Pisgah!

By Russell Harter, Southern California Grotto

The largest concentration of caves in southern California is in the Pisgah lava field, about 40 miles east of Barstow, south of Interstate Highway 40.

The lava is basanite, a variety of basalt. Dates on the lavas at Pisgah are in the range of 25,000 to 21,000 years old. Because of the relatively young geologic age, and the desert environment (average less than 4 inches of rain per year), the lava flow surfaces are well preserved.

The Pisgah lava field is set in a valley, with the Cady Mountains to the north. From various viewpoints around Pisgah, the eastern Cady Mountains, called the Sleeping Beauty Mountains, are visible. With some imagination, the Sleeping Beauty Mountains look like a woman lying on her back, her long dark hair trailing off to the east, her profile along the ridge of the mountains, and feet to the west.

In the early 1970s bighorn sheep were reintroduced to the Sleeping Beauty Mountains; if they have survived there, they have not made themselves visible. Turning right from the Sleeping Beauty Mountains we see the Bullion Mountains to the southeast, and Lavic Lake (a dry lake playa), south of the Pisgah flows. The high point on the horizon just west of Lavic Lake is Sunshine Peak. Halfway up the flank of Sunshine Peak from Lavic Lake is a dark hill, Sunshine Crater. Sunshine Crater is a cinder cone that is distinctly older than Pisgah, with its own basaltic lava flows of pahoehoe and aa. The southern Pisgah flows, Lavic Lake, Sunshine Crater, and Sunshine Peak are off limits because they are within the 29 Palms Marine Base. West of Sunshine Peak are the Rodman Mountains, where is located Malpais Crater, with its basaltic sheet aa flow. West of the western Pisgah lava flows is Troy Dry Lake.

Mount Pisgah is a name from the Bible. In Deuteronomy, Pisgah is described as a peak on Mount Nebo, from which Moses saw much of the promised land of Canaan. Moses died without actually entering the promised land. Thus, in the journey lasting generations, Pisgah was a side trip on the longer journey that was not a place to go for itself - it was a place to go so that more could be seen. After seeing the results of cinder mining at this Mount Pisgah in the Mojave Desert, we may be reminded more of Jeremiah: “Upon all the bare heights in the desert, destroyers have come.”

Lava Tube Formation

Lava erupts from volcanoes and flows out across the land surface, laying waste to and sizzling everything in its path. Hot basaltic lavas are relatively fluid, but hot rhyolitic lavas (including obsidian) are comparatively thick and sticky. Most lava tube caves form in basaltic composition lava, sometimes in andesite (intermediate in composition between basalt and rhyolite), and not at all in rhyolite. Channelized flow, rather than sheet flow, favors the formation of lava tubes. Lava tubes are part of the gravity-driven distributary system that transmits lava away from the vent to lower elevation parts of the flow. Lava tubes can form in at least five different ways: surface tubes, semitrenches, true trenches, interior tubes, and rift tubes.

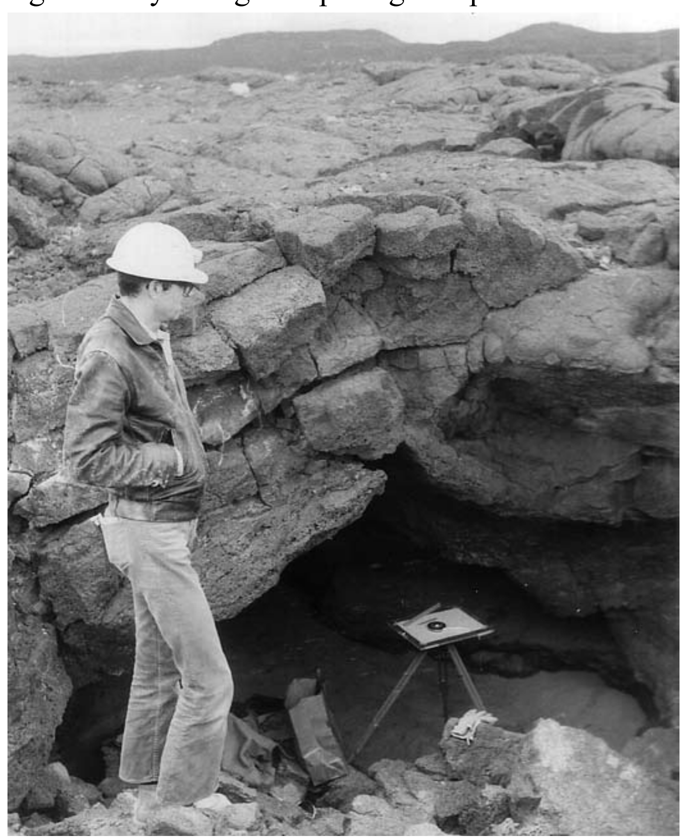
A crust can cool over the whole outer surface of a lava stream, and the liquid inside can drain out. This makes an open tube, that is perched above the surrounding surface, and is called a surface tube. This process usually makes small crawlway-sized caves or cave passages, but sometimes makes moderately large cave passages as well. Pisgah has many examples of small surface tube caves.

Pulses at the vent can cause an open lava stream to overflow its banks, sending thin sheets of lava, or sometimes surface tubes, to the sides. Repeated overflows to the sides builds up levees that, when cooled, comprise a series of thin flow units, each layer having a cast on its underside of the surface beneath. If a crust forms over the channel, it can drain out and make a cave. Roofed, leveed channels like this are semitrenches. If only one layer, or a few very thick layers, make up the channel wall, it suggests that the lava stream flowed through a puddle of lava, making a true trench. Whereas semitrenches seem to be common forms that make long cave passages, true trenches typically seem to be discrete short segments of longer lava streams. The larger passages of caves at Pisgah are mostly semitrenches.

Covered conduits can form within the mass of a single thick lava flow unit. Completely confined within the tabular mass, these are interior tubes. The walls and roof are a single lava layer containing discrete tubes. All verified examples of this type of lava tube, known to this writer, failed to drain. A variant mechanism probably accounts for the formation of many caves having the nearly round cross section that should be characteristic of interior tubes. A sheet of lava develops a crust on top as it cools, and then additional upstream lava may continue to flow in beneath the crust. The crust inflates, lifted up by fluid lava injected just below. The injecting lava, following paths of lesser resistance, apparently can make interior tubes. Reports from Hawaii say that this sort of mechanism is responsible for many caves in fresh lava flows there. The roof crust and walls should have vesicle patterns, cast surfaces, or other distinguishing indications that help identify the formation process. Cross-section exposures of inflated interior tubes should verify that the walls are massive but distinct from the roof crust. Pisgah does not have any verified examples of interior tube caves.

