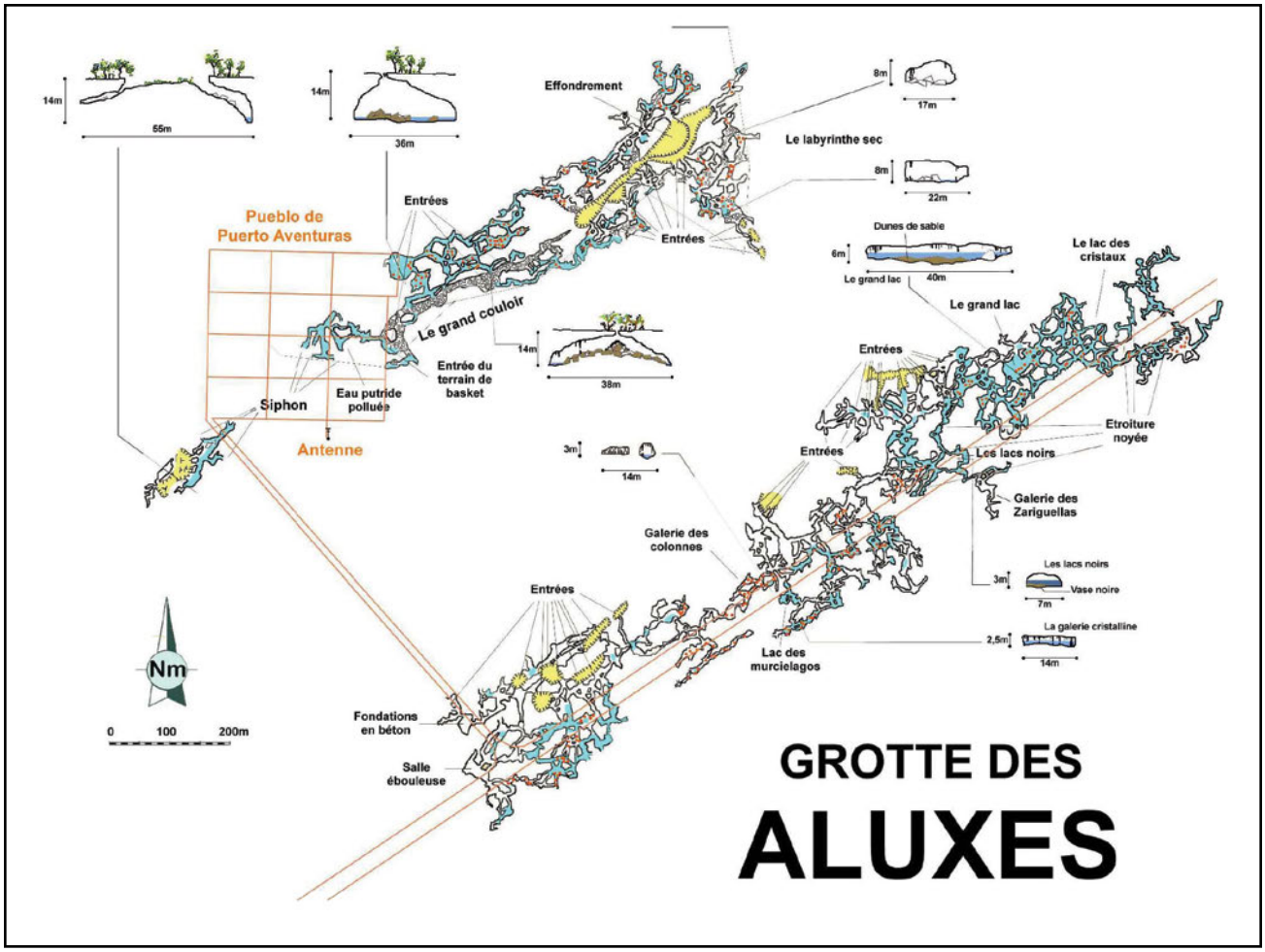


Figure 16. Map of Grotte des Aluxes. Grotte des Aluxes is formed in beach ridge located 1 km from the coast with sections that extend into the epiphreatic zone. *Cartography: C. Thomas.*

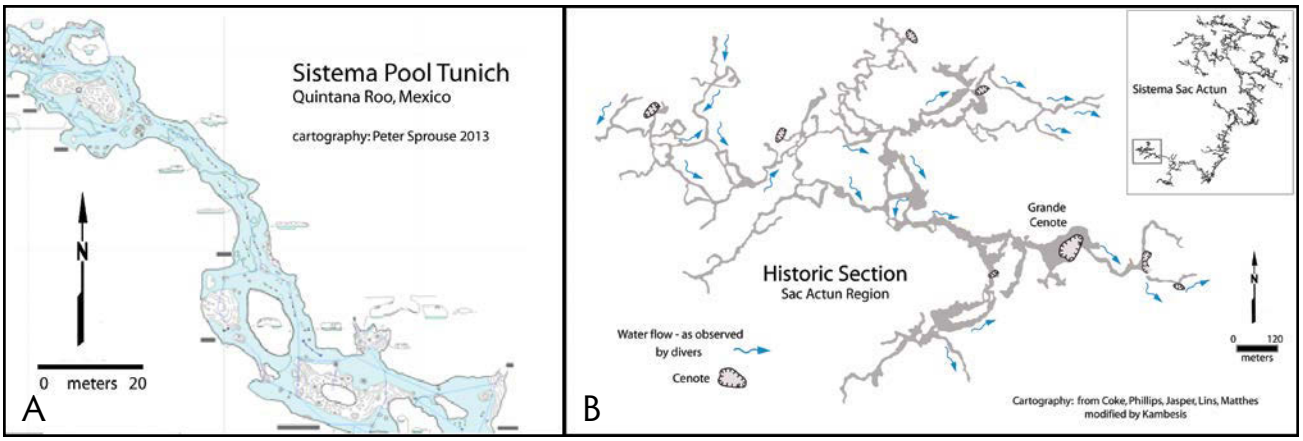


Figure 17. Water flow in underwater and vadose-epiphreatic zone caves. **(A)** ***Water flow documented in the northern most reaches of Sistema Pool Tunich;*** **(B)** ***Water flow as reported by cave divers in Sistema Sac Actun.***

Cartography: Sistema Pool Tunich, P. Sprouse; Sistema Sac Actun, Coke, Phillips, Jasper, Lins, and Mathes, modified by Kambesis

of Ox Bel Hall, drop to practically none in the Ox Bel Ha coastal vicinity. This is support for the idea of a change in geologic boundary conditions south of Tulum.

The karst inventory has identified hundreds of cenotes, i.e., sinkhole collapses, in the study area. The anastomosing configuration of the inland cave passages may in part be influenced by regional structure, but local conditions may also play a very significant role. Cenotes form as a function of the removal of buoyant support when water drained from formerly submerged cave passages causes collapse. Extensional fractures that formed as a result of ceiling collapses make for zones of weakness that result in more extensive areas of underground breakdown. Groundwater flow would find new routes around the breakdown and the multiple diversions would result in anastomosing passage configurations. The 600-meter wide collapse zone displayed in Cenote Balancanche (Figure 14a) strongly influences the morphological pattern of surrounding cave passage. In Sistema Pool Tunich, the five entrances on a circular trend in Figure 14b are the result of a large, circular surface collapse that may have initiated the formation of the complex maze characteristic of the area. Other factors that influence cave patterns because they affect water flow include sediment and speleothem occlusion.

Smart et al. (2006) proposed that coastal caves of Quintana Roo were intermediary between continental stream caves and flank margin caves. However, the fractal indices calculated for ten select caves in the study area classified them as intermediate between flank margin caves and hypogene caves (Table 1). This reflects that continental hypogene caves and the caves of Quintana Roo both form by mixing zone corrosion, which results in similar morphologies. However, the Quintana Roo caves function as a drainage system related to surface hydrology versus hypogene caves whose hydrology is not directly related to surface drainage. Turbulent flow has been documented in both the underwater caves and in sections of the vadose-epiphreatic zone caves that are deep enough to encounter the local water table. Fractal dimension is a means of classifying cave morphologies for descriptive and comparative purposes. It does not dictate process, though morphologies can suggest possible processes as demonstrated by the above analysis.

iii. Vertical development of passages

The vadose zone caves of the region range from being completely dry to containing sections that are epiphreatic. Water levels (or lack of water), within the vadose-epiphreatic zone caves of the region are a function of the cave's location with respect to sea level. Though vadose-epiphreatic zone caves closest to the coast typically contain water, inland caves may also contain water, have underwater sections, or connect to more extensive underwater systems depending on their elevation with respect to sea level. When cave development is greater than 2 meters above sea level, passages are typically dry. Passages that are located 0–2 meters above sea level have a combination of passages that are completely dry to those that contain pools or wall-to-wall water passages which respond to daily tidal pulses. Sections of caves that occur below the water table may contain underwater segments or may connect to more extensive underwater caves.

The submerged cave passages of northeast Quintana Roo are fairly shallow in terms of world depth standards. In historic Sac Actun, passage depths range from less than 2 to up to 20 meters; Nohoch Nah Chich region depth ranges span from 2–6 and 8–15m and 16–20; Actun Hu region from 5–10m; and Dos Ojos region at 5–10m and 14–20m. However, there are three notable exceptions that all occur within the Nohoch Nah Chich–Aktun Hu-Dos

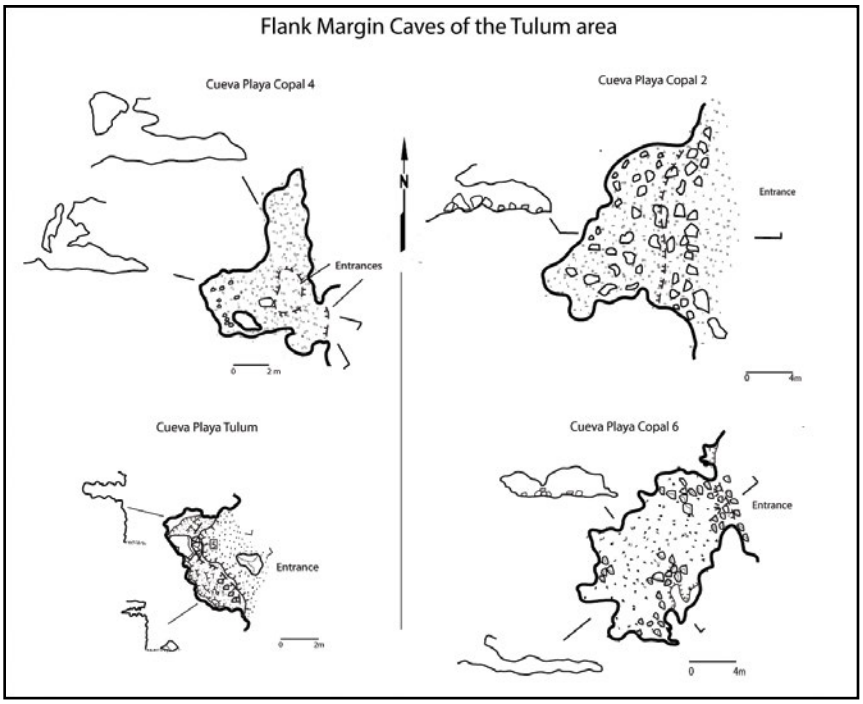


Figure 18. Flank margin caves of the Tulum area *Cartography: P. Kambesis*

Ojos regions of Sistema Sac Actun. These include Hoyo Negro (60 m depth), Blue Abyss (71 m depth) and The Pit (119 m depth). These areas require advanced cave diving techniques and equipment, and mixed gases.

The deep sections of Sistema Sac Actun are in saltwater and hint at the existence of deeper levels of cave development, which are mostly unknown. Water samples collected in The Pit were analyzed to be chemically identical to nearby marine water (Barton 2001). There are reports of large holes along the walls of the modern barrier reef at depths of 100 meters that could potentially lead to deep levels of cave development, formed when sea level was over a hundred meters lower than it is today (Barton 2001). Deep cave passages (>50 meters) have recently been documented near the coast though they have not yet been studied in any great detail (Bordignon 2014).

Smart et al. (2006) suggested that dissolution could occur in the salt-water-occupied deeper zones of the cave. Beddows (2004) documented an increase in temperature with depth in The Pit and Blue Abyss (approximately 2°C/100m). Though these waters are typically saturated with respect to calcium carbonate minerals, forced advection could cool the water and result in undersaturated water that could dissolve limestone in the deep saline zone (Smart et al. 2006).

