MINERAL INFORMATION SERVICE

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Geology of Some Lava Tubes, Shasta County

---by James R. Evans

Lava tubes (or caves) are a common but generally not well known feature of Quaternary basaltic rocks in northeastern California. For example, in Lava Beds National Monument, Siskiyou County, there are about 293 known tubes of which only 193 had been explored by 1959 (R.G. Knox and R.T. Gale).

In late 1962, the geology of five of the numerous lava tubes in Hat Creek Valley in Shasta County was studied in detail to help determine their potential use as radioactive fallout shelters. The valley is a relatively flat, northward sloping surface about 3 miles wide and 25 miles long covered by a flow of Recent basalt called the Hat Creek Valley Flow. The flow gushed from north-trending fissures near Old Station and flowed north down the valley.

Hat Creek Valley

On the north, Hat Creek Valley merges into a lava plateau incised by the Pit River; on the south, it is terminated by basaltic flows. For nearly two-thirds of its distance, the valley is bordered along the east by rather abrupt fault scarps. East of Hat Creek Post Office, Hat Creek Rim merges with a series of these fault scarps, the highest of which is nearly 1300 feet above the valley floor. The faults here border prominent eastward tilted benches.

Volcanic peaks and ridges border Hat Creek Valley on the west, one—Sugarloaf Peak—reaching 6552 feet in elevation.

There is no direct evidence of major faulting along the west valley margin, but apparently Hat Creek Valley is a structural block, as the east side is dropped down or along the series of north-trending *en echelon* faults. The Hat Creek lava flow gushed from fissures near the Old Station area to flow northward upon the now-tilted valley floor.

Hat Creek, which drains north along the west side of the valley, has its headwaters on the northeast slope of Mt. Lassen. It is joined by Rising River, which drains a series of lakes in Hat Creek Valley that are fed by ground water. From the confluence, Hat Creek drains north into the Pit River.

Lost River, to the east, drains west off the highlands through the Hat Creek Rim out into the Hat Creek Valley. After flowing in the valley for about a mile, Lost River swings north for nearly 3 miles where it disappears into the alluvium-covered lava.

Hat Creek Valley and Hat Creek Rim. View is east. The road in the center of the photo is State Highway 44 that leads over the highlands to Susanville. *Photo courtesy California Division of Highways.*

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Other publications of the Division include the Annual Report of the State Geologist; the Bulletin, Special Report, Map Sheet, and County Report series; the Geologic Map of California; and other maps and publications. A list of the Division's available publications will be sent upon request. Communications to the Division of Mines and Geology, including orders for publications, should be addressed to the San Francisco office.

MARY R. HILL, *Editor*

Climate

The weather records from nearby stations indicate that rigorous climatic conditions may be expected in the winter months in the Hat Creek Valley. State Highway 89, however, is kept open and free from snow. Summer weather is generally pleasant.

Hat Creek Lava Flow

Charles A. Anderson (1940) described the Hat Creek lava flow in detail, and much of the information below has been abstracted from his article.