At some volcanoes, lava from a central crater vent flows through rifts that radiate away from the crater. The lava flowing downhill through the wide crack can form a roof crust and then drain out, making a rift tube cave. Also, open portions of a wide crack are low places where lava flowing over the surface can flow in and then follow the rift, crusting over and making a rift tube. Rift tubes are recognizable in part because they have parallel walls of rock or soil that is older than the lava that makes the roof. There are a couple of rifts at Pisgah, but no known rift tube caves.

Various modifications commonly occur to lava tubes during their active formation, and these may significantly change the passage shape. As a lava



Bill Harter at the Maze section entrance to C10 Cave. This was shot in December of 1974. Note the plane table just inside the cave.
Previous page: Liz Harter at the entrance to BT Cave. Sleeping Beauty Mountains appear in the distance. Photo by Russell Harter.

flow cools it shrinks and cracks throughout. If the various loose blocks of the roof and overhanging walls do not happen to interlock adequately, rock fall will occur. Often, the level of hot lava subsides allowing the upper walls and roof to cool, but does not completely empty out. When a new surge of hot lava comes through it will chill a discretely separate lining on the upper walls and ceiling but not on the still-hot floor. If loose breakdown blocks lie on the floor the hot lava stream may lift and carry them away. Floating breakdown blocks may gouge the soft walls, leaving grooves. Breakdown blocks that have been floated into place may jam in narrow spots making "meatballs," or may be left as lumpy floors. Boulders sometimes float up and out of roof holes, leaving "meatballs" welded in place outside. If hot lava finds its way into an old cold tube, it will leave a thick lining and may completely plug the tube.

Hot lava flowing through a tube can emit enough heat to glaze, or remelt, the upper walls and ceiling. The presence of a remelted surface is evidence that the surface was exposed to hot lava. The hot lava can also remelt (or soften, pluck, and remove) lava from the sides and bottom of a channel. The amount of erosion caused by lava flowing over or against a surface appears limited by the available heat, but instances have been reported from Hawaii of lava streams cutting deep channels. A lava stream that has cut a deep channel should leave walls that consist of pre-flow soil or rock that was heated to near-melting close to the tube. If the channel walls are pre-flow soil or rock that chilled a lining against it, it is more likely a rift tube rather than an example of extreme floor erosion. The identification of cast surfaces, remelt surfaces, broken surfaces, vesicle trains, shears, and other features helps in learning things about how a given lava tube cave formed.

Pisgah - Prehistory to Present

About 23,000 years ago the land was desert. The bright sun shone throughout the hot summer days and there was little rain. Nearby, the older volcano Sunshine Crater with its lava flow sat quietly in the heat. The adjacent hills concealed their gold, slowly revealing small bits as the hard rock eroded away over the centuries in uncommon cloudbursts.

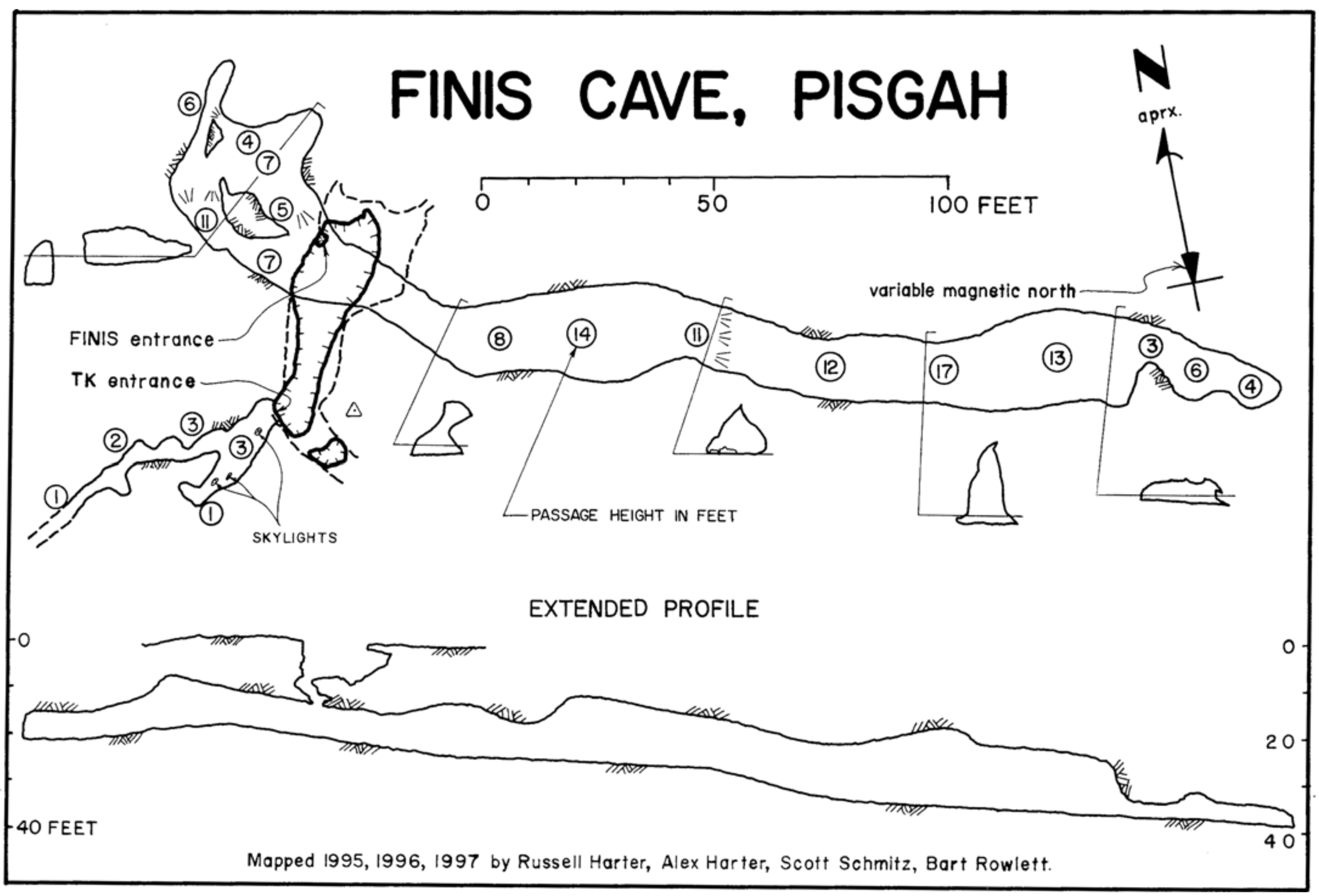
Creosote bushes dotted the alluvial fans. Lizards, kangaroo rats, tortoises, and rattlesnakes sought cover from the intense summer heat. Maybe nobody saw the cracks in the ground, or felt the earthquakes. Or, if the archaeologists ever let their paradigm shift, maybe they did. The hot desert grew hotter near the cracks. Hot steam and choking sulfurous clouds rose from the ground. A hot, acrid wind blew up from the cracks, bringing dust and small rocks with it. The hot wind rushed and throbbed, then just roared, carrying bigger and yet bigger hot rocks with it. Some rocks glowed red, orange, yellow, as they were thrown higher and still higher into the desert air. Day and night the eruption continued and a pile of fresh scoria collected around the largest of the cracks, which by this time had become a nearly round hole extending far downward into the ground, seemingly all the way to Hell. A lull occurred, and the hole filled with magma all the way into the crater that was surrounded by loose rocks. The loose gravel pile gave way and its north side pushed out, spreading into jumbled clinkery piles. Patches of bright yellow glow dulled to red, then black. The new volcano fell quiet for a time.

