Geology and Geography Session

Session Chair: Katherine Schmid
Monday, June 13, 2022 9am-5:00pm
Location: Soule Center

The Geology and Geography Session includes a variety of topics on caves and karst including karst hydrogeology, speleogenesis, cave morphologies, cave meteorology, geochemistry, and cave inventory and monitoring and geological education. The session features studies in a variety of caves including limestone, lava, glaciovolcanic, and shale.

Geology and Geography Session Schedule

Time	Speaker	Topic
0800-0900	Set-up	
0900-0920	Lee Florea	The origin and morphology of glaciovolcanic caves
0920-0940	Gretchen M. Baker	Melting Away: Ice in a High Elevation Nevada Cave
0940-1000	Sarah Arpin	Hydrogeology of Silvertip Mountain, Bob Marshall Wilderness area, Montana
1000-1020	Issam Bou Jaoude	Why Lebanon is Rich in Caves
1020-1040	BREAK	
1040-1100	Douglas Medville	Cave Development in the Mancos Shale, Colorado: Processes and Mineralogy
1100-1120	Lee Florea	Caves as polygenetic features
1120-1140	Hazel Barton	Exothenic speleogenesis: Microbes making caves from the outside in.
1140-1200	Louise D. Hose	Proposed Speleogenesis of Lehman Caves, Great Basin National Park, Nevada
1200-2:00PM	LUNCH AND SECTION MEETING	
2:00-2:20	Victor J. Polyak	Elemental signatures of the last millennium in a stalagmite from Carlsbad Cavern
2:20-2:40	Gregory S. Springer	Empirical determination of Manning roughness coefficients for moderate floods: Fullers stream canyon, Culverson Creek Cave System, West Virginia
2:40-3:00	K. M. Emanuel	The Black Hills Karst Inventory Initiative: An Application of LiDAR Data Analysis to Identify and Inventory Surficial Karst Features within the Black Hills and surrounding Region.
3:00-3:20	Wiles, Michael E	An update of surface and subsurface geological mapping at Jewel Cave National Monument
3:20-3:40	BREAK	
3:40-4:00	Sarah W. Keenan	Integrating Black Hills caves into undergraduate geology research at South Dakota School of Mines and Technology
4:00-4:20	Max Appelbaum	An exploratory case study of the internal atmospheric response of Tumbling Rock Cave (Jackson County, Alabama) to surface meteorological conditions
4:20-4:40	Jack Wood	Taking a crack at it: Monitoring and quantifying fracture dynamics within the walls of a lava tube, proximal to an active volcano
4:40-5:00	Christina L. Ferguson	Source water investigation of the Snowy River deposit within the Fort Stanton-Snowy River Cave System, Lincoln County, NM

Geology and Geography Session Abstracts
(listed in alphabetical order by presenting author)

An exploratory case study of the internal atmospheric response of Tumbling Rock Cave (Jackson County, Alabama) to surface meteorological conditions
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It has been known to cavers for many years that "if it blows, it goes," but to date there has been little widespread research into the mechanisms behind the "blow." This study aims to take the first step towards classifying the atmospheric characteristics of Tumbling Rock Cave in Jackson County, Alabama. Tumbling Rock is a large, well-known karst system that is under the care of the Southeastern Cave Conservancy, Inc. (SCCi), with more than 6.5 miles of surveyed horizontal passage, and a newly surveyed vertical section which will be open for permit application soon. There is only one known entrance that is roughly 1 meter by 1.5 meters. Surface meteorological conditions data was collected with a standard professional-grade weather station located roughly 50 meters from the entrance. Cave temperature data was collected with HOBO pendant temperature loggers placed in discrete locations throughout nearly all of the accessible horizontal passages of the cave. Early results of this study through the winter of 2021-2022 show a pronounced temperature response to surface changes near the entrance, and a slow, but notable response further into the cave. Future studies aim to broaden the range of data collected within the cave to be better able to understand the mechanisms at play behind the airflow and temperature of Tumbling Rock Cave. It is hoped that this research can expand to cover more caves of various sizes to be able to have a broader understanding of the dynamic interactions of caves and the surface atmosphere.