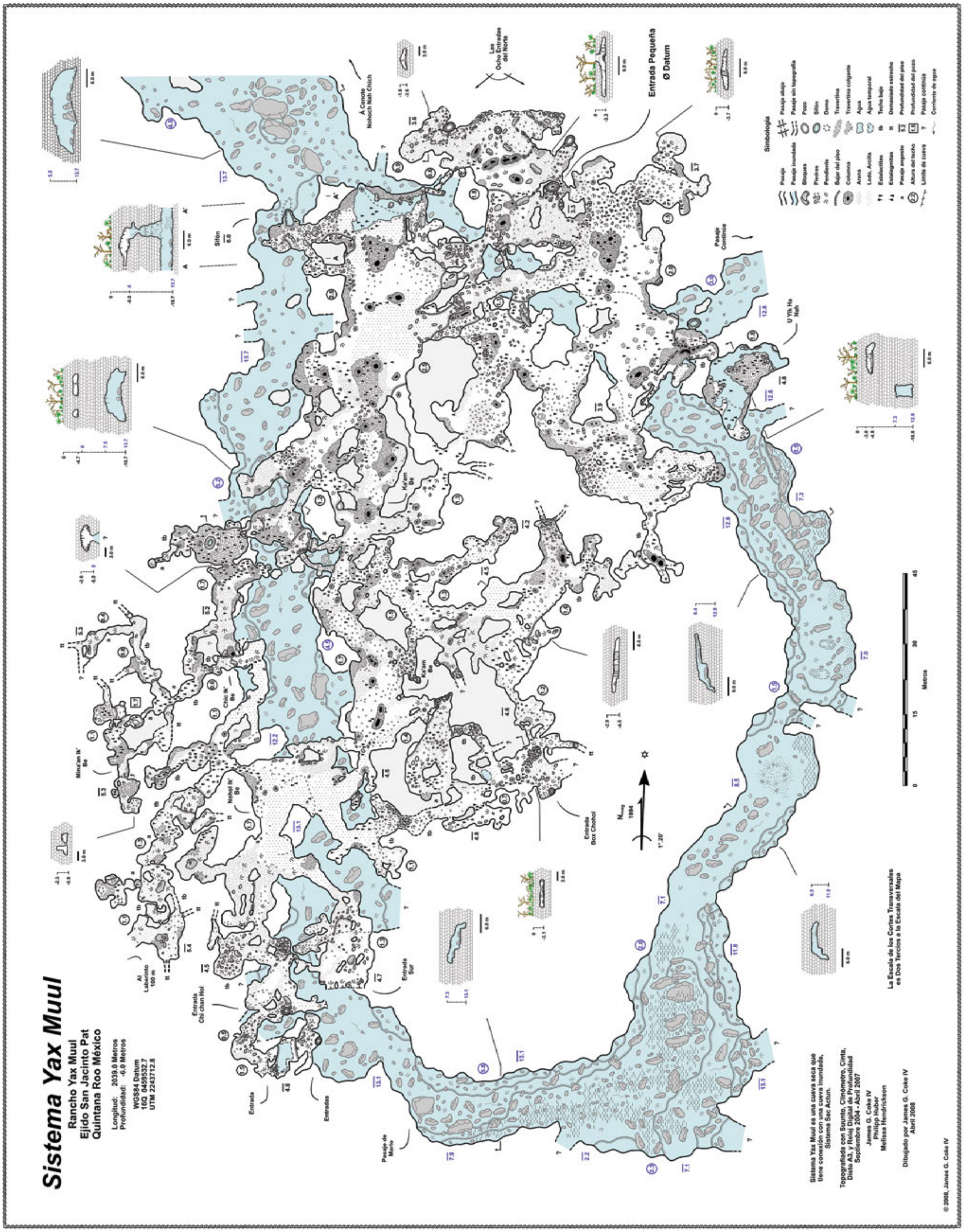
Vertical development in the vadose zone caves is all above current sea level though some elevations push above the 6-meter sea level high mark of MIS5e. These areas are where the survey line was run between the surface and down into a cenote, which means those elevations can be attributed to progradational collapse rather than anomalous glacioeustasy.

iv. Multiphase cave development

The low hydraulic gradient of the Yucatan peninsula means that water levels within Quintana Roo cave systems track sea level. The current location of the halocline and the vertical distribution of cave passages indicate that the cave systems have undergone multiple phases of development. The existence of air-filled cave passages above water filled passages, such as Yax Muul (Figure 19) and multilevel areas such Hells Gate, both in the Nohoch Nah Chich region, attest to the relationship of sea level to cave passage development.

The elevation of the limestones containing the vadose zone caves indicate that they formed when sea level was higher than today, which would likely be MIS5e. To create subareial exposure to form a freshwater lens, there had to be a drop in sea level during MIS5e. Carew and Mylroie (1995) discussed a mid-MIS5e low stand for similar situations in the Bahamas. When sea level dropped post MIS5e, the caves that formed during that time were stranded in the vadose zone.

Facing page: ***Figure 19. Map of Yax Muul section of Sistema Sac Actun. Map shows the relationship between underwater and vadose zone cave passages typical of the study area.*** *Cartography: James G. Coke IV*


Sistema Yax Muul
Rancho Yax Muul
Ejido San Jacinto Pat
Quintana Roo México
Longitud: 2039.0 Metros
Profundidad: -6.0 Metros
WGS84 Datum
16Q 0459532.7
UTM 2243712.8
Entrada Pequeña
Ø Datum
Simbología
Entrada Box Chohol
Entrada Sur
Entradas
Entrada
Metros
La Escala de los Cortes Transversales es Dos Tercios a la Escala del Mapa
Dibujado por James G. Coke IV
James G. Coke IV
Phillip Huber
Melissa Hendrickson
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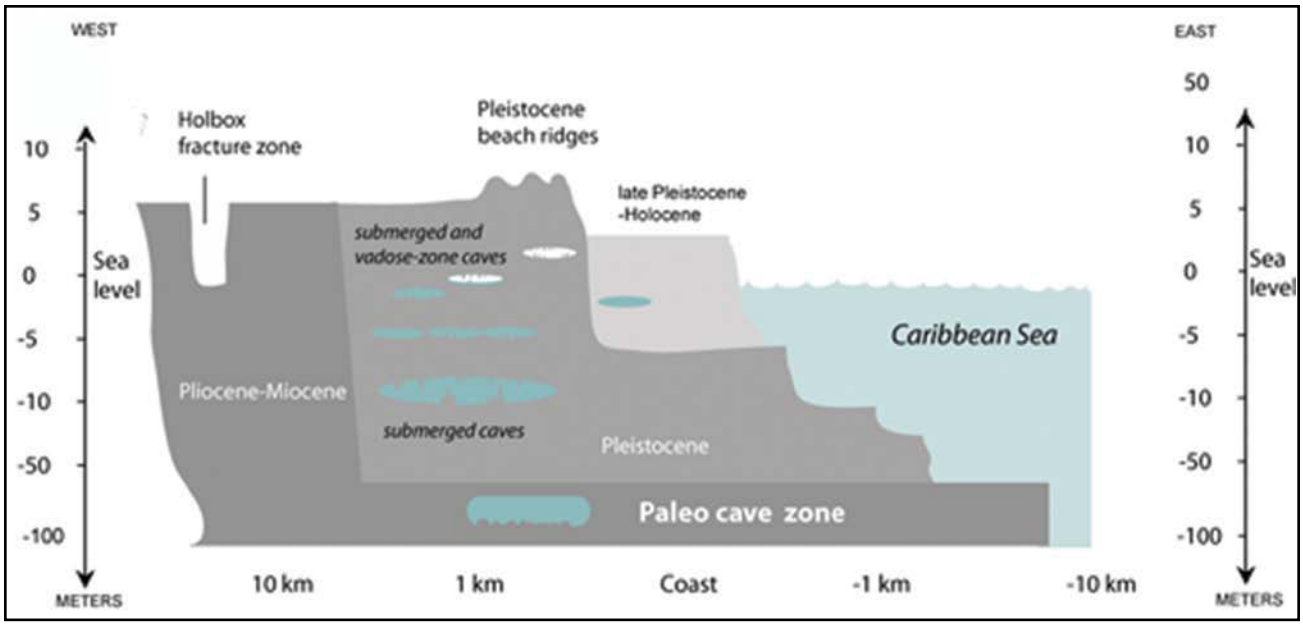

Figure 20. Cave passage development on the northeast coast of Quintana Roo, Mexico

Modified from Richards and Richards (2009)

Figure 20 illustrates the multiple phases of cave development in the Quintana Roo study area and the relationship between the underwater caves and those occurring in the vadose-epiphreatic zone.

f. Summary

The underwater caves and vadose-epiphreatic zone caves of northeast Quintana Roo share many characteristics though there are some subtle differences in terms of distribution. Exploration bias has to be considered when making comparisons between the underwater and vadose-epiphreatic zone caves of Quintana Roo as exploration and documentation of underwater caves has been ongoing since mid-1980 whereas exploration and detailed documentation of equal focus did not begin in the vadose-epiphreatic zone caves until 2008 and the data set for the latter is not as extensive as the former.

The major structural orientations and inclinations of underwater and vadose-epiphreatic zone caves are very similar. Underwater caves have a much greater depth range than vadose-epiphreatic zone caves. The vertical range of development in the vadose zone caves is above current sea level though some elevations push above the 6-meter high mark of MIS5e. These areas are where the survey line was run from the surface and down into a cenote (or vice versa), which means those elevations can be attributed to progradational collapse rather than anomalous glacioeustasy. When the depth of the vadose zone caves reaches the local water table, the epiphreatic zone is encountered and passages can contain pools of water or be inundated wall-to-wall. In some instances, the epiphreatic zone may lead to phreatic passages and connect with extensive underwater caves. The 4–6 meter above sea level elevations of the vadose-epiphreatic zone caves strongly suggest that they formed during MIS5e, which occurred approximately 125,000 ago when sea level was 4–6 meters higher than it is today.

In terms of distribution, there are no vadose zone caves located less than a kilometer from the coast. However, there is major underwater cave development in that zone. Cave divers report that the zone is devoid of speleothems, bedrock walls are characteristically friable and unstable, and there is lot of loose sediment. Beddows et al. 2007a identified the near-coast environment as the active mixing zone and location of the youngest Pleistocene limestones, with the least overprinting by other processes. There is significant vadose zone cave development in the beach ridges of the study area and the cave passages in those areas are characterized by low, rectilinear mazes, similar to passages actively forming at the coast today. It has been suggested that the caves in the beach ridges initiated as flank margin caves but became incorporated in the regional hydrology when sea levels rose. Flank margin caves have been documented in coastal eolianites near Tulum (Kelly et al. 2006, Kambesis unpublished data). Because of the small size of these particular caves, they do not display the typical morphology of more extensive flank margin caves, e.g. ramiform or sponge work with cross-linked chambers. However, they do display the large width to low height ratio

of chambers that take the form of the distal margin of the freshwater lens. The elevation of the Tulum flank margin caves and breakdown at their entrance areas suggest that the caves initially developed when sea level was higher. They were formed without entrances and were ultimately exposed by erosion and coastline retreat.

The morphological differences of caves from coastal to inland configuration may be a result of lithological controls e.g., changes in lithology and/or changes in diagenetic maturity, where Pleistocene to Holocene age carbonates transition to older, more consolidated ones and cave passages are contained within more massive and stable bedrock.

An exception to the rectilinear passage morphology of most of the near coast cave sections is that of Sistema Ox Bel Ha which displays the passage characteristics of an inland cave in its sections all the way to the coast. The discharge vents of Sistema Ox Bel Ha appear to be located in an older paleo-coastline section than caves to the northeast. The distribution of caletas, which are common northeast of Ox Bel Ha and are typically associated with coastal discharge vents, drop to practically none in the Ox Bel Ha coastal vicinity, though discharge vents are still common. This supports the hypothesis of a change in geologic boundary conditions south of Tulum.

Caletas do occur north of the study area (Puerto Morelos), but are not as plentiful. This may also reflect a change in geologic conditions.

The karst inventory has identified hundreds of cenotes, i.e., sinkhole collapses in the study area. These features serve as entrances to the many cave systems both underwater and in the vadose zone of the study area.

Smart et al. (2006), proposed that coastal caves of Quintana Roo were morphologically intermediate between continental stream caves and flank margin caves. However, the fractal indices calculated for ten select caves in the study area classified them as overlapping between flank margin caves and hypogene caves. This reflects that continental hypogene caves and the caves of Quintana Roo both display morphologies that indicate mixing zone corrosion. However the Quintana Roo caves function as an epigene drainage system.