Eruptions continued, interspersed with longer periods of quiet while there were only steam and fumes, and the rocks cooled. A second, larger, cinder cone piled up south of the first one. It partly filled with lava that started to push out the east side, then stopped and cooled. Some of the quiet periods lasted for years, while deep in the ground still-molten magma cooled slightly, forming crystals that floated, suspended in the hot mushy mass. More eruptions occurred, lifting partly crystallized magma to the surface where streams spread out in layer after layer of lava flows, some with open channels, tubes, and caves. A broad shield built up over cracks southeast of the cinder cones, sending lava flows outward for miles in all compass directions. Molten rock rose within the pile of lava flows and pushed between the layers, lifting a long oval part of the higher ground. Giant slabs of cooled lava rose, tilted, and crushed at the lower edges as the center of the mound grew higher. A giant crack opened in the top of the hill, 1500 feet long, 40 feet wide, 30 feet deep. A smaller ridge rose up, extending from the bigger lava mound nearly to the cinder cone. Cooled sheets of lava on its flanks lifted, tilted, and stopped. Near the west end of the smaller ridge, hot lava flowed out, sending a stream of lava down the notch in the length of the ridge, coating broken boulders. Part of the fluid stream cascaded down one flank of the ridge, making two small lava tube caves. Eventually the eruptions ceased and the lava cooled. The new volcano, Pisgah, sat as quietly as its older neighbor, Sunshine Crater. The new lava flows blocked the drainage through the valley, making (or enlarging) Lavic Lake.

A few thousand years passed as plants and animals slowly moved into the new territory. Summers became shorter and the desert heat was less intense. Winters became very cold, there was more rain, and Lavic Lake held water year around. The always-present westerly wind blew strong, carrying sand onto the lava flow. Blowing snow collected in low spots, melted, and refroze in the cold; the alternate freezing and thawing locally broke the surface rock of the lava flow into small crumbles. The abundant rain leached soluble minerals from the upper part of the lava flow, reprecipitating the minerals lower down in cracks and caves. The cold time lasted for thousands of years. People came to the area to get tool stone of jasper and agate from the alluvial fan east of the lava flow, and they camped by the edge of Lavic Lake. Eventually the cold time ended, the lake dried up, and the desert returned. Fewer people came to the area near the lava flow, leaving it to the tortoises and rattlesnakes. Coatings of calcite inside caves, precipitated during the wet time period and now no longer accumulating, dried and began to peel off. Later, people passed through on their way between water holes, traveling between the Colorado River and the coast, but no reliable sources of water were in this area. The most frequently traveled trails were aligned east-west, located many miles either to the north or south of Pisgah, and the earliest railroads followed the old trail routes.

A railroad finally was planned to pass near Pisgah, connecting across the desert without need for closely spaced sources of good water. Around1881, the surveys came through, and on March 12, 1883 trains began regularly puffing and clickity-clacking their way past Lavic, Pisgah, and Hector sidings, to Amboy from points west. The railroad company established a "permanent" settlement at Lavic Siding, with telegraph operators and a section crew, that lasted at least up to 1929. And in 1929, USGS Water Supply Paper 578 noted that: "Numerous caverns or tunnels were formed when the upper surface cooled and the still liquid lava beneath flowed out from under the crust thus formed."

About the time when people were in the neighborhood building the railroad, gold was found in the Bullion Mountains, a series of ranges extending southeast of the Pisgah lava flows. The mining camp of Steadman, south of what is now the town of Ludlow, was the hub of the largest gold producing area in San Bernardino County. Steadman and Ludlow had to have water hauled in by train from Newberry, miles to the west. High on Sunshine Peak are the Tip Top Mine, the Imperial Lode Mine, and the Mowry Mine, each of which included deep shafts and drifts. Gold and silver are associated with volcanic intrusions that are Miocene age, much older than any of the more obvious Pleistocene lava flows. For processing ore, Kenton Mill was set up by the southwest edge of Lavic Lake, using poor-quality



water pumped from a depth of 85 feet or more at a well located near the southwestern edge of the dry lake bed. The miners built an oiled road across the Sunshine Crater lava flow to get to Kenton Mill from the mines on the north side of Sunshine Peak area, but they missed finding nearby Dug Sunday Cave (about 100 feet long and opened by Bart Rowlett and Russell Harter in 1995), the only known cave in the Sunshine Crater flow. A railroad guidebook (USGS Bulletin 613C, by Nelson Horatio Darton & others, 1915) mentions extensive tunnels in the Pisgah

This patch of salts on the floor in the Cat section of QQ Cave was shot in December of 1989. Photo by Russell Harter.

lava flow, but gives no particulars. Considering the usual interest that miners have in caves, some of the Pisgah caves must have been well known at the time, but no surviving record has come to light. By 1920 or so, most of the mines had played out; but it was the depression followed by World War II that ended mining. The east-west route of U. S. Highway 66, paralleling the railroad, was improved to an oiled road by 1918 and by 1934 was paved. Many people emigrated to California along this route, driving right past Pisgah. Interstate 40 freeway was constructed past Pisgah during 1968, and farther east was completed in 1972. Sunshine Peak, Sunshine Crater, Lavic Lake, and the southern Pisgah flows became part of the 29 Palms Marine Base during or soon after World War II. Bombing and shelling became the ordinary activity. The California Caver in April 1950 noted: "...volcanic caves are said to occur in the pahoehoe flow from Pisgah Crater." However, it was apparently not until the early 1960s that the first groups of NSS cavers visited Pisgah. Over at least the past 45 years, dull distant booms (from the military exercises that typically involve shelling the north-sloping alluvial fan above Lavic Lake) have frequently been heard by people visiting Pisgah. The dry lake bed itself is pocked with bomb craters, as is the cinder cone of Sunshine Crater. Live artillery shells and dud bombs now litter the land on the base, together with large quantities of odd metal debris and shrapnel. Without special permission, the Marine Base is off limits.