Hydrogeology of Silvertip Mountain, Bob Marshall Wilderness Area, Montana
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Mountain hydrologic systems are the "water towers" of the world, supplying freshwater to downstream regions. The presence of karst aquifers in mountain hydrologic systems increases their complexity, but also their capacity to store water and sustain baseflow. The goal of this project is to understand the contributions of different water storage components to discharge of spring(s) in the understudied alpine karst aquifer of Silvertip Mountain, located in the Bob Marshall Wilderness Area of northwestern Montana. Alpine environments are particularly susceptible to the impacts of climate change. Water storage is vital to regional water availability, but year-round snowpack may disappear with a warming climate, reducing the contribution of recharge from that source. At more than 1.5 million acres, the Bob Marshall Wilderness is one of the largest wilderness areas in the USA outside of Alaska. As human activities continue to reduce pristine environments around the globe, areas not significantly impacted by these activities become more important to understand and protect. In examining the water storage dynamics of Silvertip Mountain, this project aims to answer two main questions: 1) where is water stored, and 2) over what time scales? Winter precipitation is stored as snowpack and recharges groundwater reservoirs on Silvertip Mountain. Seasonal changes shift water storage between frozen components (snowpack, permafrost, rock glaciers) and liquid components (talus, epikarst, karst aquifers). Spring meltwaters move surface snowpack through the various groundwater storage components, slowing discharge to sustain baseflow until precipitation increases again in winter. Hydrologic measurements, geochemical sampling, tracer tests, and continuous monitoring are being used to understand the Silvertip karst aquifer. Initial logging at the outlet spring suggests a diurnal temperature signal, which may be associated with meltwater pulses. Solute and C isotope analyses, together with solute speciation modeling,

indicate that groundwater chemistry reflects meteoric recharge modified by carbonate weathering, as expected.

Melting Away: Ice in a High Elevation Nevada Cave

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Nevada is the hottest and driest state in the United States, but due to its varied terrain contains several high elevation caves containing permanent ice. Long Cold Cave in eastern Nevada is the deepest known cave in Nevada, at 133 m (436 ft) deep and is located at an elevation of approximately 3000 m (9900 ft). The surface temperature at this elevation just outside the cave entrance averages 5.2° C, yet the cave contains perennial snow and ice, starting at about 35 m (120 ft) below the surface. Each time we visit the cave, the ice appears slightly different, but the 2021 trip showed large changes in the ice, especially at the bottom of the cave. Dataloggers recording hourly temperature show that the temperature in the cave decreases as distance from surface increases. The deepest area of the cave has an average temperature of 0.4°C, while the middle of the cave is about 0.0-0.1°C on average over two to four years of data collection. While small changes in temperature in caves usually do not have much effect, when those small changes occur near the freezing point, they can very much alter the cave. Although we are not likely to be able to do anything to change the ice melting, as the cave is located in a wild part of Great Basin National Park, we can study and record it as much as possible before it disappears.

Exothenic speleogenesis: Microbes making caves from the outside in.

Presenter: Hazel A. Barton, bartonh@uakron.edu
Co-Presenters: Ceth W. Parker, John M. Senko, Augusto S. Auler, and Ira D. Sasowsky.