The anastomotic pattern of inland cave development may have been overprinted on initial fissure or joint-controlled networks (Kambesis and Coke 2013) since these have been suggested to be the precursors to the dissolutional conduits (Tułaczyk et al. 1993). Considering the limited lateral extent of fissure-controlled passages, it is also possible that there is no structural control on incipient passages but rather that coastward hydraulic gradient resulted in the development of sub-parallel passages that randomly intersected. This bears some similarity to the development of flank margin caves as dissolutional voids that randomly connect to form larger voids.

The anastomosing configuration of the inland cave passages may in part be influenced by regional structure, but local conditions also play a significant role. Ceiling collapse is a function of the removal of buoyant support when water drained from formerly submerged cave passages. Extensional fractures occurred in association with mechanical ceiling collapse, and the formation of cenotes made zones of weakness that resulted in more extensive areas of breakdown. Groundwater flow found new routes around the breakdown and the multiple diversions resulted in anastomosing passage configurations. Other factors that influence cave patterns because they affect water flow include sediment and speleothem occlusion (Smart et al. 2006).

The submerged cave passages of northeast Quintana Roo are fairly shallow in terms of world depth standards. However there are sections with depth ranges from 70 to 120 meters suggesting potentially extensive deeper cave development. Exploration at these depths, which is technically challenging, has been minimal so far.

The low hydraulic gradient of the Yucatan peninsula means that water levels within Quintana Roo cave systems track sea level. The current location of the halocline and the vertical distribution of cave passages indicate that the cave systems have undergone multiple phases of development.

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Investigating the Social Experience of Individuals Interred in Ancient Maya Cave and Rockshelter Mortuary Sites in Central Belize

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The Cave Research Foundation funded a portion of my dissertation study in 2012, for which I am very grateful. This funding allowed me to go to central Belize to excavate dental materials from pre-Hispanic Maya burials in caves and rockshelters. In the spring of 2016, I will defend my dissertation.

The ancient Maya interred their dead in a number of mortuary contexts ranging from placement under the household or within a tomb at site cores to disposal in darkzone caves and lightzone rockshelters across the landscape. Why certain individuals came to be buried in caves and rockshelters is not immediately clear. While shallow lightzone rockshelters appear to have been used as cemeteries by rural peasant groups living on the periphery, archaeologists have long speculated that cave burials represent either the victims of sacrificial violence or the elite members of nearby site cores. The debate over what symbolic and mortuary purpose these cave burials fulfill may be aided, in part, by a biological analysis of the skeletal remains of the burial populations.

In my dissertation, I propose that by studying patterns of health disruptions in dental materials culled from these distinct mortuary settings, I will be able to add a biological perspective to the social experience of past populations. Ultimately, this study will contribute to ongoing research regarding social class and the biological consequences of status; the data for this project can articulate with previous bioarchaeological studies on paleopathology, nutrition, and diet. The biological data will intersect with current studies focused on identifying and interpreting ritual violence in mortuary contexts. Additionally, the data can further inform archaeological studies of inequality (e.g. household formation, core/periphery interaction, gender role and performance, and mortuary analysis).

Significance of the Research

Microscopic analyses of dentition will serve not just to explain health disparities, but also the timing of health stress events, resulting in a more sophisticated picture of life experience that can articulate with archaeological evidence. Through the study of microscopic health disruptions, it will be possible to determine if the health patterns of individuals interred in caves are similar to the known non-elites buried in rockshelters. By sampling individuals buried in these rural locales, I am ensuring that I am examining a true commoner population living in the periphery. Previous studies have been concerned with social ventures of elites; this dissertation proposes that understanding the social exploits of the underclass will ultimately aid in reconstructing aspects of health experience, mortuary ritual, and core/periphery interaction.

Though a prodigious amount of cultural information has been uncovered through archaeological excavation of caves, there is still much to learn about the lived experience of these individuals who received cave and rockshelter burials. Because the bioarchaeological investigation of non-elites has been largely eclipsed by studies of individuals buried in tombs, this dissertation will add another dimension to the literature regarding the social experience of the commoner population. Nesting biological data within an interpretive framework informed by archaeological evidence and ethnographic literature, I aim to address the health experience of non-elites in peripheral settlements. Because these rockshelter burials are akin to rural cemeteries, it can reasonably be stated that these interments are representative of a commoner population. The social status of cave burials is less clear, though with a properly contextualized health analysis it may be possible to better explain why these particular individuals were buried in caves.

In addition to analyzing health status of individuals interred in cave versus rockshelter locales, I compared these results to an analysis of dental material from the elite site core of Tikal (Danforth 1989). This type of multi-site evaluation has implications for understanding differential access to interment sites by using a previously generated binary model (elite/non-elite in buried in tombs/households, respectively). Archaeological evidence of Classic Maya centers demonstrates that important places were characterized by a center with corresponding periphery (Brady and Ashmore 1999; Hageman 2004). Typically, the dead are buried within the center (e.g. in temples, under household floors, within plazas or middens), but recent excavations of caves and rockshelters have complicated the mortuary ritual picture for the ancient Maya. These karstic

spaces are not considered typical burial locales (Ricketson 1925; Cucina and Tiesler 2005). Large populations at city centers would have prevented the routine interment of individuals in caves and rockshelters; how then does the selection of a resting place for the dead come about? Ricketson (1925) contended that caves containing human remains were "archaeological treasure-houses" (394), a notion that has carried through to modern archaeological thought that presupposes reverence of the cave and, possibly, the individuals buried within.

Materials and Methods

The primary source of data for this research is human dental material excavated from a series of two caves and three mortuary rockshelters in a number of river valleys in Belize. The secondary source of data for this research is the reference sample created from Late Classic high and low status burials at Maya habitation sites (Danforth 1989). The methods are standard bioarchaeological assessments of dental health, drawing on aspects of dental anthropology, physiological stress, and microscopic technology. Microscopy allows for the correlation of health stress events with chronological age, thereby producing a timeline of health experience during the duration of enamel formation. Both macroscopic and microscopic markers of stress will be observed in order to demonstrate both chronic and episodic stress occurrences, respectively.

The human dentition records health stress throughout an individual's lifespan. Insults to the individual in the form of nutritional stress or disease are recorded in the tooth enamel. Under high-powered microscopy, the internal structure of the enamel can be analyzed for the presence of micro-defect pathological bands (Wilson bands) that represent a health stress event. If the stress was severe or prolonged, there may be an observable macro-defect on the external surface of the enamel (linear enamel hypoplasias). Episodic stress can be evaluated from the enamel, allowing the bioarchaeologist to develop a time-sensitive picture of the overall health experience of an individual. Because the dentition develops on a regular biological schedule, it is possible to determine the approximate age at which the health stress event occurred. This gives the researcher a powerful body of data from which to infer social experience of individuals by understanding their health experience.

Tooth Selection Protocol

The maxillary central incisor, mandibular canine, and third molar have all been used variably in dental histology to ascertain microdefects reflective of health stress (Cassidy 1984; Condon 1981; Cook 1981; Danforth 1989; Goodman et al. 1980; Rose 1977). For this study, permanent mandibular canines and third molars will be preferentially selected following the protocol outlined in Danforth (1989). As a safeguard, maxillary central incisors will also be collected in the event that a significant number of individuals present with only one of the desired teeth. If present, the deciduous canine will also be selected for use in a study of early developmental stress. The left side will be selected arbitrarily, though because of symmetry in dental development among tooth class the right side will be sampled when the left tooth is not available.

Following Danforth (1989), canines were selected for their low susceptibility to caries formation, simple cusp morphology and high rate of recovery owing to the large root. Additionally, the long enamel formation period of canines encompasses the time shortly after birth to approximately five years (Fanning and Brown 1971). Third molars have not been a traditional focus of study in dental histology, with relatively little research presented in the literature (Cassidy 1984; Danforth 1989; Knick 1981). However, the third molar represents a period of later childhood development, conceivably when an individual is more incorporated into the adult social role that will be upheld throughout life. Maxillary incisors have been demonstrated to be a highly canalized tooth that is less likely to alter its size or development due to stressors (Condon 1981). The formation period is shorter than the canine, but begins earlier around 3–4 months of age. The combination of these teeth will inform of stresses occurring in early childhood development.

The observation protocol was devised using the methodology outlined in Danforth's (1989) dissertation on enamel defects in the pre- and post-contact Maya. Photographs of each tooth will be taken from both occlusal and labial/buccal views. The following measurements will be taken for each tooth: 1) maximum bucco-lingual width, 2) maximum mesio-distal width, 3) distance between cemento-enamel junction and tip of tooth on buccal side, and 4) distance between cemento-enamel junction and root tip (Danforth 1989).

All dental samples were analyzed for macroscopic defects (linear enamel hypoplasias, or LEH) using standard procedures reported on in the literature (Buikstra and Ubelaker 1994). The distance of the LEH from the cemento-enamel junction was measured and recorded in order to determine if a microdefect corresponds with the observed macrodefect. After macroscopic defects were documented, each tooth sample will be embedded in epoxy resin and cut in the midline using a standard laboratory saw for histological analysis (creating a "thick section"). Because the tooth is cut in the midline, there were two resultant thick section blocks. One block was subject to

thin sectioning procedures using the techniques outlined in Hillson (1996), with each thin section measuring 100 microns in width. These thin sections were mounted to a glass slide for analysis, effectively curating them for future research projects as well.

Using a standard optical microscope, each thin section was magnified to between 400–600x, the power range at which enamel microdefects are best observed. A truncated protocol for data collection was adopted from Danforth (1989) wherein presence, length, and variation of the defect will be recorded. Because width and color of the defect have not been continuously cited as factors contributing to the understanding and interpretation of defects, these variables were removed from the study. The length and depth of any observed LEHs on the surface was recorded. It is possible that the LEH observed in cross section is indicative of only a pit in the enamel rather than a true LEH (noted for traversing the length of the crown surface), and that limitation is acknowledged here.

Correlation of Microdefects with Age-at-Formation

Following Cook (1981), Danforth (1989) developed a population-specific age-at-formation schedule for the Maya. Upon discussing my research project with her, she stated that it would be reasonable for me to incorporate the dental enamel formation rates she established in my own study. Each tooth will be divided into 1mm sections along the dentino-enamel junction beginning at the tooth cusp. In the instance that the enamel is worn into the dentine, the tooth will be divided and measured starting at the cervical end. Cook (1981) outlined this protocol to account for the fact that, within one tooth, enamel forms at a constant rate. Danforth's (1989) assignments of developmental age to these millimeter sections will be used for this research. All divisions can be done with the aid of computer software associated with the optical microscope.

Because dental enamel develops on a fairly regular schedule from the time an individual is in utero to about twelve years old, the age-at-formation of defects can be matched to the position of the defect on the tooth. This enables bioarchaeologists to create a narrative about health stress events occurring in childhood.

Conclusions

Currently, I am still analyzing the microscopy data for the samples. Initial patterns indicate, however, that individuals experienced health stress independent of their social status; that is, elite residence did not buffer against physiological disruption. The Cave Research Foundation grant was instrumental in collecting data for this study as I was able to stay in Belize to excavate more burials to add to this study, as well as to make connections to other archaeologists working in country who were able to provide comparative samples.

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Paleohydrology and Climate Change in the Eastern Caribbean from Barbadian Speleothems

Final Report

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This project began in January of 2012, and the majority of fieldwork is complete. The goal of this research was to use several speleothem samples from the island of Barbados to identify potential mechanisms of multidecadal precipitation variability in the region. This goal was intended both to close a geographic gap in paleoenvironmental reconstructions and provide some information on long-term precipitation drivers in the region to help improve scientific information available to resource managers.

Figure 1: The principal investigator (Gil Ouellette) in Mekkaman cave, on the Island of Barbados.

Between January 2012 and August 2012, four stalagmite samples were obtained from the island of Barbados. Two of the speleothems were recovered from the Great Hall in Harrison's Cave (Hobbs, 1994). Harrison's Cave is a state owned show cave, and one of Barbados top natural attractions. Samples were obtained with permission from the management at Harrison's Cave, and Harrison's Cave staff and tour guides were integral in assisting and facilitating this project. The other two speleothem samples were obtained from Mekkaman Cave, in the vicinity of the Ape's Hill area (Fig.1). The focus of this project thus far has been on fine sampling the best of these samples, using the others for replication and for concerted study in further studies. For this project, sample HC-1W (obtained from Harrison's cave) was the object of major analysis (Fig.2).

While samples were obtained, ceramic plates were placed directly where speleothem samples were taken. These plates were left to capture calcite precipitated from the drip source for the sampled speleothems. Additionally, cave climate monitoring equipment was placed in-situ to record relative humidity and temperature variations at the sampled sites in the cave (Polk et al., 2011). Local cave guides were trained in collecting drip samples and have been collecting weekly samples of drip water from sample collection sites. On the surface, a tipping bucket rain gauge was deployed to measure rainfall amount and collect weekly rainfall samples for isotopic analysis. The in-cave and rainfall monitoring systems were deployed in order to both calibrate speleothem samples to the local hydrologic system while also verifying previous research that identified the dominant drivers of isotope fractionation in rainfall and cave drip waters (Polk et al., 2011).