Pisgah cinder cone was first mined for aggregate in 1948. A succession of owners have mined cinders, and for about ten years in the 1960s and 1970s Paul Reeves leased the cinder cone and portions of the lava flow in order to quarry slab lava from the surface for use as building stone. The roadways on the lava flow northeast of the cinder cone remain from these surface quarry operations. Some surface tube caves were destroyed during this time, their roofs later appearing on store fronts, restaurants, and apartment houses in Los Angeles.

Southern California Grotto members who went caving at Pisgah from to 1961 to 1963 included Harold Morehead, Dick Reardon, Don Rimbach, Bruce Patton, Ed Simmons, Stan and Miriam Ulfeldt, (Dr.) Dick Mallory and his wife, Kit and Dorothy Porter, and Bill Stewart. Bill Stewart had worked on a survey for a gravel separator for quarry owner Neal Garrett at the cinder mining operation in 1956, saw some caves, and later came back to Pisgah at the urging of Dick Reardon for grotto trips to hunt for more. On a series of desert forays, often including Pisgah as a stop on some longer trip, additional caves were found. Bill Stewart began making sketch maps of some of the caves. Grotto founder and lifetime member Bill Halliday had recently authored Caves of California, and cavers throughout the western states continued to correspond with him regarding their recent finds. During Grotto trips around 1963 to 1965 a surface survey was started by Tom Rohrer along with Bob Atwood, Bob Carnie, Don Rimbach, and Bill Stewart. Surface survey points and cave designations were marked on the black lava rock with white paint and a brush, in letters a few inches high. Caves usually seemed to be designated with a number located beside a circle with a spot in the center, and we later found up to number 30 in this sequence. The center spot on some marks had a nail

The same salts on the floor of QQ Cave shot in January of 1998. Careless visitors have thoroughly trampled this formation that had been pristine 18 years earlier. Photo by Russell Harter.

in it, which was likely the exact survey location. Bill Stewart sent a sketch map dated 26Jan63 to Halliday of “Double Loop Cave #1”, which we (not knowing the earlier name) later called Finis Cave. Caves that were marked Circledot 1 through 5 are located nearby Finis, but no mark in the field identified the larger and more attractive Finis Cave. Different Southern California Grotto groups gave alternate names to the same caves: Bill Stewart’s “4 O’Clock Cave” is the same as the two entrances marked in the field as Circledot 6 and Circledot 7. Harold Morehead’s “4 O’Clock Cave” is what we later named B Cave. The cave marked on the ground as Circledot 12 is called Don Peters Cave in Bill Stewart’s notes. The various painted marks have faded to invisibility over the years, and have been replaced by stainless steel tags nailed to the rock.

The stainless steel tags were first used in 1966 to label our survey stations, and then were used for cave entrances. The tags have generally endured the years but a few have occasionally been stolen by vandals or souvenir hunters. Bill Stewart’s notes show that he was trying to locate cave entrances by taking bearings with a compass on nearby landmarks. A few years later, I tried the same thing and found that the technique did not work because the local magnetic declination varies drastically. We quickly came to the conclusion that a nonmagnetic survey technique was needed to do surface surveying at Pisgah. For the surface survey, Bill Harter made use of a nonmagnetic triangulation-based method that allowed a single person to find a cave entrance, measure a couple of angles between three known points, and calculate location coordinates. We calibrated and oriented the survey with a long base leg chained out with a steel tape, and at night measured its orientation with respect to the North Star. The method did not require a rod man, which was good because we often had only two of us on a trip, and we wanted to do other work also, besides just surface surveying. While Bill worked on the surface survey I could get sling psychrometer readings, and make notes about recently found caves. Bill’s required instrument only needed to measure angles, which was good because we had almost no money for expensive survey equipment. Bill made a small sextant, practical to carry while hiking across the lava flow, from a piece of a plastic drafting protractor and a dime store mirror, with a hand scribed vernier scale. With patience and repeated readings he was able to measure angles accurately enough to locate newly found cave entrances within a few feet. The mathematics required to reduce the data were possible for him to do by hand with tables and a slide rule, but were complex and very slow. Soon he had written a computer program that was a 1-inch pile of computer punch cards. He managed to get time in those pre-personal computer days on an IBM 1620 main frame computer at Santa Monica City College, accessed through our brother-in-law Wally Beitzel. In later years, sometime caver Lee Blackburn collected old 1620 computers that were being discarded, and Bill ran survey data through those.

By the early 1970s, footprints and trash appearing on the lava flow and in caves made it clear that Pisgah was being more heavily visited. Glove Cave looked especially worn from the increased number of visitors and in late 1975 a register was set at the uphill end of the walking-size passage in the cave.

Hugh Blanchard in SPJ Cave with a 26-inch soda straw made of dried mud. Shot in November of 1971. Photo by Russell Harter.

The register at Glove Cave is likely a good indicator of the overall visitation rate at Pisgah, since the cave is probably the most commonly visited of the many caves in the area. The Pisgah lava flow has only a few landmarks that are easily recognizable to newcomers, but a group needs only a leader who can find the cave or good GPS coordinates to locate it. In order to sign the register, people must walk across the lava flow to the cave entrance, enter the cave, and make their way about 300 feet underground. Only some of those who get to the entrance will make it to the register, and some people who get to the register may not sign it. Despite incomplete tallies because of periodic vandalism and pack rats shredding the register pages when someone leaves the lid open, the recorded number of annual visitors is instructive. Up through 1981 the number was less than 200 per year. From 1986 to 1991 every year has had more than 200, 1992-1996 each year has been more than 300, 1998-2003 each year has been more than 500, and since 2004 each year has had more than 600 visitors sign the register in Glove Cave. Most people visit the cave during fall, winter, or spring; very few brave the heat of summer. Most visits are on holidays, holiday weekends, or ordinary weekends. Groups of six or more people account for about 90% of the total visitors. The diversity of groups ranges from high schools, college geology field trips, and church youth groups, to boy scouts and outing clubs.

Caves

More than 300 lava tube caves are present at Pisgah (just how many depends in part on your definition of ‘a cave’). The longest, SPJ Cave, is a braided semitrench about 1300 feet in length. Many of the Pisgah caves are surface tubes that make small crawlways. Within various caves there are typical primary lava tube features including remelt glaze, drip pendant stalactites, lava drips, remelt sags, spatter, linings, rafted breakdown, breakdown jams, dip-layered stalactites, railroad tracks, tube-in-tube, blowout pockets, multilevel passages, layered lava, pillars, and cast surfaces. Outside we see features including flow units, ropy pahoehoe, clinkery aa, jumbled block lava, plate lava, pressure ridges, collapse pits, lava coatings, overlapping flows, and hornitos. At least three small lava tube caves at Pisgah were fed from aa flows. At many locations on the lava flow, well removed from any open tubes, there are blind collapse pits that have deformation of the inner walls, indicating that the lava was still hot when the pits fell in.