The tropical regions of Brazil, including Carajás, Iron Quadrangle (IQ), and Southern Espinhaço Range, contain some of the most extensive landscapes of Proterozoic banded-iron formation (BIF) deposits in the world and host the largest iron ores deposits in the world. These iron landscapes are covered in a ferruginous duricrust known as canga, which can range in thickness from a few centimeters to 30 m. The weathering-resistant nature of these landscapes suggests that karstification would be limited, but the contact between canga and the underlaying BIF represent some of the most cave-rich areas of Brazil. We have been studying the processes that lead to the development of caves at this contact. Our data suggest that these iron formation caves (IFCs) are formed by iron-reducing microorganisms that reduce the iron-oxides to soluble Fe(II), increasing porosity and allowing the mass transport of Fe(II). This process occurs behind an iron-richcrust that forms on the walls, generating a paste-like material called *sub muros*. Over time, the accumulated *sub muros* destabilizes the crust-like walls of the cave, leading to an inward collapse and enlarges the cave passage. We call this novel mechanism of speleogenesis, where passage enlargement is caused by material collapsing from behind the walls into cave void, exothenic speleogenesis.

Why Lebanon is Rich in Caves

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With more than 700 documented caves and thousands of dolines, in an area of 10,425 km^2, Lebanon is considered a country rich in caves. Several factors have contributed to the development of this high density of caves, including lithology, structure, topography, history and depth of karstification, and precipitation.

Limestone rocks are spread along an exposed stratigraphic column. Starting with the 1,500-m thick Jurassic limestone and dolomite, then the Cretaceous 900-m limestone and marl, passing the Eocene 600-m thick crystalline nummulitic limestone, followed by a 300-m thick sequence of Miocene limestone and carbonaceous conglomerates, finally ending with the variable thickness of Quaternary calcareous sands and calcareous glacial deposits. About 65% of the stratigraphic column is limestone and 65% of the surface area of the country is covered with karstic limestone. Structurally, Lebanon is located along a restraining bend in the central segment of the N-S trending Dead Sea Transform Fault. This created two mountain chains (maximum height 3018 m asl), a small coastal plain and an inland valley. The mountains capture humidity from the Mediterranean Sea resulting in an average precipitation of around 1,000 mm/year. It changes from rainfall along the coast to thick snow cover, as deep as 7 m in high mountainous areas. Major geological events, such as tectonism in the Jurassic, Cretaceous and more recent periods, associated volcanism and migration of oil from those units, accompanied by sea level fluctuations have generated favorable conditions for the development of karst to depths reaching the lower units of the Jurassic and as old as the Jurassic period. One of the major events that played an important role in the karstification of Lebanon is the Messinian Salinity Crisis, resulting in a deep sea level drop. These combined factors have created favorable conditions for the development of a country rich in caves.

The Black Hills Karst Inventory Initiative
An Application of LiDAR Data Analysis to Identify and Inventory Surficial Karst Features within the Black Hills and surrounding Region.

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A systematic Inventory of karst and cave related features for the Black Hills region was initiated approximately 4 years ago using a combination of high resolution aerial photography and the then newly available LiDAR coverage which was released for the northern part of the uplift during late 2018. Since that time, well over 20,000 surface karst features have been identified, catalogued and prioritized for Initial field verification. The methodology employed until quite recently has concentrated on manual canvasing of hillshade, slope and hydrologic fill models at scales of 1:1,500 or less and assigning points in 3D space associated with each. The results of ground truthing efforts for key test areas have been highly encouraging, and have resulted in the identifications of a number of significant subsurface systems. To date, only a small fraction of the predicted features have been possible to visit but the number of cave verifications to date indicates that this endeavor has been well worth the effort. In the last few months, Lidar coverage has become available for the remaining portion of the Black Hills and for parts of the Bighorn uplift, as well. An updated and improved methodology relying on the same base-models is now being employed to expand the inventory. A semi-automated predictive methodology is now being used to identify closed sinks as 3D polygons using 1m resolution 3DEP LiDAR data along with the Priority Flood Algorithm (Hydrologic Fill), Minimum Bounding Geometry and Zonal Statistics tools in ArcGIS Desktop and ArcGIS Pro. This process has proved to be an even more effective tool set for identifying sinkholes and collapse entrances to endokarstic features (i.e. caves). It is particularly helpful for locating these highly important karst features in areas with dense forest and brush coverage. Preliminary estimates for the total number of features present in the uplift now appears that it will be well in excess of 30,000.