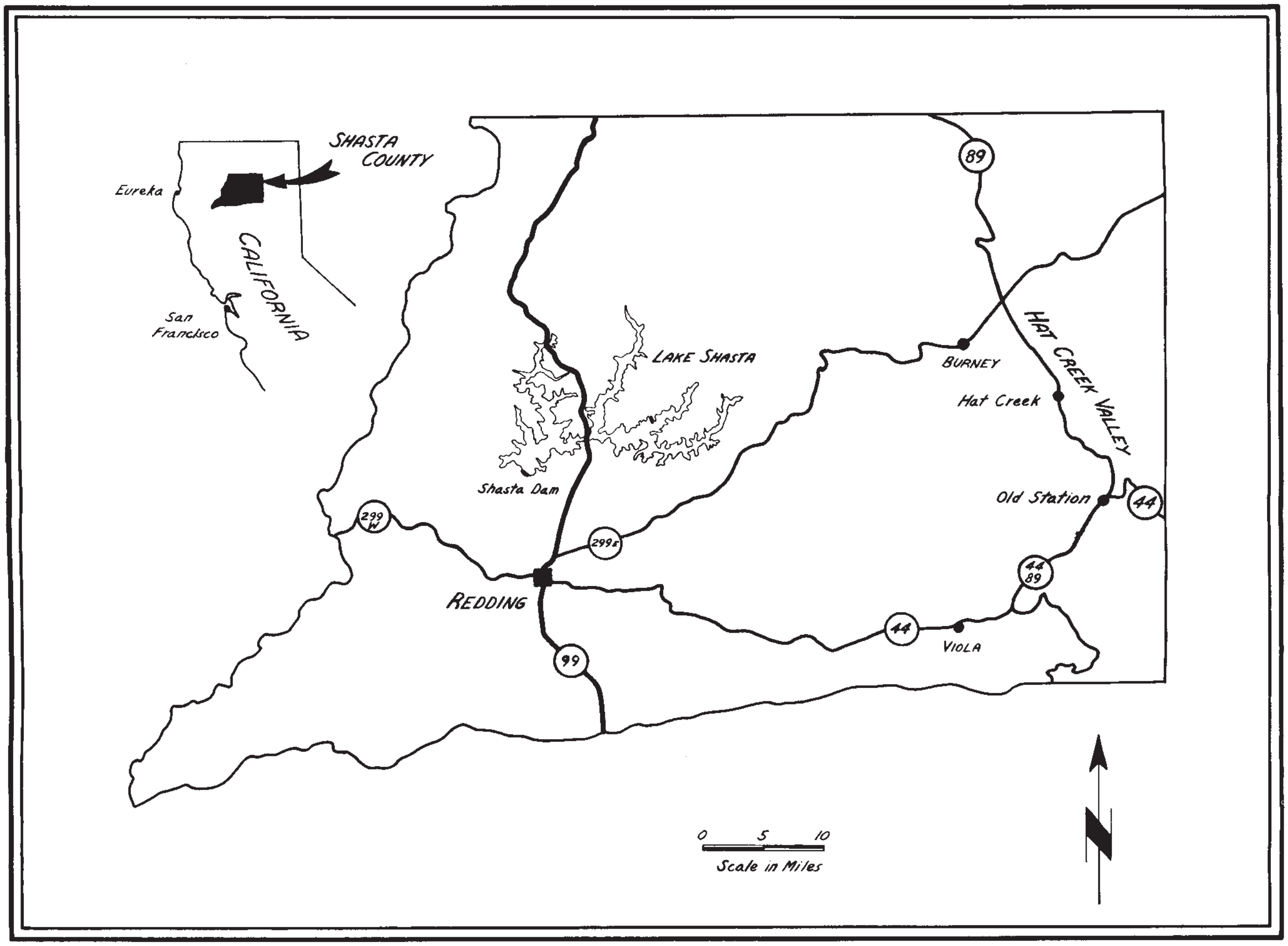
Basaltic lava was spewed from north-trending fissures just south of the site of Old Station, and has formed a north-trending ridge about one and a half miles long rising 320 feet above the flat floor of Hat Creek Valley. Spatter cones, ranging in height from 3 to 30 feet, are irregularly distributed along the axis of the ridge. They were formed by the accumulation of molten ejecta spewed from lava fountains along the the fissures. A few of them contain cylindrical depressions as much as 40 feet deep. A lava river once flowed from each cone down onto the floor of Hat Creek Valley. Now, irregular tongues of highly vesicular basalt connect the cones to the main flow on the valley floor. Because of the eastward tilt of the valley, the flow is likely to be thicker on the east side than on the west.

Some lava that poured out of the fissures flowed west, but most of it flowed east and then north down the Hat Creek Valley to the Rising River Lake area, a distance of about 18 miles. The flow surface is highly irregular, and there are many mounds and elongate, north-trending ridges.

Although nearly all the lava is pahoehoe,* it has a rough, irregular surface.

*Hawaiian term for a highly gas-charged basaltic lava that issues from the source in a highly fluid state and solidifies with a generally smooth surface in ropy, billowy, and irregular mound-like forms. These flows typically contain lava tubes.

Bigfoot Chamber in Subway Cave. View south. Ceiling height in foreground is 8 feet. *Photo by Phil Lang.*



Map of Shasta County showing location of Hat Creek Valley.

Samples of lava examined under the microscope by Anderson were basalt composed of an average of 56 percent plagioclase feldspar (An_{70-85}, bytownite), 24 percent pigeonitic pyroxene, 16 percent olivine, and 4 percent magnetite.