Post-cooling secondary features include accumulations of soluble salts leached from the lava, including thenardite (Na_2SO_4), calcite ($CaCO_3$), trona ($NaHCO_3\ Na_2CO_3 \cdot 2H_2O$), natron ($Na_2CO_3 \cdot 10H_2O$), halite (NaCl), sylvite (KCl), and gypsum ($CaSO_4$). The accumulations of salts in lava tubes are delicate features that are easily destroyed by carelessness.

Tan, fluffy dust is present in thick accumulations on cave floors, as well as in low places outside. Some of the dust comes directly from weathering of the lava, evidenced by its filling vesicles inside freshly broken rock. Some portion of the dust in caves is derived from off the flow, evidenced by quartz being present in small amount. (Quartz does not occur in the Pisgah lava.) Possibly unique to Pisgah are fragile ephemeral soda straw stalactites composed of dust.

Wildlife at Pisgah observed or reported over the years has included deer, coyote, fox, striped skunk, spotted skunk, jackrabbit, lizard, collared lizard, chuckwalla, tortoise, kangaroo rat, pack rat, and rattlesnake. Indications of some of the outside animals have sometimes been found well within caves. Cave dwellers include bats, spiders, scorpions, and probably smaller organisms.

Finis Cave

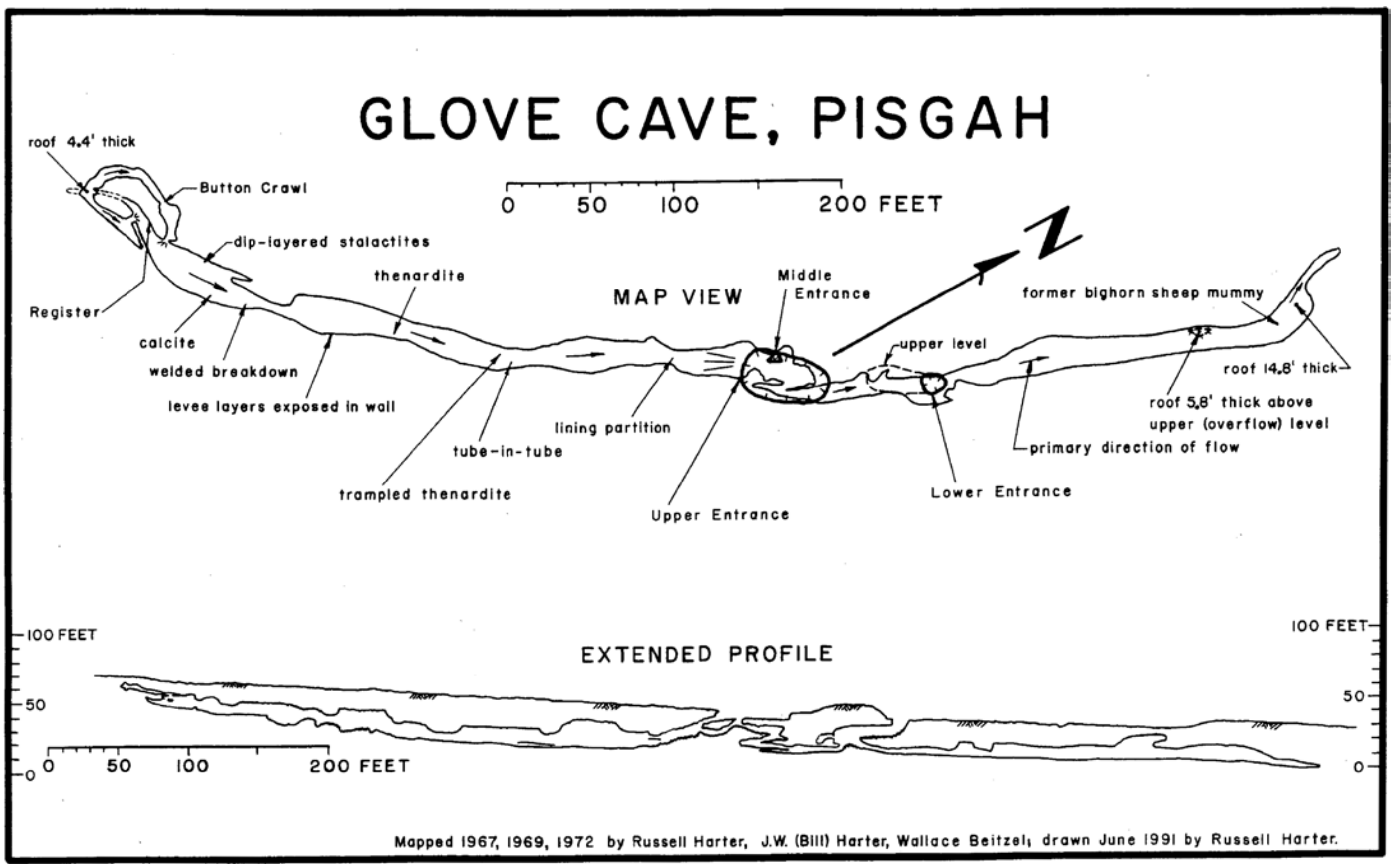
Wally Beitzel, Bill Harter, Barry Levin, and Russell Harter got to the downstream end of the open tube where the lava sumped, and we stopped to consider what the cave should be called. Wally’s suggestion was likely to weigh most, since he had found the entrance. He said that since we were at the end, the finish, we could call it Finis. By that time we had found at least 127 caves at Pisgah, surveyed entrance locations for most of them, and were running low on imagination for new cave names. It was April 1967, and none of us was an NSS member. I had written repeatedly to the NSS without receiving any response. We finally connected with Southern California Grotto through the short-lived Ventura County Cave Survey grotto of the NSS in 1969, and by that time the early 1960s Southern California Grotto enthusiasm for Pisgah had ended.

The entrance to Finis Cave is in a collapse trench in the top of a low hill. A vertical descent of about 10 feet places the explorer in a walking-height passage that goes uphill to two connected loops, and downhill to a single large passage. The cave has abundant remelt stalactites and little breakdown. Walls and ceiling have patches of white crusty deposits of calcite ($CaCO_3$). White cotton-like masses on the floor are primarily thenardite (Na_2SO_4). Analyses were run by Bill Besse in 1976 using X-ray diffraction equipment at Cal State Los Angeles. Visitors are cautioned not to trample the thenardite. It requires a long time to grow back, and experience so far shows that once crushed, it requires upwards of forty years to regain its fluffy, cottonball-like appearance.

The lava source of the tube that made Finis Cave was from the west, and could be the same tube as the one that fed Circledot 12 Cave. A couple of red spatter lava piles west of the Finis Cave entrance are hornitos that undoubtedly built over holes in the roof of the main tube just upstream of the cave. The lava tube formed as a semitrench; an open channel was confined by levees that were built up by repeated overflows to the sides. The open channel continued to build higher banks with lava spatter that gradually grew inward, eventually closing at the peak. This is a “zipper” style of roof, and has been observed forming on some active lava tubes in Hawaii. Uphill of a constricted spot in the passage, lava filled the tube, lifted the roof, and overflowed making an upper level room. The roof of the upper level room later collapsed, making the entrance to Finis Cave.