Caves as polygenetic features

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Multigenerational cave development is a common thread that connects hydro-geochemical processes across the history of the host rock. These processes leave stratigraphic, morphologic, and chemical fingerprints in varying degrees of visibility and discoverability. The title of this talk conveys a large scope; however, the content is selective of personal examples by the authors. We are aware of many others. In south Florida, overprinting generations of syngenetic cave development are clearly evident in rocks less than 125,000 years old. The first generation dates to the last glaciation and sea-level low-stand and the second generation formed entirely in the past 6,000 years. Broadly available evidence outlines repeated generations of syngenetic cave development in south Florida and elsewhere during the cyclic sea-levels and carbonate sedimentation of the Quaternary. In west-central Florida, Tertiary carbonates were repeatedly exposed to meteoric groundwater circulation, leaving paleokarst between depositional cycles. This is most prominently displayed where Miocene-age siliciclastics infiltrated caves of Eocene and Oligocene age and cemented. Since the Pliocene, sea-level fluctuations have resulted in multigenerational eogenetic caves both guiding and being guided by aggressive geochemistry along the potentiometric surface. These 'modern' caves exhume earlier paleokarst generations. In the Mitchell Plateau of Indiana, sulfur in groundwater has played a significant role in the evolution of telogenetic caves in Mississippian-age carbonates. Where hydrocarbon-sourced sulfides rise as hypogenetic fluids through fractures, sulfuric acid enhances cave development, especially during early fracture enlargement. Later meteoric flushing likely overprints this early hypogenetic generation with epigenetic features. Finally, the Cumberland Plateau of Kentucky combines aspects of the other examples in this presentation. Hypogenetic fluids, rich in sulfur, have influenced epigenetic cave development since the late Miocene. These observable telogenetic caves have exhumed paleokarst composed of eogenetic caves from early in the rock history later filled with sediment, tectonized by distal orogens, and mineralized by hypogenetic fluids.

The origin and morphology of glaciovolcanic caves

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Glaciovolcanic caves are exceptionally dynamic; they originate from the transfer of heat between superimposed media. Contrasting with caves embedded in extrusive igneous rocks and sedimentary carbonates; they evolve and decay in conjunction with variations in climate, weather, and volcanic heat. In short, glaciovolcanic caves, even those which have endured for decades, are ephemeral landforms. As a corollary to the thermal gradients of glaciovolcanic caves, limestone caves form from dissolution along chemical gradients. Drawing upon the language from studies of limestone caves, but substituting thermal gradients for chemical gradients, glaciovolcanic caves are hypogenic features where the kinetics that drive their formation are from below. Completing the analogy, moulins and subglacial conduits are epigenetic features where the kinetics originate from the surface. The significance of this statement arises from the implied connection to the surface; glaciovolcanic caves can form independent of surface processes - entrances are not obligatory. Yet, like their bedrock counterparts, cave size is limited by the magnitude of the driving kinetics and the rate at which the byproducts of speleogenesis are removed. Aside from these generalizations, studies of the characteristics of glaciovolcanic caves are rare, perhaps in part due to challenges getting to the sites by crossing icefields or climbing mountains, all in remote locations. Both the challenge of access and difficulty of exploration limit the size of expeditions, the transport of research equipment, the lifespan of monitoring equipment, and the scope of samples. Yet these collective factors make glaciovolcanic caves excellent analogues for the planning and application for missions to other worlds, including the design of the sensor, survey, sampling, analysis packages for planetary missions, and the robotic mobility systems for landers.