During the fall and winter of 2012, stalagmite samples were processed at the Hoffman Environmental Research Institute (HERI) at Western Kentucky University. Samples were slabbed and polished with a coarse grit disc grinder. One half of each slabbed sample was sampled via hand held dremel tool to obtain powder samples for Uranium series dating. U-series dates were determined by Multi-Collector Inductively Coupled Plasma Mass Spectrometry at the University of New Mexico's Radiogenic

Isotope laboratory. The remaining half was fine polished and mounted onto a computer-automated micromilling system at HERI. Powder samples of approximately 250 micrograms were micromilled from these slabs in a continuous fashion for oxygen and carbon isotope analysis (Spotl and Mattey, 2012). Sample resolution was 100 microns along the growth axis (U-series dates indicate this sample resolution is roughly annual). Sample and analyses schema was designed based on previous studies of stalagmite geochemistry in Harrison's cave (Jones and Banner, 2003; Jones et al., 1998; Mickler et al., 2004). For the purposes of this study, a subset of samples was run initially in order to minimize costs while addressing the projects scientific questions at an appropriate temporal scale. The subset of samples consisted of a sample each millimeter, which translates to just over two samples per decade. U-series dating indicates that the sampled length of HC-1W represents approximately 1,500 years of calcite accumulation. This sampling schema prevents meaningful discussion of high frequency variability in precipitation on Barbados that occurs on the annual to multiannual time scale; however, this schema is more than adequate for meaningful analysis of the decadal scale precipitation influences that this study sought to identify (Mann and Lees, 1996).

Oxygen and carbon of the subset of powder samples were analyzed via Gas Bench Isotope Ratio Mass Spectrometry at the Environmental Research and Training Laboratories of the University of Kentucky. Oxygen isotope ratios served as a proxy for rainfall amount, with more negative oxygen 18/oxygen 16 ratios corresponding to greater precipitation amount. Preliminary results from the in-cave and surface monitoring system confirm that the amount effect is the dominant driver of precipitation oxygen isotope variability and that this translates to cave drip water and then

Figure 2: Slab of speleothem sample HC-1W. This sample was obtained from the Great Hall in Harrisons' Cave, Barbados. HC-1W is ~ 33cm in height, and includes two main types of lamina; pristine columnar calcite layers, and siliciclastic and organic clasts in an amorphous calcite matrix.

speleothem calcite. Carbon isotope ratios were compared to oxygen isotope rations using a least squares regression analysis for the full sample time series, as well as for several windows of the time series to ensure that oxygen and carbon isotope ratios were not correlated. Correlation between carbon and oxygen ratios would suggest kinetic isotope fractionation effects biasing the record. All correlation analyses returned low r^2 values, suggesting limited correlation between carbon and oxygen, thus improving confidence that speleothem isotope ratios were minimally impacted by kinetic fractionation effects interfering with the precipitation signal (Dorale and Liu, 2009). Correlation results were bolstered through replication with samples obtained from Mekkaman cave, adding confidence that the oxygen isotope ratios derived from HC-1W were indeed representative of a hydroclimatological signal, rather than kinetic fractionation (Dorale and Liu, 2009).

The results of the multidecadal analysis of oxygen isotopes in speleothem samples obtained in this project are currently being finalized and prepared for publication in a peer reviewed publication. Preliminary results indicate a strong influence of Atlantic variability on long-term precipitation patterns on Barbados.

While the major focus of this project was on identifying major influences on Barbadian precipitation variability at supradecadal time scales, novel non-destructive analyses was carried out on speleothem slabs using the Large Chamber Scanning Electron Microscope (LC-SEM) at the WKU NOVA center. The LC-SEM allowed high-resolution imaging of speleothem materials without requiring the destruction of the sample to produce thin sections. LC-SEM analysis revealed several siliciclastic layers within speleothem samples that were filled with well-preserved tests of foraminifera. Non-destructive Raman microscopy was also conducted to identify shifts in calcite crystal geometry along speleothem growth axes. The results of Raman analysis show clear variations in calcite crystallography, which we interpret as being a result of varying levels of calcium substitution in speleothem calcite (Rividi et al., 2010). While these non-destructive analyses show some clear and interesting patterns that appear to match human development on the island, continued analyses and methodological refinement is needed.

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Conserving Cave Bats in the Philippines

Assessing the Impact of Cave Disturbance on Bat Communities

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Project Introduction

Bats spend more than half their lives in roosts, which provide a stable environment suitable for roosting and rearing young as well as shelter from inclement weather and predators. Caves represent critical roosting sites for numerous bat species because of their permanency and stable microclimates. Some of the largest and most diverse aggregations of bat species in the world roost in caves. Cave-dependent bats provide vital ecological and economic services, specifically pollination, seed dispersal, and consumers of insects that damage crops and carry human diseases as well as supply the primary nutrient input (guano) in caves. Yet cave-dependent bat populations continue to decline globally, with human disturbance at caves identified as the leading cause of these declines.

The Philippine archipelago is home to extraordinary bat diversity, with 78 documented species of which 21 are endemic. Half of these species are highly dependent upon caves as roosting sites. Cave-dependent bats in the Philippines are threatened by numerous human activities; this is particularly so on Bohol Island. Recreational exploitation of caves is increasing steadily on Bohol Island; many caves are currently advertised for tourism. Frequent visits by tourists at show caves can cause bats to abandon roosts. Other common activities that disturb roosting bats include guano harvesting, treasure hunting, and collection of cave swiftlet nests for birds nest soup. Logging has greatly reduced suitable foraging sites, and expanding rice fields engulf remaining forested habitats. Most bat species are highly dependent upon intact forest stands for foraging, making them especially vulnerable to current deforestation rates. Thus, the impacts of human disturbance at caves can have detrimental effects on the viability of cave bats in the Philippines.

With 27 cave bat species, Bohol Island represents a biological hotspot in the Philippines; however, many of its cave-dependent bats are vulnerable to human disturbances at roosts. Thus, the aim of my study is to compare cave bat communities among caves experiencing differing levels of human disturbance to: i) assess the status of cave-dependent bats in an increasingly human-dominated landscape; and ii) identify human threats that have the greatest impact on cave-dependent bats.

Specifically, my objectives are to:

- Quantify levels of disturbance at caves,
- Characterize species diversity and composition of bat communities, and
- Assess physical health parameters of individual bats.

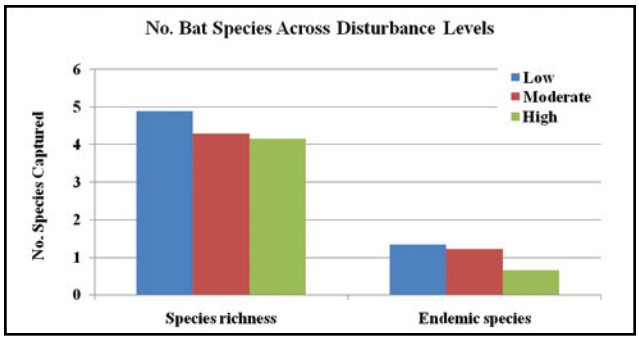
My study tests the hypothesis that cave-dependent bat communities inhabiting highly disturbed caves will have: i) lower species richness and diversity; ii) composition devoid of rare, endemic or functionally significant species, and iii) individual bats with inferior body conditions and higher rates of ectoparasitic infections.

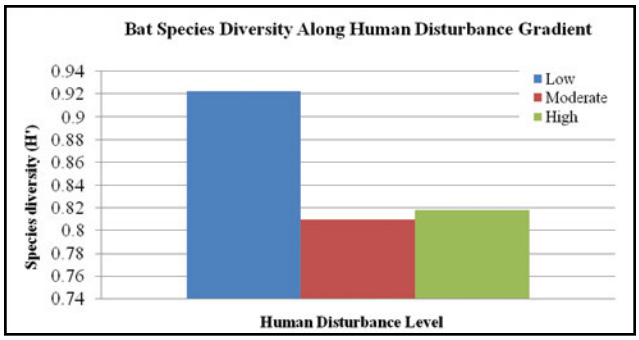
Figure 1: Location of caves used in this study.

Preliminary Results

Quantify Human Disturbance

Using standard cave survey methods, 60 caves were surveyed near 55 villages across Bohol Island between July 2011 and June 2013 (Figure 1). During surveys, cave dimensions were measured including width and height of cave entrances, chambers, and observed roost sites as well as total cave length. Microclimatic variables, including





Figures 2 and 3. Comparison of species richness/number of endemic species and species diversity across a human disturbance gradient in caves on Bohol Island, Philippines.

temperature, relative humidity, and wind speed were determined at each survey station. A unique feature of my project is to systematically quantify levels of human disturbance inside the cave as well as across the landscape immediately surrounding the cave entrances. Using a modified karst disturbance index I developed, invasive forms of human disturbance that may impact cave-roosting bat populations such as limestone/phosphate mining, tourist visitation rates, deforestation, and resource extraction (bat/guano/swiftlet nest) were quantified based on a scale ranging from 0–3 depending on the extent and severity of the disturbance.

Interviews with 559 local residents revealed the most common form of human disturbance in caves is tourism, either on a large scale with hundreds of national and international tourist visits per day or on a smaller scale with groups of local residents. The second most common form of human disturbance was guano collection, typically on a frequency of twice annually coinciding with the rice-planting season.

Combining data gathered through observations inside and outside the caves with information learned through one-on-one interviews with residents, caves were categorized as low, moderate or high disturbance. Of the 60 caves, 20 caves were classified as low disturbance caves, 20 caves received moderate levels, and another 20 were subjected to high levels.

Characterize Bat Communities

Cave bats were captured using mist nets placed across cave entrances for 2 consecutive nights at each cave. In total, 7,419 individuals of 24 species comprising 8 families (Pteropodidae, Hipposideridae, Rhinolophidae, Vespertilionidae, Megadermatidae, Miniopteridae, Emballonuridae, Molossidae) were captured during 120 trap-nights. These samples represent 83% of all documented species on Bohol Island.

It is clear that caves subject to moderate and high levels of human disturbance have reduced species richness and notably less endemic species when compared to low disturbance caves; as well as, decreased diversity of cave bat species (Figures 2 and 3). Thus, any form of human disturbance has observable impacts on cave bat communities. This could have devastating consequences for the ecosystems because bats comprise 50% of all mammals in the Philippines and provide essential ecological functions not provided by any other wildlife species.

Health Parameters of Individual Bats

Human disturbances have the potential to alter significantly the quality and quantity of available resources (i.e., foraging, roosting sites), ultimately impacting an individual's fitness. In this study, individual fitness was measured as 1) ectoparasite loads and 2) body condition.

Individual bats were visually screened for external parasites; samples were carefully removed using forceps and preserved in 70% alcohol. Seven hundred and twenty-one (721) ectoparasite samples were collected, and have been sent to a collaborator at Northern Arizona University for identification. Ratio of body mass (g) to forearm length (mm) was used to calculate a body condition index (Pearce et al., 2008). This method assumes that an individual with a higher ratio will be in better physical condition than an individual with a lower ratio. Rates of ectoparasitism and body condition will be compared to levels of human disturbance.

Future Plans

Though I have provided very preliminary findings in this final report, a more thorough data analysis is needed to prepare manuscripts for publication in peer-reviewed journals and to present final results at scientific conferences. Requirements for a doctoral degree will be completed by May 2015.

Effects of Landscape Evolution on the Growth of Sub-aqueous Speleothems—Rise of the Guadalupe Mountains

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This research project is part of a PhD dissertation with the intent of linking the growth of scalenohedral dogtooth spar to landform evolution in the Guadalupe Mountains of southeast New Mexico and west Texas. During the time of this grant, 20 samples of spar were collected from 18 different caves. Each of these samples were subjected to elemental analysis on the Neptune X-series II mass spectrometer to find the uranium, thorium, lead and strontium amounts, which in turn were used to determine whether there was enough uranium and lead to run a more thorough analysis on the Thermo-Finnegan Neptune Inductively Coupled Plasma Mass Spectrometer (ICPMS). The final analysis of which allowed us to calculate the age of the spar. Of these 20 samples, 18 had the proper ratio and high enough amounts of uranium and lead to run on the ICPMS. Each of these samples were divided into eight sub-samples (144 total sub-samples), which were then subjected to ion exchange chemistry to separate the uranium, thorium and lead from the calcite matrix. After running the ICPMS and data reduction using both Pb-Dat (Ludwig, 1993) and Isoplot (Ludwig, 2000), we found that the ages of the calcite spar fell into two well-known date ranges: 42 to 36 Ma and 32 to 28 Ma. These ages correspond with known volcanic activity in southeast New Mexico and west Texas that are correlated to Basin and Range and Rio Grande Rift development. Each of these 144 sub-samples was also subjected to a different ion exchange resin to separate out the strontium, which was also run through the ICPMS to get ratios of the strontium isotopes which gave us temperatures of formation (Fietzke and Eisenhauer, 2006).