Glove Cave

Glove is one of the longest and best known caves in the Pisgah lava field. The name Glove Cave was adopted by Bill Harter, Wally Beitzel, and Russell Harter when we first found the upper and middle entrances of the cave in about January, 1966, with a number of worn out gloves laying around on the ground near the upper entrance. Earlier, Southern California Grotto people had visited the cave and Bill Stewart had the name “Pisgah Lava Tube #1” on his notes for the upstream portion of this cave. It is mostly a single passage, with three entrances nearby one another in the middle. Passages go uphill and downhill from the entrances, with a short middle section connecting the upper and lower entrances. The main passage is mostly a semitrench; a leveed channel with horizontal overflow layers in the walls. Levee layers are exposed in the wall about 250 feet upstream from the upper entrance. Once a crust had formed over the lava stream, overflows repeatedly occurred through holes in the roof, leaving lava layers that buried the relatively thin initial crust over the tube. The tube cooled for a time, causing breakdown to fall. The breakdown stoped upward into the overlying lava layers, leaving a stepped, grossly lumpy, ceiling. Renewed flow of lava through the tube carried breakdown blocks to a point just uphill of a passage constriction (located 300 feet upstream of the upper entrance), leaving large boulder lumps welded to the floor. The large collapse containing the upper and middle entrances fell in during the intermediate cooling stage, and the additional lava floated and pushed aside rubble, leaking through the breakdown and leaving a small connecting passage through the middle of the cave. The cave passage downstream from the lower entrance has a much flatter gradient than the uphill part of the cave and may be a true trench type of tube with walls made of a single layer or only a few thick layers. Before the tube roof formed, at what is now the upper end of the cave, the leveed channel overflowed, feeding two smaller lava streams



that continued along either side of the channel. As luck would have it, both of the smaller surface tube streams flowed back to and reentered the main channel (which was still open and unroofed), creating the crawlway loop at the uphill end of the cave. The infamous Button Crawlway is the constricted spot in one surface tube passage where the shirt buttons of numerous explorers have been torn off as they squeezed their way through. The 6 feet high room at the highest elevation in the cave is the chamber on the crawlway loop where lava rose up from the main tube below, which is now plugged at this location. A piece of lava a few inches thick fell from the ceiling of this room upon final cooling, exposing a cast surface on the underside of the next layer above. The cast surface shows that all of the lava from that point upward overlies the initial crust of the tube, so was emplaced later as overlying lava. The roof thickness over the room, determined with Bill Harter's cave radio, is 4.4 feet. Outside, the ground surface above is nearly flat, indicating that the overflow dome that formed on top of the Glove Cave tube was completely buried by later lava flow units.

The cave has good examples of remelt stalactites (indicating exposure of the ceiling and upper walls to radiant heat that was sufficient to remelt the lava surface and make it drip), dip-layered stalactites (a record of repeated rising and falling of the lava stream with a frothy molten surface), blowout pockets, sagged remelt, lava droplets, level splits made by lining partition, and other intriguing lava tube features.

Glove, like many other caves at Pisgah, contains whitish crusts on walls and ceiling that are probably calcite; white cottonball-like masses on the floor are probably thenardite. About 150 feet upstream of the upper entrance there is a white patch of floor some 3 feet wide and 20 feet long. In 1966, this white patch of floor was a mass of fluffy white cottonballs two inches thick, primarily thenardite. The floor is flatter here, so the thenardite is the natural place that people will walk through. Over the years this entire large patch of fine white crystals has become trampled, and there is no sign that it can recover.

Bighorn sheep skeleton in Glove Cave. This photograph of unknown date by Bill Stewart was made before the skull was removed, which occurred around 1965 or early 1966.

The lower end of Glove Cave once contained the desiccated skeleton of a bighorn sheep, complete with dried skin on the legs and on portions of the torso.

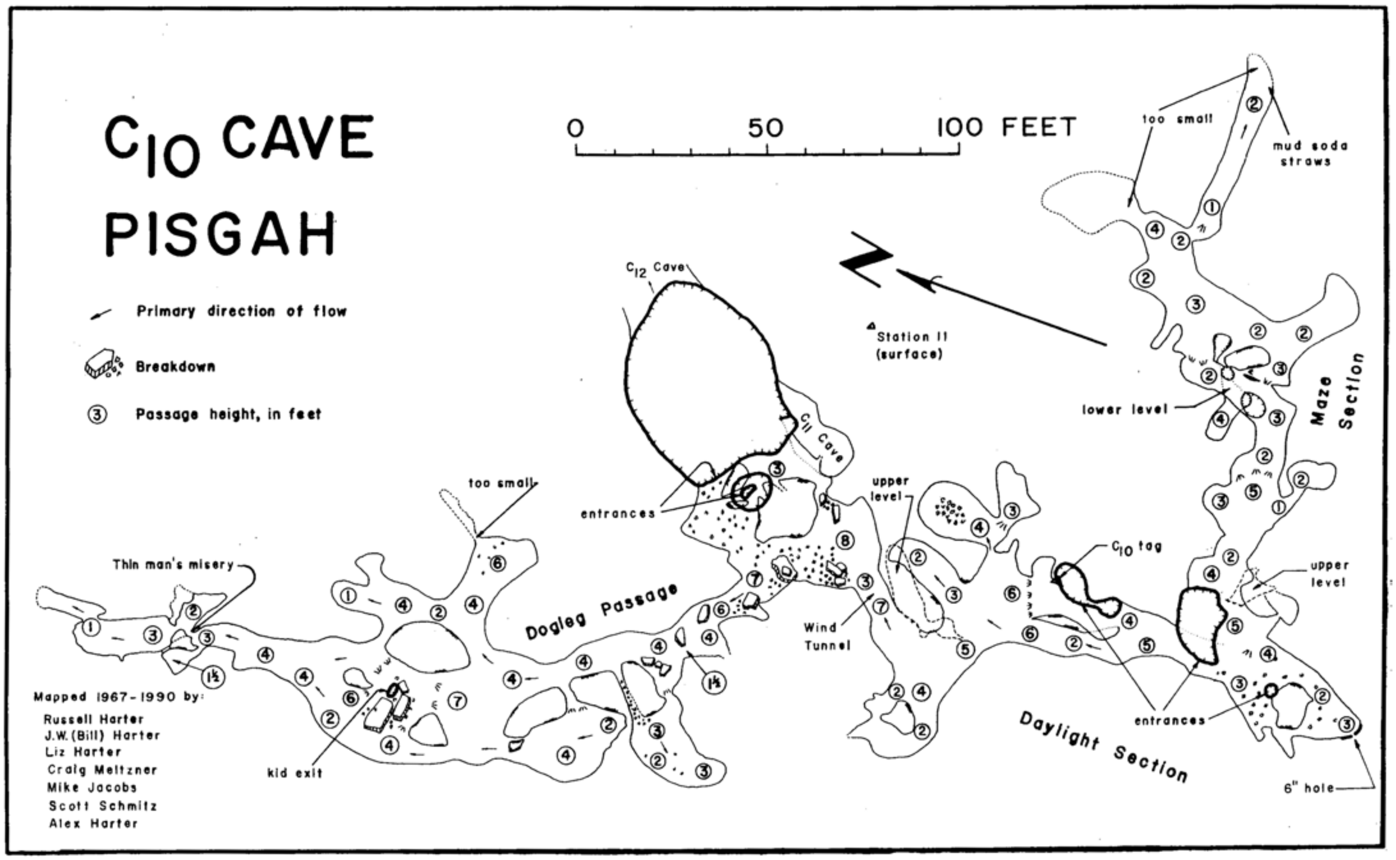
Soon before I first saw this part of the cave in April, 1966, the skull was removed. Over the next few years, malicious visitors trampled the remains, breaking bones and removing portions. By 1979 only a few splinters of bone and small, scattered, shreds of sinew remained. No bighorn sheep have been reported on the Pisgah flows in historic time. Whatever scientific or cultural value the partially mummified bighorn sheep might have had was destroyed.