A chemical analysis of the basalt by Herdsman (Anderson 1940, p. 486) gave the following results:

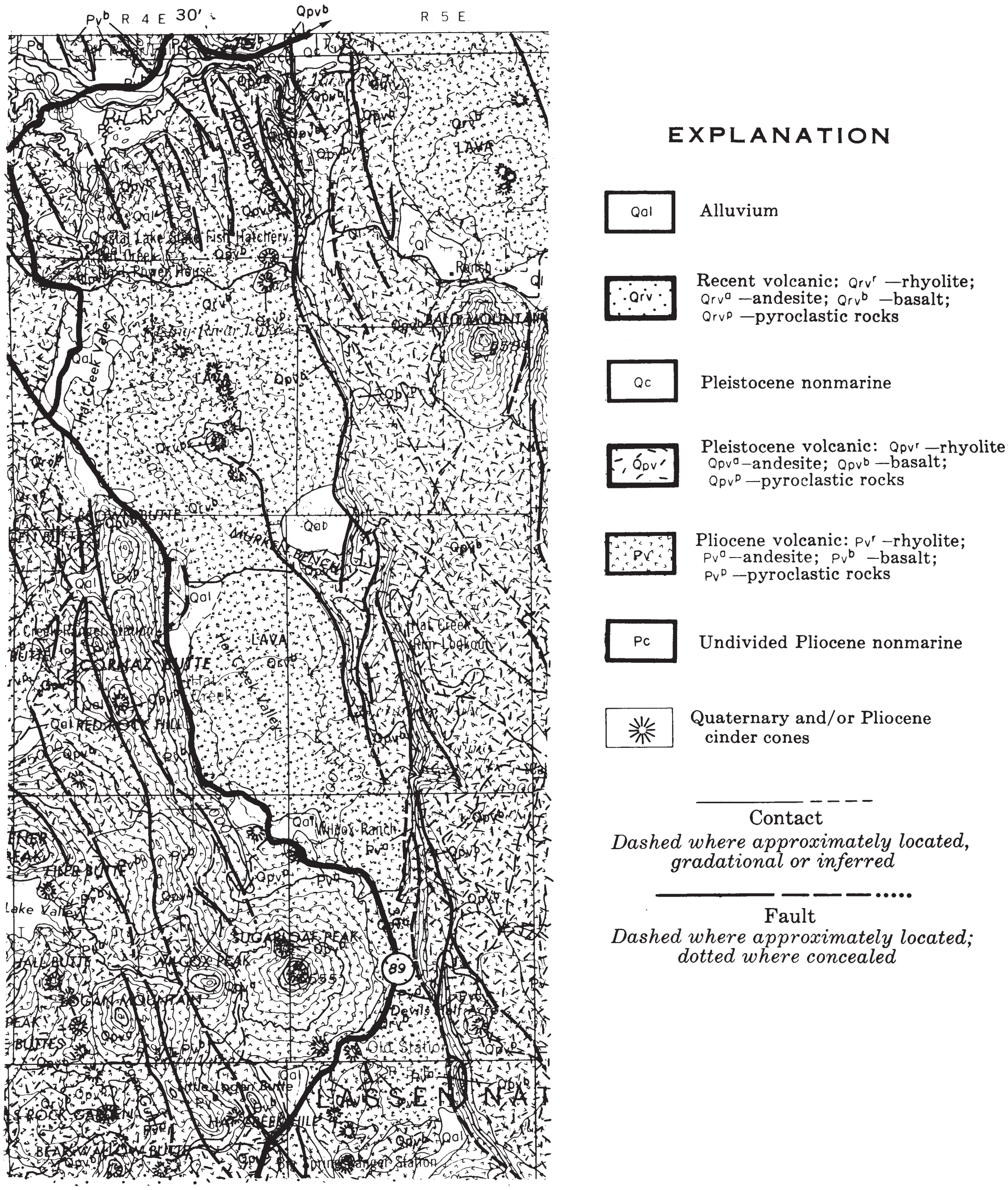
SiO_2	47.98	Na_2O	2.48
Al_2O_3	18.66	K_2O	0.27
TiO_2	1.18	H_2O+	0.04
Fe_2O_3	0.94	H_2O-	0.05
FeO	8.66	P_2O_5	0.07
MnO	0.15		
MgO	9.48		
CaO	9.92	Total	99.88 %

The age of the Hat Creek flow is not known precisely, but the flow must be very young, perhaps 2000 years or less (Anderson 1940, p. 484). The soil mantle on the lava is thin, and vegetation generally sparse. In addition, the basalt is only mildly altered by chemical decomposition, and flow features are still preserved. Hat Creek, however, has had time to form its shallow, but well-established channel.