Part of these findings are in the process of being published through the Geological Society of America Special Bulletin 516, Caves and Karst Across Time (Decker et al., in press). The remainder of the data have been written up, and we are in the process of submitting these articles to several journals for publication. Since 2013, I have presented four posters, three at the annual GSA Convention, one in Charlotte, NC, one in Denver, CO and a third in Vancouver, B.C., the fourth poster was presented at the New Mexico Geological Society Spring Conference in Socorro, NM. I also gave a talk on my findings at the Southwestern Regional Winter Technical Event in Albuquerque, NM.

This project began in January, 2011 and will extend to August of 2015 when the dissertation is expected to be completed. My budgetary requirements for 2013 lab work included sample preparation, chemical analysis, radiogenic isotope analysis, supplies and storage solutions (see attached budget for details). This grant partially covered these expenses; the rest was covered by an NSF grant and a Vehslage grant from the National Speleological Foundation.

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Paleoseismology of the Shillong Plateau, India

Constraints from U/Th Dating of Tectonically Broken Cave Deposits

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The state of Meghalaya in NE India is a dynamic landscape where the human population is significantly effected by the regional geology and seasonal climate. The east-west oriented Shillong Massif dominates the topography of Meghalaya with steep cliffs and gorges to the south and rolling hills to the north. The east-west trending Dauki Fault runs along the southern margin of the Shillong Massif and separates Meghalaya from Bangladesh to the south. Tectonic convergence along the Dauki Fault is responsible for the uplift of the Shillong Massif (Chen and Molnar, 1990; Khattri, 1992) and has resulted in major seismic events such as the 1897 Great Assam Earthquake with an estimated 8.2 magnitude (Morino et al., 2011). The last major earthquake to affect Meghalaya was the magnitude 8.7 Assam-Tibet earthquake of 1950. Meghalaya's position in this tectonically active region along with the third fastest growing population in India (Meghalaya Population, 2013) renders its human population at risk of future mega earthquake events (Saikia, 1981). The current seismic history of NE India is only constrained to the last 1,500 years and as the regional population continues to grow, a better understanding of future seismic hazard is necessary (Sukhija et al., 1999; Bilham, 2013).

Along with producing large seismic events, uplift of the Shillong Massif in Meghalaya has exposed massive limestone deposits, which has allowed for intense karstification of the southern margin of the massif, producing over 1,300 registered caves (Arbenz, 2012). Given the proximity of caves on the Shillong Massif to faults that are associated with large historic earthquakes, dating broken speleothems in NE India could expose a currently unexploited archive for paleoseismic events in this region (Kagan et al., 2005). Previous paleoseismic research in the region has relied upon radiocarbon dating of liquefaction features found in observable surface ruptures and suggests a recurrence interval of 400–600 years for mega-earthquakes on the massif (Sukhija et al., 1999). However, the lack of observable surface ruptures, the inability to date events beyond 50,000 years bp, and large errors (± 150 years) associated with radiocarbon dating limit the accuracy and temporal span of this approach (Sukhija et al., 1999). The use of speleothems as paleoseismic archives have been applied in numerous regions (Kagan et al., 2005; Forti, 2001; Gilli, 2005; Becker et al., 2006; Panno et al., 2009), but this method has yet to be applied in NE India. Given the close proximity of Shillong Massif caves to active faults, seismic waves associated with mega-earthquakes such as the Great Assam of 1897 likely had the ability to fracture speleothems and produce paleoseismic archives that can be dated precisely. My research focused on validating this hypothesis by dating speleothems broken during observed mega earthquake events to allow for a stronger understanding of how broken speleothem may be used as paleoseismic archives of events prior to the observed historic record in this region. A stronger understanding of the seismic history of NE India would aid in the evaluation of a possible reoccurrence interval for mega earthquakes in this region and assist in the preparation for future mega earthquake events.

Speleothems undergo various types of damage during large earthquake events such as fracturing and collapse of stalagmites, and fracturing of stalactites and soda straws (Kagan et al., 2005; Becker et al., 2006). Broken speleothems and new carbonate growth were collected from Mawmluh Cave and Krem Umsyngrang on the southern margin of the Shillong Massif for Uranium-Thorium (U-Th) dating and paleoseismic analysis. Care was taken while caving to avoid collecting speleothems from areas where human traffic, loose cave sediments, or active cave streams clearly might have caused speleothem breakage. In an attempt to identify structures that may have broken during the well-documented 1950 and 1897 earthquakes, broken speleothems associated with small, actively growing post-breakage formations (2cm–10cm) were preferentially sampled. Dating preference was given to samples collected from Mawmluh cave due to their high initial U concentration (37.6–72.2 ppm) and low detrital 232Th values (0.00157–0.0251 ppm), making them highly favorable for precise dating of young samples (Table 1). U-Th sample preparation and analysis were performed at the Berkeley Geochronology Center using a Thermo Neptune Plus Multi-Collector-Inductively-Coupled-Mass-Spectrometer (MC-ICP-MS).

Seven fallen soda straws and two collapsed stalagmites from Mawmluh Cave have been analyzed for paleoseismic evidence. Broken soda straws collected from Mawmluh Cave reveal breakage dates ranging between 1988.7 and 2007.3 (C.E.) (Table 1). Dating of the lower-most layers

of the post-breakage growth on the two collapsed stalagmite structures from Mawmluh Cave produce U-Th ages of 1954.7 ± 2.1 (MAW 03-01) and 1965.7 ± 2.5 years (MAW 02-01) (Table 1). Layer counting results were used to quantify annual lamina present between the lowermost dating sample and the new growth-old growth transition which estimated the depositional age of MAW 03-01 and MAW 02-01 to be 1952.2 ± 2.1 and 1957.2 ± 2.2 respectively. Previous research in Mawmluh Cave performed by Sebastian Breitenbach has dated a separate small stalagmite (MAW-4) deposited on a flowstone for a modern climate assessment. MAW-4 exhibits growth morphology similar to MAW 02-01 and MAW 03-01 and has a depositional age of 1954.0 ± 2.0 years (Cetti, 2012).

Despite the clustering of soda straw breakage around the late 1980s, early 2000, and 2007 (Table 1), NE India experienced no mega earthquakes during these intervals. Lower-magnitude earthquakes are very common along the southern margin of the Shillong Massif and could have caused the observed soda straw breakages; however, the small dataset makes this hypothesis difficult to support. The fractured stalagmite new growth structures that have been analyzed from Mawmluh Cave have post breakage event depositional ages between 1952.2 ± 2.1 and 1957.2 ± 2.2 years. The evidence that all three of the new growth structures from Mawmluh Cave were deposited shortly after 1950 suggests that the fractured stalagmite features from Mawmluh Cave may have broken during the 1950 Assam-Tibet earthquake. The estimated 8.7 magnitude Assam-Tibet earthquake brought widespread destruction and 1,500 casualties to the Shillong Massif region (Chamlagain, 2009). Results presented here suggest that Mawmluh Cave on the southern margin of the Shillong Massif holds potential for elucidating the paleoseismic record through continued speleothem paleoseismology research. The young ages and lack of correlation with known mega-earthquakes indicates that soda straws may be too reactive and break during proximal low magnitude events. Thus, to focus on large magnitude earthquakes, future work should target larger collapsed stalagmite features in Mawmluh Cave for paleoseismic information. The ability to extend the seismic record would allow for a more accurate estimate of mega earthquake reoccurrence and improved earthquake risk management for the growing population in NE India and Bangladesh.

An unanticipated but very exciting outcome of my paleoseismology work in Mawmluh Cave was the opportunity to produce high-resolution speleothem 18O modern climate record for NE India. When new growth stalagmite, MAW 02-01, was analyzed for paleoseismic evidence, we discovered growth laminations with an average thickness of 0.38mm, allowing for 7–8 18O samples per year at 50 m spatial resolution (Myers et al., 2015). Furthermore, MAW 02-01 had very high initial U concentrations and low detrital 232Th values (Table 1), producing a sample that yielded very precise U-Th dates and a strong age model for 18O interpolation. Comparison of MAW 02-01 18O with records of SST anomalies in the central and northern equatorial Pacific demonstrate a significant correlation between NE India speleothem 18O and northern Pacific decadal variability, along with a significant correlation between NE India speleothem 18O and SST anomalies in central equatorial Pacific (Figure 1) (Myers et al., 2015). This high resolution speleothem 18O record supports the observations that central Pacific El Niño

Sample Name	Sample Type	Wt (mg)	U (ppm)	^{232}Th (ppm)	^{230}Th/^{232}Th	^{232}Th/^{238}U	2s %err	^{230}Th/^{238}U	2s %err	^{234}U/^{238}U	2s %err	Detr-Uncorr Age (ka)	Detr-Uncorr Err (2s)	Detr-Corr Age (ka)	Detr-Corr Err (2s)	Initial ^{234}U/^{238}U		Date (C.E.)	Err (2s)
MAW 01-01	SS	*26.41*	47.47	0.0026	3.99	1.71E-05	1.04	6.48E-05	4.70	0.886	0.42	0.0080	0.0004	0.0062	0.0010	0.886	±0.004	**2007.3**	**1.0**
MAW 01-02	SS	*27.65*	60.91	0.0074	2.30	3.94E-05	0.85	8.69E-05	7.84	0.897	1.00	0.0106	0.0008	0.0066	0.0022	0.897	±0.009	**2007.0**	**2.2**
MAW 01-03	SS	*17.76*	72.18	0.0251	2.60	1.13E-04	0.95	2.91E-04	5.48	0.865	0.68	0.0367	0.0020	0.0249	0.0064	0.865	±0.006	**1988.7**	**6.4**
MAW 02-01 High	Stal (NG)	*14.04*	43.44	0.0027	2.71	1.81E-05	0.62	3.98E-05	12.6	0.930	0.60	0.0047	0.0006	0.0024	0.0011	0.930	±0.006	**2011.1**	**1.1**
MAW 02-01 Low	Stal (NG)	*13.04*	49.20	0.0024	25.9	1.41E-05	1.39	4.03E-04	4.81	0.892	1.20	0.0493	0.0024	0.0478	0.0025	0.892	±0.011	**1965.7**	**2.5**
MAW 03-01 Low	Stal (NG)	*13.14*	37.61	0.0030	19.6	2.41E-05	0.69	5.05E-04	2.66	0.899	0.58	0.0613	0.0017	0.0589	0.0021	0.899	±0.005	**1954.7**	**2.1**
MAW 04-01	SS	*14.89*	61.89	0.0117	2.93	6.10E-05	0.89	1.73E-04	2.93	0.916	2.00	0.0206	0.0007	0.0146	0.0031	0.916	±0.018	**1999.0**	**3.1**
MAW 04-02	SS	*30.03*	56.36	0.0016	11.4	8.40E-06	2.99	9.88E-05	4.72	0.928	2.40	0.0116	0.0006	0.0108	0.0007	0.928	±0.022	**2002.8**	**0.7**
MAW 04-03	SS	*20.43*	61.87	0.0020	10.0	9.78E-06	1.62	1.01E-04	2.38	0.916	1.80	0.0120	0.0004	0.0111	0.0006	0.916	±0.016	**2002.5**	**0.6**
MAW 04-05	SS	*45.14*	52.67	0.0108	2.26	6.72E-05	1.89	1.49E-04	5.71	0.905	0.94	0.0180	0.0010	0.0113	0.0036	0.905	±0.009	**2002.2**	**3.6**

Table 1. All isotope ratios are activity ratios. Errors are 2-sigma. Detritus-uncorrected ages are calculated from measured ratios. Detritus-corrected ages were corrected for initial 230Th assuming that measured 232Th reflects detritus with (232Th/238U) = 1.21 ± 0.5 , (230Th/238U) = 1.0 ± 0.1, and (234U/238U) = 1.0 ± 0.1; i.e., detritus with the Th/U ratio of average crustal silicate, with 230Th and 234U approximately in secular equilibrium. Decay constants are those of (Jaffey et al., 1971) for 238U and (Cheng et al., 2013) for 230Th and 234U. The detritus-corrected age of MAW 02-01 High, a "zero-age sample", is corrected for 0.5 year, the approximate time between collection and analysis. (234U/238U) initial is back-calculated from the measured ratio and corrected 230Th age. Calendar dates (Dates C.E., common era) are calculated by subtracting detritus-corrected ages from the date of analysis (2013.56). Soda straws and new growth portions of collapsed stalagmites are denoted by sample type "SS" and "Stal" respectively.