Source water investigation of the Snowy River deposit within the Fort Stanton-Snowy River Cave System, Lincoln County, NM

By Christina L. Ferguson, Johanna M. Blake, and Keely E. Miltenberger
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The Fort Stanton-Snowy River Cave, located in the eastern foothills of the Sierra Blanca Mountains in south central New Mexico, is entirely developed within the Permian San Andres Formation. This formation consists of limestone with minor gypsum beds. The Snowy River deposit is a unique calcite deposit that resembles a white riverbed within the cave. The calcite deposit has been mapped to over 11 cave miles in length, making it one of the longest speleothems in the world. Because of its unique and delicate nature, its preservation is of great importance to cave and natural resource managers. However, the source of the super-saturated water that deposits the calcite is unknown. Flooding of the Snowy River portion of the cave has been roughly correlated to large precipitation and run-off events within the local watershed area. Three small creeks in the area, Rio Bonito, Little Creek, and Eagle Creek, have been hypothesized as possible sources of water to the cave. To understand if these creeks contribute to subsurface water, major and trace elements and isotopes of water and strontium were analyzed in both surface waters and groundwater. To compare with the water samples, the same constituents were also analyzed from local rock samples and cores from the Snow River calcite deposit. Geochemical analyses of the waters show that cave waters are similar in composition to Rio Bonito and Eagle Creek water and nearby groundwater, and dissimilar to Little Creek water. Analyses of the rock samples and cores show similarities between the calcite core samples and the limestone collected from the lowest member of the San Andres Formation. These results indicate that the groundwater is mixing with the surface water as it enters the subsurface, likely within the lowest member of the San Andres Formation, before it enters the cave and deposits the Snowy River calcite.

Proposed speleogenesis of Lehman Caves, Great Basin, National Park, Nevada

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Recent investigations within Lehman Caves, Great Basin National Park, have documented extensive and compelling evidence of its hypogenic origin, probably between 10-8 Ma. Bubble trails, ceiling channels, cupolas, boneyards speleogens, and pseudoscallops, all relics of hypogenic processes, abound throughout the cave. Furthermore, gypsum crusts, hollow coralloidal stalagmites, probable metatyuyamunite (Ca(UO2)2V2O8·(5-8)H2O – a mineral associated with several sulfuric acid speleogenesis—SAS--caves), and, most compelling, an ancient acid pool support the likelihood that this cave formed from sulfide-rich, rising waters. Studying the original speleogenesis of the cave is, however, challenged by the extensive overprint of Pliocene through modern calcite speleothems. Fortunately, a mostly impermeable cover of meta-quartzite helped protect the Gypsum Annex passage, which reveals the strongest evidence of hypogenic-SAS origins. Lehman Caves is in the Middle Cambrian (~520 Ma) Pole Canyon Limestone, which was buried thousands of feet by subsequent deposition through the Pennsylvanian and experienced low-grade, burial metamorphism. About 28.5 Ma, the youngest of the region's granitic intrusions cooled and is now just a few hundred meters west of the cave. Some thermal metamorphism is reported in the cave bedrock. The major geologic event in the area was the (~17.5 Ma) Snake Range Décollement, which locally metamorphosed the Pole Canyon into a mylonite and obliterated all earlier features. Basin and range uplift and extensional faulting fractured and uplifted the Southern Snake Range between 17-8 Ma and was most active in this area between 10-8 Ma, forcing the water table to drop prompting active speleogenesis.

Integrating Black Hills caves into undergraduate geology research at South Dakota School of Mines and Technology

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Research experiences for undergraduate geology students can provide an important and transformative educational opportunity. One factor that motivates students to enroll in a geology-based degree is the ability to explore and study in the field. At South Dakota School of Mines and Technology our proximity to the Black Hills, including world-renowned karst areas, presents us with the opportunity to integrate field-based research into the undergraduate curriculum through capstone research projects. For the last 3 years, students have studied various aspects related to mineralogy, geochemistry, and microenvironments in several caves, including Rushmore Cave, Keystone, SD, a regional tourist cave. These efforts have provided new insights into CO2 ventilation, speleothem (and drip water) geochemistry, and speleothem growth fabrics in an understudied karst region. From 2019 to 2022, CO2 within Rushmore Cave exhibited typical trends expected, with seasonal ventilation in the winter/early spring, and closed system behavior in the summer. Sampling during summer 2020 when tourism halted due to COVID-19, followed by the return of tourists in 2021 and 2022 indicate that in Rushmore Cave, tourism results in a 66% increase in CO2 concentrations, reaching a maximum of ~12,500 ppm. In terms of speleothem geochemistry, individual layers within six speleothems varied significantly, particularly with respect to strontium concentrations, and were enriched compared to host rock composition. Growth fabrics of speleothems indicate periods of interrupted growth at the microscale, evident by accumulations of siliciclastics, as well as periods of dissolution at the individual crystal and laminae scale. This presentation will provide an overview of the past and current research projects by South Dakota Mines geology students currently taking place in Black Hills caves.