C Tube

Lava emerged near the eastern base of Mount Pisgah cinder cone, forming one particular distributary feeder tube that made a series of collapse trenches and caves extending at least 2/3 of a mile to the north-northeast. For convenience of description, this is designated the C Tube. Segments of the main C Tube and its most obvious overflow distributaries account for at least 75 lava tube caves. Portions of C Tube are plugged, other portions are collapsed, and a number of comparatively short segments make caves. The main lava channel occupies the axis of a low, broad, ridge that comprises the built-up levee walls. The main C Tube channel is a semitrench that fed a few smaller semitrenches and many surface tubes, located on the flanks. Upstream segments of C Tube are single passages including Russell Stewart, RC1, and RC3 Caves. Farther downstream, the tube separated into multiple branches, making caves Station 7 A, B, and C. Downstream of the Station 7 caves is a long collapsed portion with only small lateral branches and half-talus holes along the way; then come C10, C12, C13N, and SPJ caves. Along the way are many small caves, and B Cave formed in one flank of the ridge. C10 has multiple-passage maze sections, C12 split into north-and northeast-trending passages, C13N is a single passage (with roof and side overflows) that began to branch in the downstream direction, and SPJ is a braided distributary network.

C10 Cave

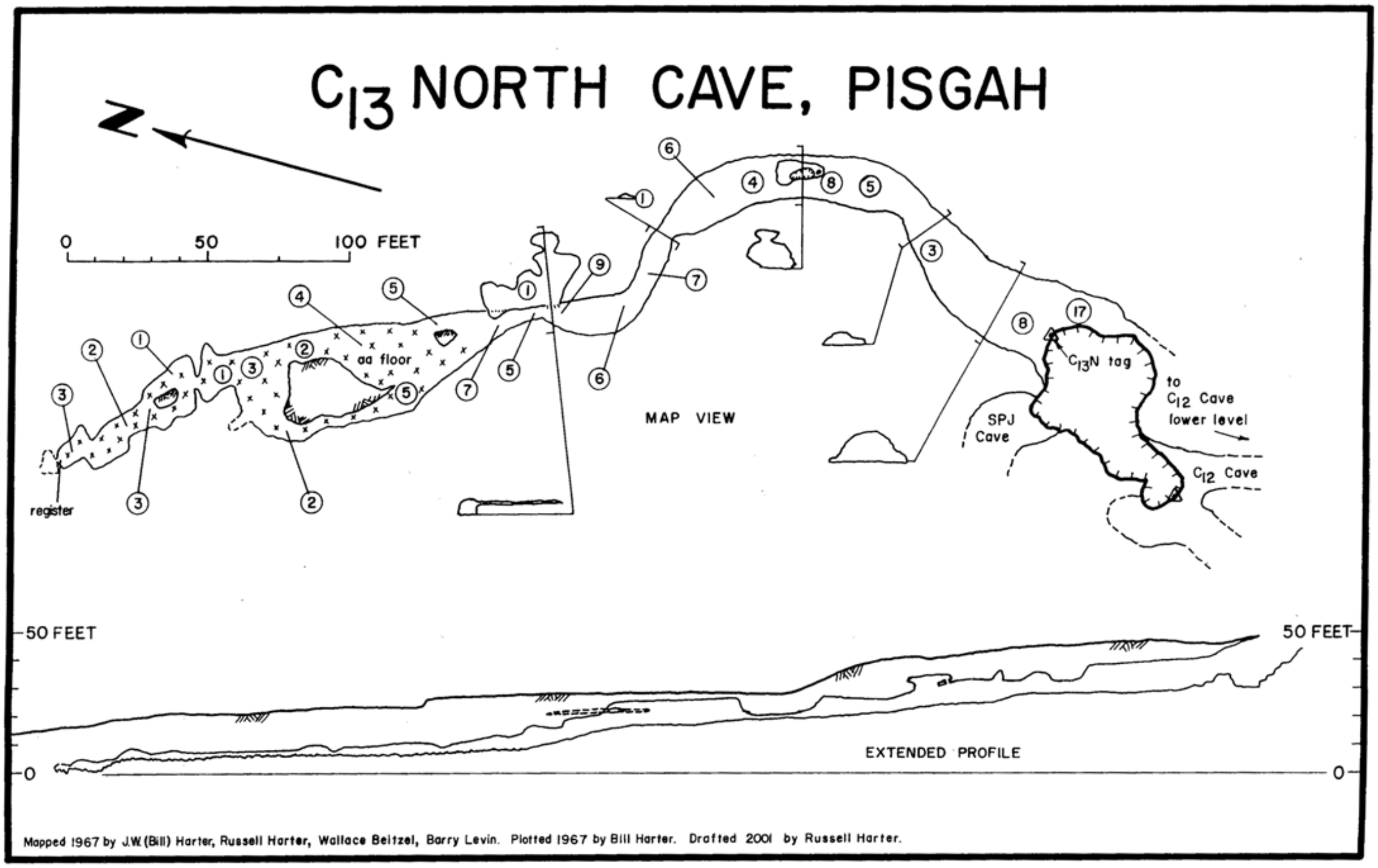
Bill Harter, Wally Beitzel, and I first saw C10 Cave in December of 1965 when I was 18 years old,