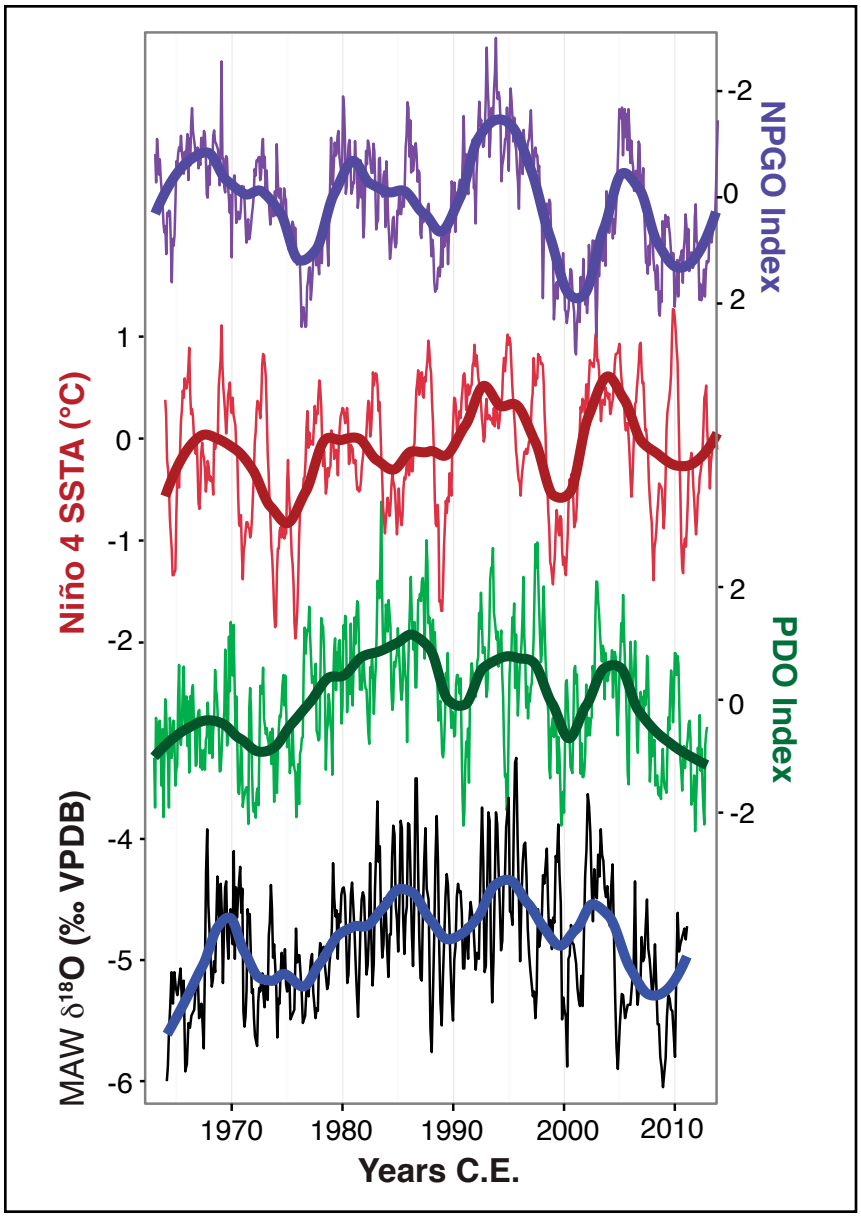

Figure 1. (from bottom to top) 18Ospel, the PDO index (http://jisao.washington.edu/pdo), Niño4 SST anomalies (www.cpc.ncep.noaa.gov), and the NPGO index (y axis reversed) (http://www.o3d.org/npgo/npgo. php). Bold lines are LOESS smoothing (see Myers et al., 2015).

events are more effective at suppressing Indian Summer Monsoon rainfall over central India (Kumar et al., 2006; Weng et al., 2007), and modify moisture transport trajectories over NE India (Myers et al, 2015). Results from this speleothem 18O time series suggest that NE Indian speleothems are effective tools for investigating El Niño dynamics and teleconnections to Pacific climate prior to the historic record. A stronger understanding of how Pacific variability disrupted ISM precipitation in the past will improve our foresight as to how ISM variability will evolve in the future.

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Evaluating the Effectiveness of Regulatory Stormwater Monitoring Protocols on Groundwater Quality in Urbanized Karst Regions

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Non-point pollution from stormwater runoff is one of the greatest threats to water quality in the United States today, particularly in urban karst settings. In these settings, the use of karst features and injection wells for stormwater management results in virtually untreated water being directed into the karst aquifer. Currently, no policies exist specifically to provide water quality protections to karst environments. This study utilized a combination of karst stormwater quality data, along with survey data collected from MS4 Phase II communities, and an analysis of current federal, local, and state water quality regulations, to assess the need for karst-specific water quality regulations. When compared to quarterly water quality monitoring data collected in Kentucky by the City of Bowling Green (CoBG) data collected during this study indicate that significant levels of contamination are mobilized during storm events, and often are directed into the karst system via Class V injection wells with little to no filtration or pretreatment.

Utilizing bi-weekly baseline data collection at six sites, three paired input/output locations coupled with storm sampling and real time water quality monitoring at select locations, this study reinforces the need for revised water quality monitoring protocol in karst areas. Samples were collected over a 12-month period and analyzed for common stormwater contaminants for each of the representative land uses (commercial, industrial and residential). Analytes included TSS, Oil and Grease, BOD, COD, nitrate, phosphate, fecal coliform, *E. coli* and various metals. Results show that in Bowling Green, significant contamination is mobilized during storm events regardless of land use in the surrounding area and that contaminant travel time is highly variable. These data reinforces the need for high frequency monitoring of stormwater runoff in karst areas as it shows that karst systems can exhibit increased containment loading for several days after storm events. The length of the increased contaminant levels means that grab samples, the current norm for stormwater sample collection, do not accurately reflect true loading. An increased monitoring frequency is especially important in urban karst areas where the use of the karst system, through both natural and human-made inputs, introduces contamination instantly into the aquifer with minimal pretreatment. A monitoring program with an increased sampling frequency, which includes storm sampling, is needed to generate sufficient data for the characterization of a karst system's water quality (Ryan and Meiman, 1996). Monitoring by municipalities becomes more important as public awareness and appreciation of water availability grows. Increasing demands on fresh water supplies increase the value of any available waters, meaning that a

correlating increase in monitoring and research must be undertaken to ensure proper resource management. For a monitoring program to remain a financially viable and publically acceptable undertaking for MS4 Phase II communities, the contaminants of concern must be kept to a reasonable number and should reflect contaminants that may reasonably be expected given the surroundings and possible pollutant sources. Because increases in monitoring programs require increased funding, many MS4 Phase II communities would need to form stormwater utilities or seek other public funding. This requires increased public involvement and buy-in, which raises another set of problems. Where do public opinions lie on the importance of karst water quality protection? Do the six minimum control measures laid out in the MS4 Phase II permit provide an adequate framework for building public support of an increased MS4 Phase II scope?

To answer the question of public karst knowledge and support of MS4 monitoring requirements, survey data was collected from MS4 stakeholders in the karst regions of Kentucky, which indicates stakeholders are generally unable to explain local karst regulations or the steps taken to develop them. This confusion comes in part from insufficient progress on evaluation criteria available for the MS4 Minimum Control Measures (MCMs). While a heavy emphasis is placed on public participation and outreach in the MS4 Phase II permit requirements, a lack of benchmarks means that identifying strengths and weaknesses in the program is difficult. Members of county planning and zoning commissions, public works and engineering officials along with Kentucky Department of Environmental Protection scientists and private consultants were all invited to participate in the survey. Responses showed a general lack of understanding of karst systems and a noticeable lack of enthusiasm for enhanced monitoring requirements. Along with the lack of benchmarks, research into local and state water quality regulations revealed that significant confusion exists as to protections offered to water in karst systems. Karst waters are often placed into the legal "gray zone" due in part to differences in definitions of key terms in state and federal regulations. A key factor in this is the current school of thought which exempts groundwater from the Waters of the United States. This exemption means that groundwater is not covered under the majority of the Clean Water Act provisions, even in cases where direct surface connections and recharge are evident. Through an examination of state and local policies in Kentucky and the surrounding region, it was determined that a new policy framework would be necessary to provide protection to karst waters under existing federal regulations.

While this study recommends the development of regulations specific to karst waters at the state and federal levels, it is important to remember that regulatory change is not instantaneous. Water quality data collected during the first portion of the study show that building a meaningful dataset in karst systems requires significant time, material, and financial support. The key to achieving this is to build public support for such projects through increased educational efforts aimed at raising public awareness of karst systems and the current status of the regulations that cover them. By using "real world" examples of water quality degradation such as this study, it will be possible to enact meaningful change. The high levels of variability seen between individual karst systems means that standardized regulations will be difficult to develop and enact. It is hoped that this study can serve as a starting point for future research into issues with water quality and public education in urbanized karst areas, not only in Kentucky, but globally as well. I would like to thank the Cave Research Foundation for helping to make this research possible.

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Speleothem Strontium Concentrations in Eogenetic Carbonates

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Abstract

Three questions were asked during this research. One: Does the Sr content of Caribbean speleothems have a direct relationship with the age of the host rock at the time of speleothem precipitation? Two: Do older speleothems contain less Sr than younger speleothems in the same climatic setting? Finally, three: Will speleothems record the change in Sr concentration of eogenetic carbonates as a faster depletion in climates of higher precipitation as opposed to drier climates?

The speleothems and cave rocks in this study were analyzed with various methods in an attempt to understand the rock processes that affect speleothem Sr concentrations. Evidence to support the hypothesis that younger host rock contributes higher concentrations of Sr to speleothems was found in the stalagmites of Curaçao while Bahamian stalagmites indicated climatic variations. These results have implications for using stalagmites from relatively young, eogenetic limestone as a proxy for Sr-related paleoclimate data.

Introduction

The presence of strontium (Sr) in carbonate rocks has been long documented (Kulp et al., 1962) and has been recognized as a contributor to the trace element content of speleothems used for paleoclimate reconstruction (Goede et al., 1998). Sr in speleothems can originate from multiple sources although for the majority of current research the Sr is assumed to be infiltrated from a surface source (White, 2004; Van Beynen et al., 2008; Finch et al., 2003; Sinclair et al., 2012; Roberts, et al., 1998). In younger, eogenetic carbonates the mineralogy is aragonite and the aragonite crystal structure accommodates Sr in replacement of Ca (White 2004; Hill and Forti, 1997). Over time, aragonitic carbonate rocks will invert to the more stable polymorph mineral, calcite (Hill and Forti, 1997). This inversion releases Sr to the vadose zone, as the Sr cannot be accommodated in the calcite crystal lattice.

The carbonate host rocks that are mineralogically aragonite will naturally have a greater Sr content than those rocks that are calcite. The older eogenetic rock units of the Caribbean typically have a higher calcite to aragonite ratio than those that are younger. It can then be surmised that younger carbonates in the Caribbean should have a greater amount of Sr contribution from the host rock into those speleothems than speleothems that form in older carbonates that are inverted to calcite.

Uplifted island carbonates, such as the carbonate units in the study area of Curaçao, Netherlands Antilles (Figure 1A and B), are often terraced where the oldest unit is on top and the youngest on the bottom (Schellmann et al., 2004). These units are composed of coral carbonates that were originally composed of aragonite (Schellmann et al., 2004). The inversion of aragonite to calcite is not only time dependent, it is also dependent on the flux of meteoric water through the limestone. Abaco Island, Bahamas, is the wettest island in the Bahamian archipelago (Figure 1C); Long Island and San Salvador, Bahamas are one of the driest islands in the archipelago (Sealey, 1990). However, the islands have carbonates of the same approximate age, so any difference in aragonite inversion degree should be a climatic signal as opposed to an age signal as for Curaçao.

Speleothem research has become an integral part of paleoclimate data because these cave deposits preserve the conditions that were present at time of speleothem deposition. As cited earlier, most of this research is looking to interpret the surface conditions at the time of deposition such as temperature, rainfall, vegetation and more. However the state of the host rock itself can also be preserved in the speleothem record.