Cave Development in the Mancos Shale, Colorado: Processes and Mineralogy

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A pseudokarst on the Cretaceous Mancos Shale in western Colorado contains a 300m long vadose cave, entirely within the shale. Swelling soils allow meteoric water to reach the shale beneath the regolith and oxidize pyrite in the shale, producing sulfuric acid which in turn, reacts with calcite in the shale to produce gypsum. The gypsum wedges apart the shale beds and allows surface water to flow through openings in the shale, removing it via corrasion and ultimately resulting in enterable voids. A seasonal stream enters the cave at the distal end of a blind gully. Based on local incision rates of about 0.5 mm/year, ceiling heights, and the age of Pleistocene terrace gravels, the cave age is probably on the order of 6-12 ka. The cave contains extensive sulfate mineralization including 2-4 cm dia. globular deposits at water level, crusts on passage walls at the high water mark, subaqueous white deposits, dry crusts on passage floors, and needle-like extrusions on passage walls. The sulfates are a mixture of thenardite and blodite with lesser amounts of gypsum, hexahydrite, and possibly konyaite, as per powder XRD. Na+, Mg2+, and SO42- ions in the cave stream are derived from soluble salts in Mancos soils with measured concentrations of up to 7000 mg/L. As cave pools evaporate, concentrations of these ions increase until saturation is reached and the sulfate minerals observed at water level are deposited as crusts, coatings, and accretions.

Elemental signatures of the last millennium in a stalagmite from Carlsbad Cavern

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Elemental analyses in speleothems are routinely studied, and their significance can be complicated. Important elements are Mg, Sr, and Ba due to their abundance, but advances in mass spectrometry allow for a large list of elements that can be measured precisely and accurately. Application of elemental analyses towards short-lived events, exemplar to volcanic eruptions seen as sulfur peaks in ice cores, can particularly be of value in speleothems. This is especially the case for laser ablation ICP-MS elemental studies that can produce higher resolution time-series. Here we show elemental time-series results for stalagmites from the Guadalupe Mountains in the southwestern United States that (1) mimic some stable isotope time-series, (2) show historic events related to Carlsbad Cavern, and (3) reveal short-lived events from volcanic eruptions. Of particular importance are a prominent peak of multiple elements coincident with the Tambora eruption, the atmospheric Pb peak, and variations of elemental changes accruing at the initiation of mining and commercialization of Carlsbad Cavern. Identifying short-lived events such as volcanic eruptions would help place speleothem chronologies that are further back in time to within a few years.

Empirical determination of Manning roughness coefficients for a cave flood: Fullers stream canyon, Culverson Creek Cave System, West Virginia