The Lava Tubes

Five lava tubes in the Hat Creek Valley were mapped by a four-man crew on a scale of 1 inch equals 100 feet. The mapped tubes are Subway Cave, Christmas Tree Cave, Broken Arm Cave, Dogleg Cave, and one of the Ice Caves. Subway Cave is the largest, and Christmas Tree Cave the second largest of all those mapped or examined. Because these two caves exhibit most of the characteristics of lava tubes in this area, they will be described in detail.

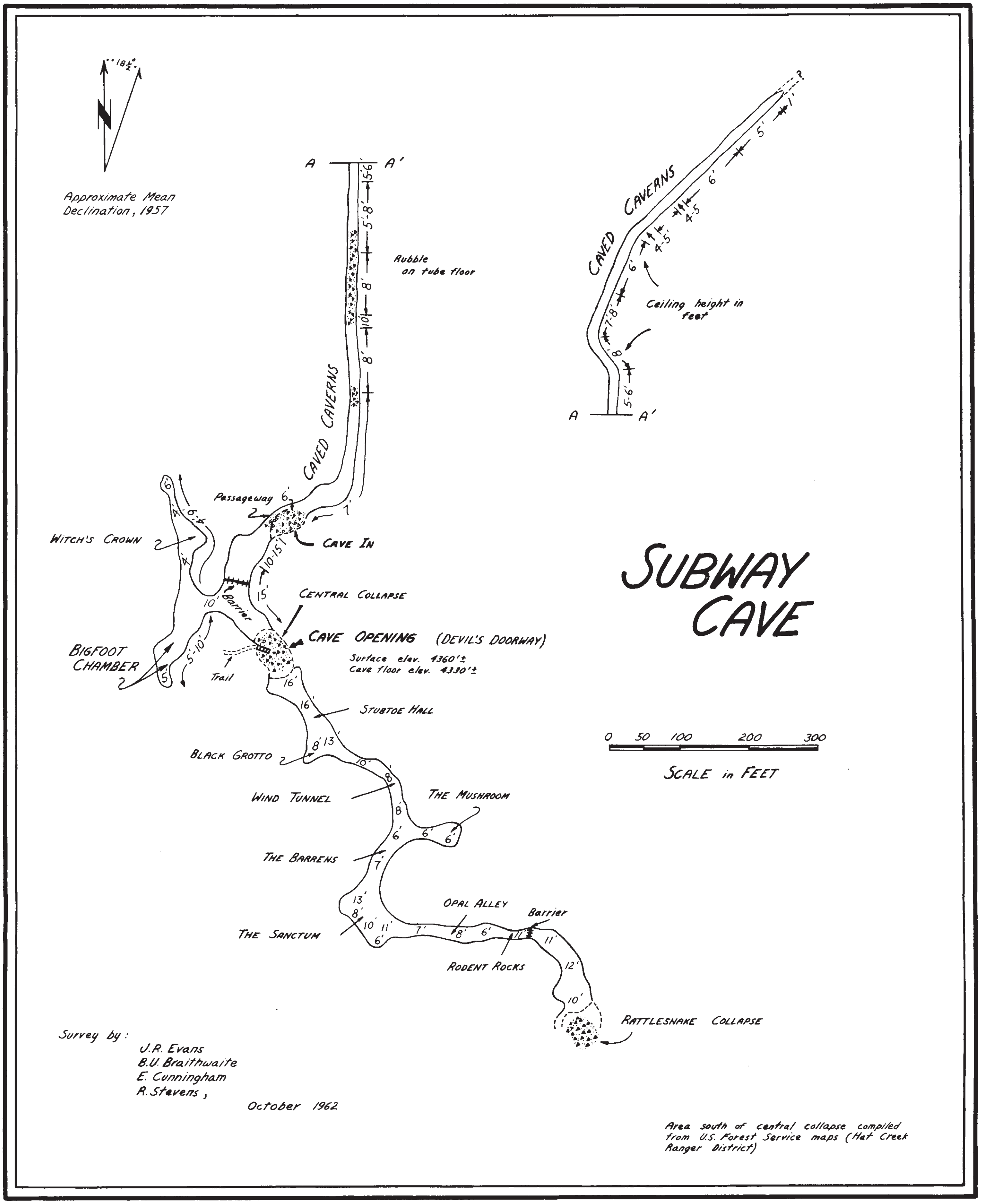
Subway Cave is only two-tenths of a mile east of State Highway 89, a mile north of Old Station on graded dirt road. A trail leads from the parking area a few tens of yards to the main entrance known as the Devil's Doorway, where a rock stairway descends to the cave floor. The cave is irregularly shaped in plan, but trends generally north for at least 2300 feet.