This research sought to answer three questions. One: Does the Sr content of Caribbean speleothems have a direct relationship with the age of the host rock at the time of speleothem precipitation? Two: Do older speleothems contain less Sr than younger speleothems in the same climatic setting? Finally, three: Will speleothems record the change in Sr concentration of eogenetic carbonates as a faster depletion in climates of higher precipitation as opposed to drier climates?

This research will contribute to the many past and future studies of speleothems. Present work on speleothems has been concentrated on those located in much older geologic settings where the limestones are all calcite and Sr is more

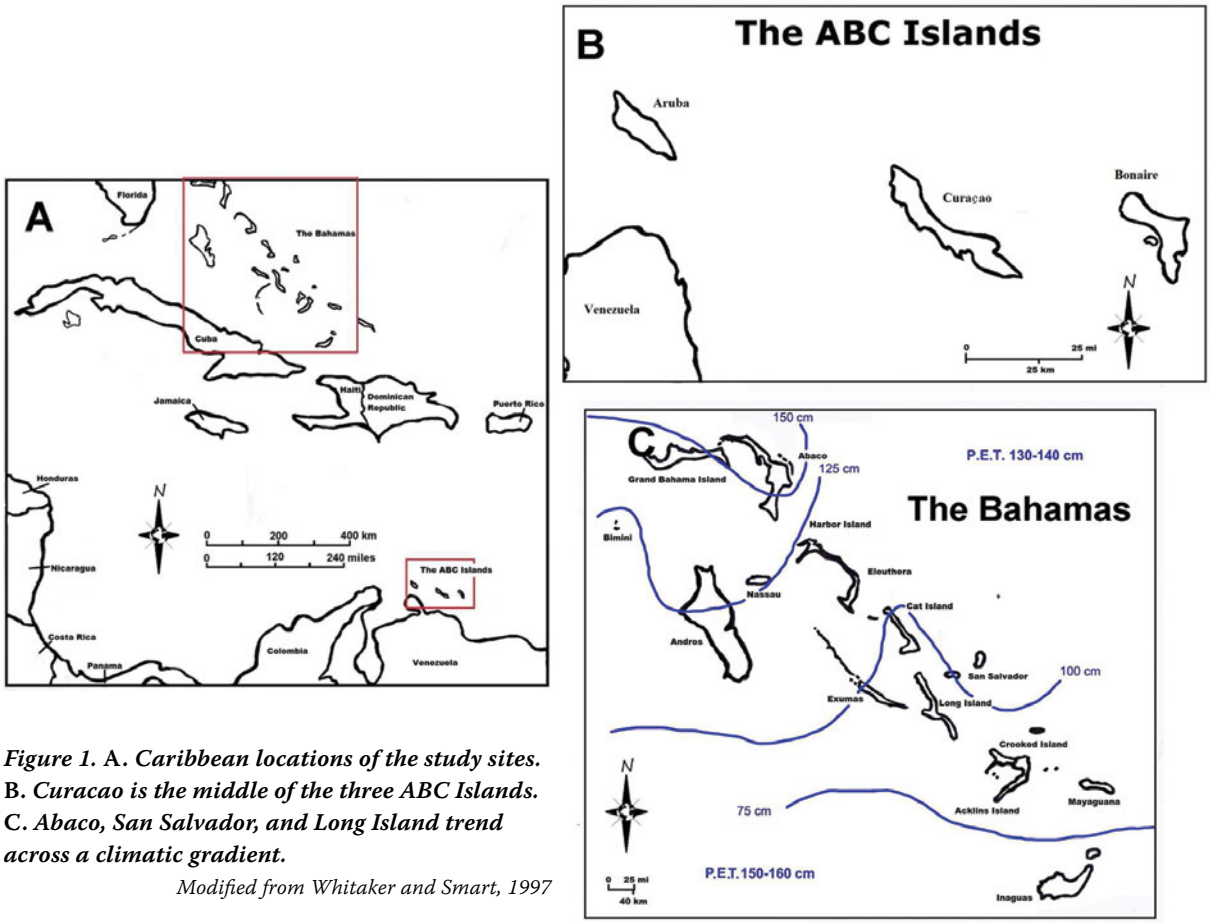

Figure 1.* A. *Caribbean locations of the study sites.* B. *Curacao is the middle of the three ABC Islands.* C. *Abaco, San Salvador, and Long Island trend across a climatic gradient.

Modified from Whitaker and Smart, 1997

likely to be an infiltrate from an external source. The work on speleothems in younger, Sr-enriched host rocks will need to consider the possibly significant amount of host rock sourced Sr within the speleothem record. This could affect the interpretations of paleoclimatic data from the use of speleothems in young carbonates. By determining the correlation of host rock age with strontium concentration in the speleothem in contrast with the variation of strontium in differing climatic settings, earlier paleoclimatic studies may be able to calibrate their interpretations. Recently, research has been shifting to oceanic islands to obtain speleothem climate records not available on continents. The rock hosting the speleothem-containing caves are commonly young and aragonitic, so the research for this thesis was timely and important.

Methods

The fieldwork on the island of Curaçao took place in December of 2012 while the fieldwork on the islands of Abaco, Long Island and San Salvador took place in June of 2013. Prior fieldwork of Dr. J. E. Mylroie, J. R. Mylroie, P. Kambesis, E. Larson and others provided knowledge of the caves in these field areas that allowed for planning of sample collection. Due to the delicate nature of exporting specimens, permission was sought before planning. Permission for six stalagmites (two each from three caves, one cave in each terrace) was obtained from the Carmabi Foundation for Curaçao (their national park service) by Dr. John Mylroie. Permission for multiple stalagmites was obtained for collecting on Abaco Island, San Salvador Island and Long Island from the Bahamas Environment, Science and Technology (BEST) Commission, issued to Dr. John Mylroie. All paperwork was carefully arranged before travel to these countries.

The Curacao caves identified as the preferred caves for collection were Lardem Cave in the lowest, youngest terrace, Raton Cave in the middle terrace and Hato Cave within the top, oldest terrace (Figure 4). The stalagmites were carefully selected as the most optimum specimens within the caves (Figure 2A). They were collected from deep within the caves identified as primary candidates for this study to ensure humidity was high and airflow was minimal. They were collected from hidden locations to preserve cave internal appearance

The specimens from the Bahamas were collected from three islands that are located in areas that have differing precipitation budgets (Figure 1C). Abaco, the northern-most island in the study area, has a positive water budget with the highest precipitation rate of the three. Long Island has a negative water budget with the least amount of precipitation. San Salvador has a water budget and precipitation between the two extremes of this study. The first island visited was Long Island and the two caves that were identified as prime candidates for collection were Salt Pond and Hamilton's. Hole in the Wall Cave and Roadside Cave, from the southern end of Abaco, were sampled. Lighthouse Cave was the San Salvador Island sample site.

All rock samples were carefully cut into blanks for the creation of thin sections (Figure 2B and C). The rock blanks were each cut with a wet saw with a diamond tipped blade manufactured for the purpose of cutting tile and stone. They were cut to specifications set by Spectrum Petrographics, the company chosen to create the thin sections. Each blank was notched with the wet saw to preserve the upright direction previously marked on the samples in the field. Rock samples from Curaçao were analyzed for composition using laser ablation and ICP-MS at the Rensselaer Polytechnic Institute by Dr. Rinat Gabitov. The Bahamas rock samples as well as additional samples of the Curaçao rocks were prepared in powder form through the ICP-OES at Western Kentucky University. The process was thoroughly documented in notebook and photograph for each rock specimen for further reference if needed. The preparation of the stalagmites was done at Western Kentucky University in the Earth Sciences and Technology building under the guidance of Dr. Jason Polk. Stalagmites were cut in half parallel to the growth axis, perpendicular to the growth layers. They were then evaluated for feasibility of study.

Results

Curaçao

Rock samples from within the lower terrace of Curaçao contained well-preserved fossils when collected from inside the cave (Figure 2C). The rock specimen collected from the surface was highly altered. In both cases, crystals growing into the pores of the rock from all directions indicated vadose conditions during crystallization. The caves in the higher terraces had progressively less preserved fossils and different pore spaces. The rock samples from within Raton cave,

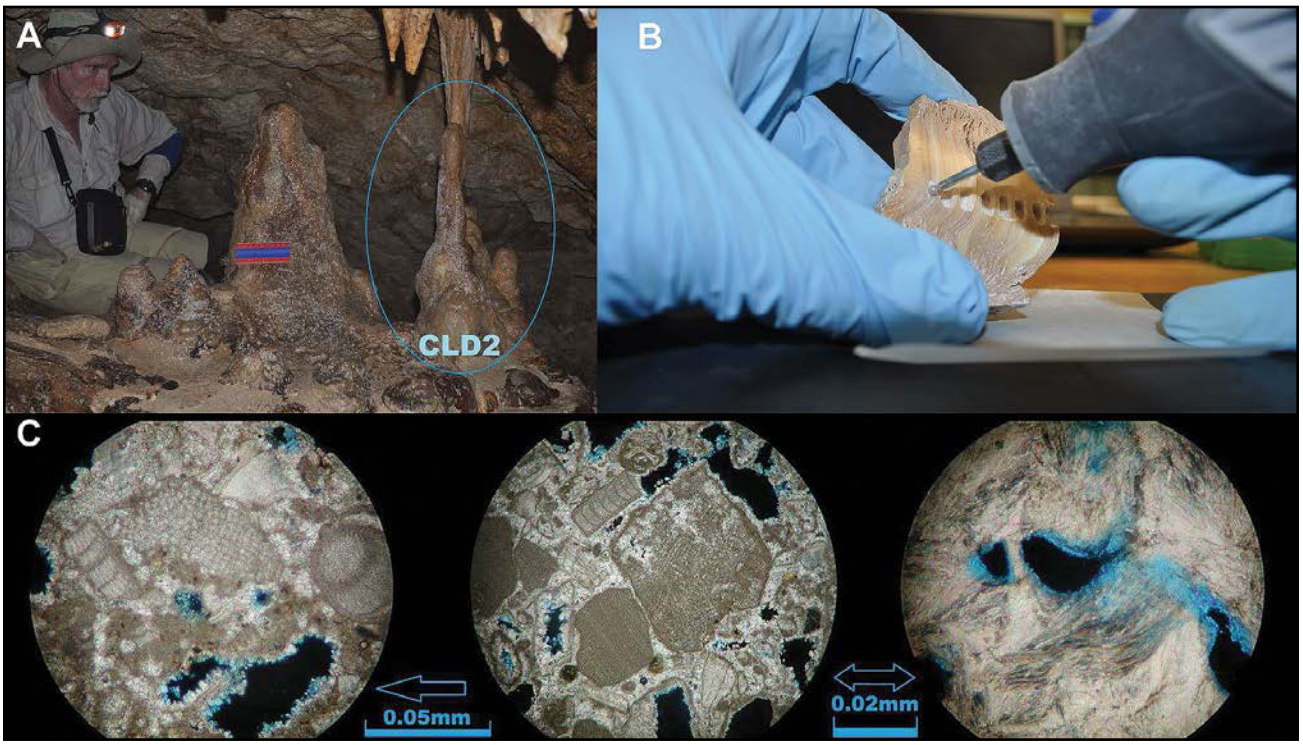

Figure 2.* A. *Collection site for sample CLD2 in Lardem Cave, Curacao. Each sample site has a before and after image taken.* B. *Collection of powder sample every 0.5 cm from a stalagmite for analysis.* C. *Lardem thin sections. From L to R Cave Wall rock, Cave ceiling rock, surface rock. Note the two thin sections on the right have a different scale from the thin section on the left.