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Open conduit modeling of cave stream floods can yield useful information about water velocities and shear stresses, which can in turn be used to estimate sediment transport capabilities. All such calculations require roughness coefficients for estimating energy losses and a priori knowledge of either discharge or flow depths to set model boundary conditions. However, the difficulties associated with observing in-cave floods generally preclude measuring discharge and roughness coefficients must be assumed based on channel properties. To overcome these challenges, we monitored stream flow depths in Fuller's Cave, Greenbrier County, West Virginia using pressure transducers, and simultaneously measured stage and discharge in a karst window immediately upstream of the cave. The five pressure transducers were deployed opportunistically along a 93-meter-long reach in a 10+ meter high canyon averaging 1.5 to 3 meters wide. Stage-discharge relationships were determined with an electromagnetic flow meter. The observational data was used to obtain the empirical Manning's roughness values (n), head losses, and energy gradients for a flood with peak discharge of 1.66 $m^3 s^{-1}$. Calculated floodwater velocities are comparable to values obtained from scallops on passage walls. Major energy losses were observed where breakdown partially occludes the passage ($n \geq 0.069$) and cobble-floored canyons had n values of ~0.055 at peak discharge. As expected, roughness declined exponentially with increasing discharge in all reaches with n generally >0.1 for discharges of ~0.5 $m^3 s^{-1}$. Our empirical roughness coefficients can be applied to similar cave passages and future work will allow us to tie flood hydraulics to sediment transport regimes in the cave.

An update of surface and subsurface geological mapping at Jewel Cave National Monument

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Jewel Cave has over 210 miles (340 km) of mapped passages, representing three percent of the entire cave system. This project seeks to establish clear relationships between surface and subsurface geological features, to eventually help predict the location of unknown cave passages based on the surface geology. The Jewel Cave fault zone consists of linear features, beginning with a few high displacement faults at its east end. To the west, it progressively splinters into subordinate faults that cross Hell Canyon before disappearing on the west side. Passages in the Main Cave section are within a downthrown block that shows only minor internal structural deformation. Surprisingly, even the straightest passages don't consistently align with a single joint, but run diagonally to it – until the joint ends and the passage jumps to the beginning of a nearby, sub-parallel joint. Many of joints are actually low-displacement faults. The walls on the upthrown side are more intensely fractured, producing a distinctive spalling effect – while the downthrown side is more intact. The park has created a spreadsheet to calculate the strike and dip of unreachable planar surfaces by using three shots from a DistoX at a common reference point, allowing extensive strike and dip measurements. The bedrock typically dips 8 to 10 degrees across the passage, toward the south. The overall impression is that the cave formed along the faulted dip-slope of the southern limb of an east-west anticline These observations provide new tools for understanding the origin and extent of Jewel Cave

Taking a crack at it: Monitoring and quantifying fracture dynamics within the walls of a lava tube, proximal to an active volcano

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The U.S. National Park Service (NPS) has several 1000s of documented caves within 99 of the 423 management areas. There are 17 NPS units known for lava tubes, including Hawai'i Volcanoes National Park. Nāhuku (Thurston Lava Tube) is a basaltic tube within the park and is ~5 km from Hale Ma'uma'u Volcano Crater, the active center of Kilauea. Nāhuku was likely formed during a shield-building event approximately 500 years ago. It is now publicly accessible via a paved trail into and between two collapse features. The large 2018 eruption of Kilauea generated over 60,000 shallow earthquakes, causing a partial but dramatic collapse of the crater, and minor but appreciable rockfall within Nāhuku. Lidar scans conducted in 2019 detail passage geometry and allow for the estimation of ceiling thickness, with some sections measuring ~1m between ground surface and the passage. In 2020, digital vibrating wire extensometers were installed, spanning two different through-going fractures on the cave ceiling. These devices sense both fracture width variation and expansion velocity, properties which could portend failure. Nearly two years of data show fractures have brittle and elastic behavior, and that alterations in fracture geometry are not fully correlated with earthquake occurrence. This suggests that thermal processes are potentially underestimated and wedging through mineral or particulate

intrusion may have an underappreciated role in fracture propagation. The permanent deformation recorded by the crackmeters may result when enough rock bridges between micro-fractures break, the accumulations of a hundredths of a mm deformation, through episodic stressors such as earthquakes and propagated over time by gravitational tension. Understanding the dynamics of fractures within lava tubes can better inform safety and management decisions within the NPS while possibly gaining new insights for the processes in basalt caves preceding roof collapse.