Geologic map of the Old Station area, Shasta County. This map is taken directly from the Westwood Sheet of the Geologic Map of California. Three sheets of the state map—Westwood, Alturas, and Redding—cover the areas discussed in this paper. They are available in color for $1.50 each from the Division of Mines and Geology. "Uncolored" versions (which are actually printed in black, brown, red, and blue) may be obtained for 50¢ each.

There are several side chambers such as the Mushroom, Witch's Crown, and Bigfoot, as well as a second entrance known as Rattlesnake Collapse. The floor of Subway Cave is relatively flat, dropping only 2 feet in 600 from the Rattlesnake Collapse to the Devil's Doorway. A sheet of fine-grained sand and silt a fraction of an inch thick covers most of the floor as far north as the Cave In (see map). The sediment is deposited on the surface of a lava flow which, when hot, poured down the tube. North of the Cave In, which apparently has been effective in blocking the deposition of sediment, one can see the rough, irregular surface of the flow on the tube floor.

The ceiling is broadly arched and generally symmetrical in cross section, but locally it is highly irregular (see accompanying photos). The ceiling is,



Map of Subway Cave, Shasta County.

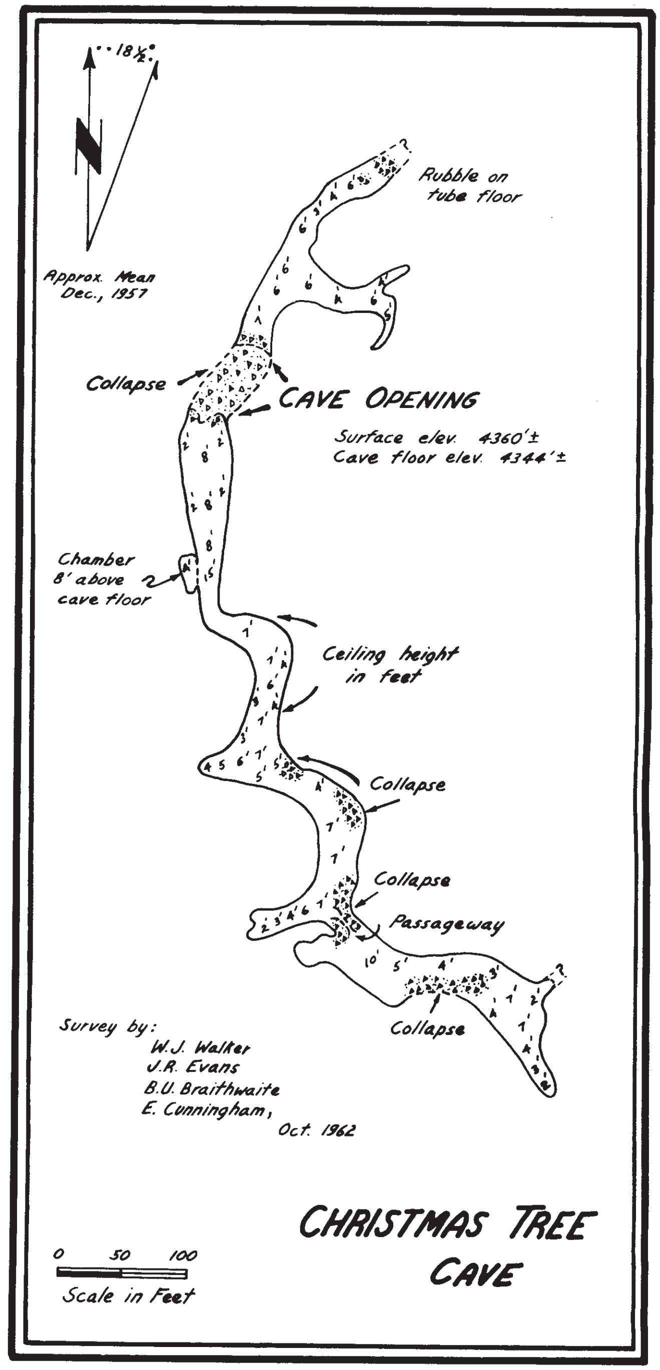
throughout most of the cave, highest in the center of the tube, ranging from 5 to 15 feet in height. There are local constrictions, however, such as the passageway 4 feet high leading into the 9-foot-high Witch's Crown and another near the end of the Caved Caverns.