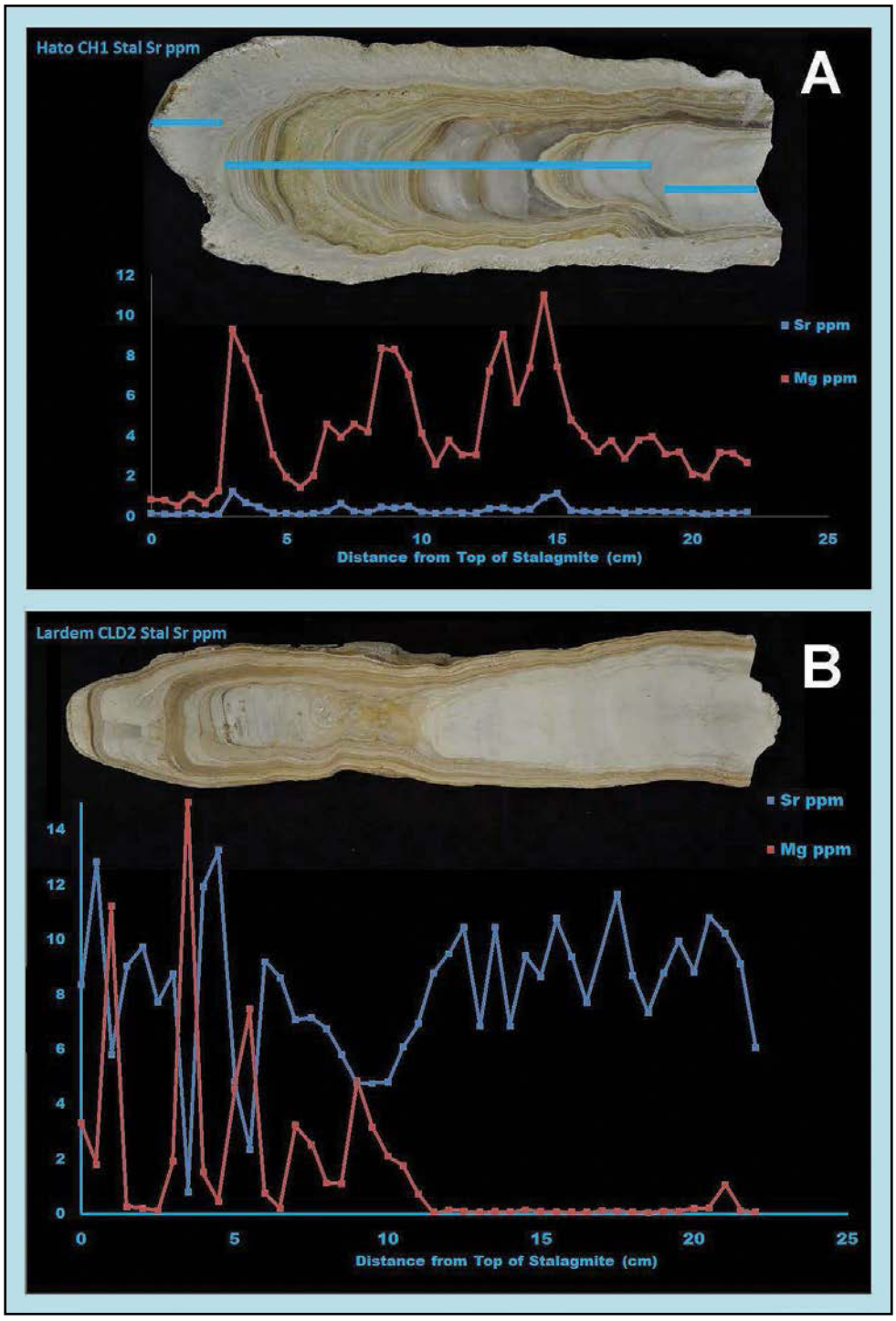

Figure 3. The Mg and Sr results from the stalagmites of Curaçao.* A. *Stalagmite from Hato Cave in the oldest, highest terrace; Mg and Sr appear correlated.* B. *Stalagmite from Lardem Cave in the youngest, lowest terrace; Mg and Sr appear anti-correlated.

in the middle terrace, displayed predominantly broken fossil pieces with the exception of echinoderm spines which were remarkably preserved and, as luck had it, sliced perpendicular to the length to display striking gear-like allochems. As expected, the Sr levels in the surface rocks decreased with age and also with distance from the shoreline. Rock samples from within the cave tell a different geochemical story. Hato rocks seem overall depleted of Sr and Mg in comparison to the younger Raton and Lardem rocks. The Lardem and Raton specimens have an interesting relationship, especially when coupled with the Mg ppm data from the same rock specimens. Lardem cave rock samples, both wall and ceiling, seem to be overall lower in Sr ppm than Raton and the stalagmites from within Lardem (Figure 4.11). The Mg ppm is the opposite, with Lardem being higher and Raton being lower.

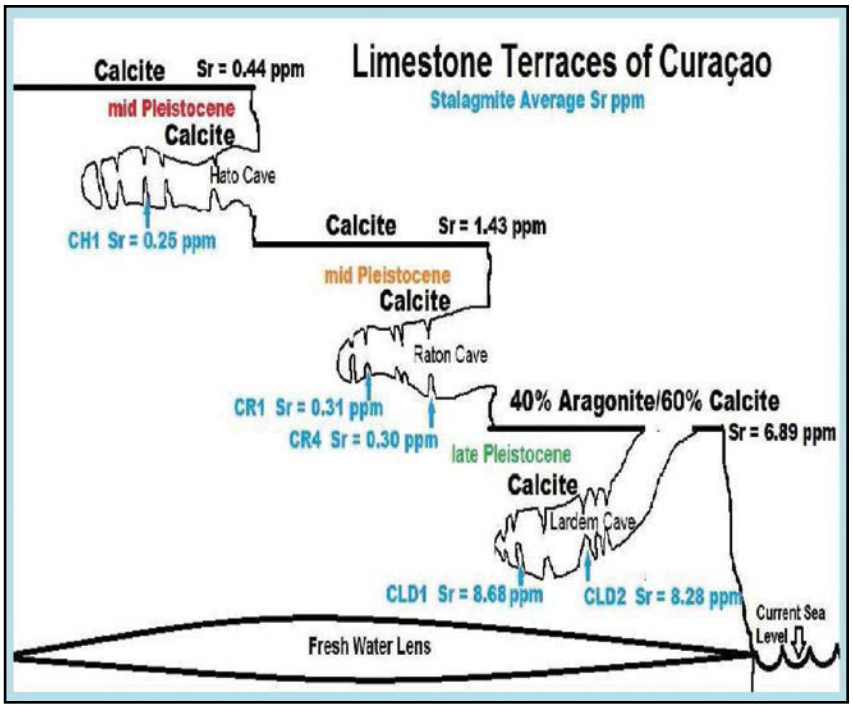

Figure 4. Summary data for Curacao, showing the decrease in Sr values upward into older rocks which are the Ca and Sr source for stalagmite growth in the caves.

The levels of Sr in the stalagmites from the cave, Lardem, located in the youngest eogenetic carbonate of this study, were notably higher than the Sr of Raton or Hato (Figures 3 and 4). The stalagmites in Raton and Hato were close in value although it was discernible that overall the stalagmite from Hato had a lower Sr ppm than the stalagmites of Raton in the middle terrace (Figure 4). As far as concentrations of Sr ppm, the hypothesis of this research is supported by the data collected this far. The majority of the stalagmites from Curaçao show a trend of increasing Sr ppm progressing down the axis (to older material) indicating that Sr levels have decreased over time.

Bahamas

The increased meteoric fluid flux of the furthest north study area, Abaco, should deplete the speleothem Sr levels faster than an island in the southernmost of the Bahamian study area, Long Island. The concern for this part of the study was an accurate age for the host rock.

The Sr data for the stalagmite from San Salvador, SL4, had a very high Sr ppm in comparison to the stalagmites from Abaco, AH1 and AR1. The samples closest to the top of this particular stalagmite were likely to be contaminated by the tidal influx in Light House cave. This followed expectations until the Sr content of the stalagmite from Long Island (LH1) is observed to have the lowest Sr content of all the Bahamian stalagmites. Not only was the Long Island stalagmite depleted of Sr it was also depleted of Mg.

The rocks of the Bahamian study areas are equally as chaotic as the stalagmite data. The rocks from within Hamilton's cave on Long Island were relatively low in Sr and Mg concentration. Abaco and San Salvador were as expected relative to one another. Abaco has a lower Sr concentration in the cave rocks than San Salvador, hypothetically due to the larger water flux on Abaco. The Mg concentration was inversely related in the cave rocks of Abaco and San Salvador. Abaco was low in Sr but high in Mg relative to San Salvador. The data for the cave rocks of Long Island are depleted of Sr or Mg. The surface rocks for Abaco were lower in concentration than San Salvador. Surface rocks from Long Island had a very high Sr concentration but relatively low Mg concentration. This is unusual because Hamilton's Cave of Long Island is actually further from the coast than Hole in the Wall Cave and Roadside Cave of Abaco.

Summary

This study was seeking to find evidence of the Sr concentrations in speleothems deposited in eogenetic carbonate caves in relation to the relatively young and unchanged mineralogy of the rocks. It sought to answer three questions in regards to Sr concentrations in speleothems of these settings. The hypotheses were as follows.

1. The Sr content of Caribbean speleothems has a direct relationship with the age of the host rock at the time of speleothem precipitation.
2. Older speleothems contain less Sr than younger speleothems in the same climatic setting.
3. Eogenetic carbonates within climates of higher precipitation will lose Sr content faster than those in climates of lower precipitation and the speleothems deposited in the caves within these rocks will record this trend.

Hypothesis 1: The Sr content of Caribbean speleothems has a direct relationship with the age of the host rock at the time of speleothem precipitation.

The stalagmites collected from within the youngest cave rock unit on Curaçao had a significantly higher concentration of Sr than the stalagmites collected from the older carbonate terraces. The stalagmites in the caves of older rock units had lower Sr values indicating that the Sr had already leached out of the bedrock.

Hypothesis 2: Older speleothems contain less Sr than younger speleothems in the same climatic setting.

The stalagmites collected from Curaçao were all obviously from within the same climate with no variation in precipitation or temperature. The only difference in these stalagmites are the times at which they were deposited and the age of the rocks that hosted the cave they were deposited in. The Lardem stalagmite could not be older than 115 k years old, the end of the MIS 5e interglacial. Dating would be needed to ascertain if the age of the Hato and Raton stalagmites are younger than Lardem, but they did have the opportunity to begin depositing long before Lardem cave even existed. In any case, the host rock is older. The Lardem stalagmite clearly has more Sr than the Raton and Hato stalagmite, but further investigation is necessary to determine the relative age of the two stalagmites from Raton and the stalagmite from Hato.

Hypothesis 3: Eogenetic carbonates within climates of higher precipitation will lose Sr content faster than those in climates of lower precipitation and the speleothems deposited in the caves within these rocks will record this trend.

The stalagmites from caves on the island of Abaco clearly show a lower Sr content than the stalagmite collected from the island of San Salvador. The cave rock and stalagmite from Long Island seemed to be leeched of Sr and could be explained by either a difference in age of the rock or the thickness of the rock unit where the cave is located, or perhaps a shift in glacial to interglacial climate.

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Survey and Inventory of Craig Cave, Craig Temple Cave and Vicinity, Lava Beds National Monument, California

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Principal Investigator

This research project was planned and proposed early in 2013. Craig Cave and Craig Temple Cave are two pieces of a lava tube system developed in the basalt of Mammoth Crater (Donnelly-Nolan, 1987; Waters et al., 1990). Although the planimetric map published by Waters et al (1990) is an excellent planimetric map, there are no supporting survey data, and there are neither cross-sections nor profiles of the cave. As this set of caves is a key Inventory and Monitoring site for its biological resource, Resources Management will benefit from a complete cartographic depiction of the resource. The geology of this system is underappreciated. Thus, a collection permit was sought and granted to enable CRF personnel to sample the lava flows preserved within and near these caves, in addition to conducting the cartographic studies. Donnelly-Nolan (personal communication, 2012, 2013) noted that the basalt tongues that erupted and flowed from Mammoth Crater's source areas into the more westerly portions of the Monument vary systematically in chemical composition from early to late stages. However, comparable data do not exist for basalt of Mammoth Crater flows that erupted and flowed into the eastern areas of the Monument and beyond. This study will obtain samples to discern if the systematic differences in composition of the lavas erupted from Mammoth Crater in the western part of the Monument contain an early-to-late stage chemical evolutionary history comparable to that shown for western mapped equivalents.

The entrance to the Craig–Craig Temple system is via a collapsed portion of the lava tube developed in the basalt of Mammoth Crater (Donnelly-Nolan and Champion, 1987). Up-gradient leads to the relatively short segment known as Craig Temple Cave, and down-gradient leads to the more extensive Craig Cave. Initial fieldwork was conducted during May 2013. Despite the exigencies of breakdown, many original flow features and lavacicles are preserved on pahoehoe floors, and multiple linings exposed by wall collapse testify to a multi-stage eruptive history during the development of this lava tube system. Its large dimensions indicate it likely was a major distributary feeding the eastern side of the Monument. The cave does contain a J.D. Howard painted sign; the cave apparently has been known since the early explorations of the region by Europeans. The abundance of mammal scat on the floor of the cave indicates that Craig Cave is a reliable source of water derived from drip sites. Also of interest is that the overlying basaltic andesite of Valentine Cave flowed over the western lip of the entrance collapse, partly filling Craig Temple cave. Had the younger flow continued and filled up the present entrance, we might not have access to this remarkable east side lava system. As it is, the area affords a fine example of two different ages of lava flow separated by outwash deposits and a minor paleosol.

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