several years before I joined Southern California Grotto. It was one of the longest and most complex of the caves we had found, with a series of rooms and passages, mostly not very big, but including short sections that are high enough to walk through. The crawls are relatively easy, mostly in soft dust. Each time that a crawl or stoopway was passed, and opened up beyond, it encouraged us to keep going. We entered the largest, easiest entrance (now tagged) and followed the largest passage downhill - around a corner, through a stoop, around some breakdown, and daylight at another entrance. Darkness continued low to the left, where the passage continued. Past more breakdown, stoop, and then a belly crawl. The ceiling rose to a stoop, we passed some low crawls on the left, and beyond the ceiling rose enough to stand. Daylight streamed through a small hole in the roof that was much too small for an adult to go through, but it could (and years later, did) serve as a 'kid' exit. The passage branched, reconnected, and funneled into a single narrow stoopway. The ceiling lowered and the passage seemed to end abruptly with a small hole ahead in the floor and another small hole in the base of the right wall. Moving of loose rocks and a little digging with hammer and chisel eventually opened up the small holes to three more small, low, rooms. Mapping of C10 was based on traverse with Brunton and tape, but part was also done with a plane table and crude alidade. Foresight and backsight differences in the traverse of up to 30 degrees were found, showing the variations in local magnetic declination of the lava.

The maze section of the cave seemed particularly warm when we visited in December, 1990. This had been noted before, and psychrometer readings had shown that the warm feeling is due mainly to high humidity rather than high temperature. There were also still-moist drip holes in the dust floor just inside. I assumed that the source for moisture must have been rain. This happens at Pisgah; rain causes drips inside, the moisture stays in the cave air, and the cave seems warmer. Water runs downhill through cracks into the cave; nothing unusual, right? Since the overnight low temperatures had been around 15° Fahrenheit, two cavers figured that the maze section of C10 Cave would be a comfortable place to sleep. That night they observed firsthand a different micro climatic phenomenon: the cave breathed its very moist air into the cold outside, causing condensation on the ceiling of the entrance passage where they had their sleeping bags laid out. The condensation dripped onto them as they tried to sleep. The moist drip holes in the dust floor were due to condensation, not rain.

Also in December, 1990, mud soda straws were noted in the far end of a low, dusty, crawlway in the maze section of C10 Cave. The floor is soft dust



and the ceiling height is less than one foot. Some of the mud soda straws have dropped from the ceiling and poked into the dust, making tiny slim dust stalagmites; there are even some continuous columns from ceiling to floor.

About February, 1997 a group of cavers from Desert Dog Grotto was visiting C10 Cave and found a quantity of glassware and containers of chemicals not far in from the main entrance. It was the beginnings of a drug lab being set up. The county sheriff was notified and taken to the spot, the materials were cleaned out, and since then similar uses of caves at Pisgah have not turned up.

C13N Cave
This is another segment of the main leveed channel (semitrench) of C Tube, farther downstream from C10 Cave. In between are C11, which is a single room about 30 feet long; and C12, a large multiple-passage cave of about 260 feet. Two downstream entrances of C12 come into the entrance collapse of C13N. The lower level of C12 connects to C13N under the drip line, so C12 and C13N could be considered the same cave. So far, only the C13N portion has been mapped. On the west side of the C13N collapse, a separate entrance, formerly identified as C13W, not under the drip line from C12 or C13N, goes to a crawlway about 70 feet long that continues into SPJ Cave.

The entrance of C13N starts out large, but after about 50 feet goes down to a knee crawl. After opening up again, about 150 feet from the entrance the passage goes down to a belly crawl about 8 feet long. The ceiling then rises to a walking height and we see the nicest part of the cave: a curving passage with lining curb on the left and an upper level crawlway on the right that is a surface tube overflow from the main semitrench passage. Farther along, the ceiling gradually lowers and then we come to the first clinker room. With a ceiling height of 2 to 5 feet and clinker aa on the floor, the room is a challenge to pass through. Two low passages connect to the second clinker room, only 1 to 3 feet in height and similarly floored in clinker. At the back right corner of the second clinker room is a low and awkward narrower crawl over clinker. For anyone daft enough to continue the last 85 feet or so, there is a register at the end of the passable crawl.

Lava tubes are distributary systems. The ever lower passages in the downstream parts of C13N Cave are the last remnants of open tube. Still farther downstream, the tube did not drain at all; the lava remained in the tube, plugging it when it cooled. The aa floor in downstream portions of the cave is the last remnant of flow that passed through, and the clinker aa was too thick and sticky to drain. In C13N Cave we see the downstream transition take place from a moderate sized semitrench to much smaller and lower semitrench, to surface tube. The lower end of the tube is buried by overlying lava, giving a cave roof thickness (determined with cave radio) of about 10 to 12 feet.

Tea Cave

Tea Cave is a surface tube with several rooms connected by crawlways. The roof over the cave is probably all less than two feet in thickness, but the cave can still provide a sense of claustrophobic remoteness. The single entrance opening is a hole in the roof at the juncture of two low rooms. Most of the 260 feet of passage is dusty crawlway extending downstream from the entrance. About 35 feet from the entrance there is a hole a few inches wide in the roof, which helps to show the thin roof of the cave. A room about 75 feet from the entrance has its floor at a lower level than either the incoming or outgoing passageways; drainage of the lava from this room seems to have been through a now plugged tube that exited to the southeast. This room, and the room at the downhill end, are the only places where one can stand, or nearly stand, in the cave. The downstream end of the cave has clinker on the floor, and in the last room there is a narrow, crooked, crack in the roof that admits a dim glow of sunlight. Measuring through the crack tells us that the cave roof is 1 1/2 feet thick at this point.

Tea Cave was mapped on May 14, 1966, with a magnetic navigation compass (having no clinometer), and steel tape. The compass gave bearings that were recorded to the nearest 5° only. Even where foresights and backsights disagreed, these were roughly averaged on the spot and a single bearing was recorded for each survey leg. After plotting a rough copy of the map, we went back to the cave to check the survey and laid out a single line outside from the entrance to the crack-in-roof at the downhill end of the cave. I took a wire coat hanger inside and wiggled it up through the crack in the roof. Bill Harter stood on the surface, looking around the spot where the survey said the crack should be. Since the rock is ubiquitously fractured, it was unclear from the surface which crack was the one we wanted. As he searched for the coat hanger, Bill suddenly discovered it rising into the leg of his trousers! We considered this a net loop closure error of about 2 feet, quite acceptable considering the methods employed. We always figured that this survey closure illustrated the point that sometimes errors can cancel one another, just by dumb luck. Bill located both the entrance and the downhill crack with his surface survey. Using the surface survey orientation that was referenced back to Polaris (true north), we concluded that the net orientation of magnetic north at traverse stations in the cave is north 50° east, referenced to true north. This shows once again the limitation of using a magnetic compass in a magnetic lava flow.