At the Cave In, part of the ceiling has collapsed on one side of the tube, and there is a rubblepile composed of angular blocks of lava. A few hundred feet north of the Cave In the ceiling has again partially collapsed and there is more rubble on the floor.

At the Devil's Doorway and the Rattlesnake Collapse, the two entrances, the roof has completely caved, leaving a pile of coarse lava blocks with open sky visible. Judging by the amount of rubble, the tube roof was thin in these two areas. The rest of the tube roof, however, is from 11 to 22 feet thick. Although virtually all of the ceiling shows widely spaced cracks, only in the north part of the tube is it fractured enough to result in rock falls. It is likely that some of the cracks, even though tight, may connect to the surface, as roots can be seen in places in them. Most of the fine root networks extend into the ceiling of the tube only an inch or so, but some are about a foot long. Water was seeping slowly from the cracks in November 1962. Most of ceiling appears to be safe in spite of the cracks.

Christmas Tree Cave is 1 mile southeast of Old Station and a mile and three-tenths south of Subway Cave. It is so named for the illegally cut Christmas trees stockpiled in the small chamber just south of the cave opening several years ago. A good dirt road connects the cave entrance with State Highway 89-44.

This cave, also, is irregular in plan, and it, too, trends generally north. It is at least 950 feet long. Ceiling heights range from about 5 to 15 feet, but here, too, there are local constrictions. There are three interior collapses, the largest of which chokes the passageway leading to the extreme south part of the tube. In this south chamber a slab of lava about 12 feet long, 6 feet wide, and 2 feet thick that has broken away from the ceiling centerline is propped against the ceiling and the floor. The cave opening is somewhat restricted by rubble. There are cracks in the ceiling which, in the extreme south chamber, contain rootlets. Most of the floor is a rough surfaced lava flow, although there is some silt and sand in the chamber south of the cave opening. In the central and south part of the tube, delicate stalactites a fraction of an inch to 5 inches in length hang from the ceiling. They are solidified drips of once fluid lava.



Map of Christmas Tree Cave, Shasta County.

Origin of the Lava Tubes

Tubes in the Hat Creek area formed in much the same way as those in Hawaii (see Wentworth and Macdonald, 1953, pp. 43-55). The larger ones formed by crusting over of lava rivers, and the smaller ones by rapid cooling of fluid basalt "toes".

The Mushroom in Subway Cave. View east toward the east wall. Ceiling height is a little over 6 feet.

Rivers of pahoehoe flowed east from the fissures south of Old Station in open channels for perhaps a quarter of a mile. The velocity of the river decreased as it reached a flatter gradient and the top part of the flow congealed to form a crust. At first the thin crust broke easily, but soon masses of the broken material formed jams too thick to break. As the lava river surged and then subsided, another layer of lava congealed beneath the surface of the crust making it stronger and more stable. A tube-shaped structure was thereby created, with a crust of varying thickness. In this manner flow layers were formed and as each cooled, polygonal contraction cracks developed.

"Toes" formed when the crusted lava over the front of a large tube structure broke open because of fluid pressure, and one or several spurts shot out. Some of these tubes or "toes" also broke through their chilled skin and gave rise to a host of new "toes". In this fashion the entire flow front advanced. Lava spurting through each toe allowed the level in the main tube to drop and unless replenished with lava from the source, the tube remained partially void. Not all potential toes broke through; some tubes filled with flows which congealed there. In the cross section of a tube, a number of concentric flow bands are exposed, each representing a flow unit.

Jagger (1947, pp. 121-122) has vividly described a torrent of lava in a tube in Hawaii:

> On the north side of the cone . . . two windows in the roof of the cavern leading from it revealed a brilliantly incandescent cavernous space where, about 12 feet down, the orange-colored melt flowed northward in a majestic torrent. Under the cone, one could see the wellspring which ceaselessly fed the ever-pushing fronts 1½ miles away, and by looking downstream through the window one could see the river pour northwestward in a tube, where blue fume rose through cracks in the roof of hardened flow lava. The entire lining of the tube was at bright-orange heat, and the gases emerging were not particularly sulphurous. This tube had been filled like a sewer when the flow pressure was at its height, and its partial evacuation was evidence of decline in volume of lava.

After eruptions near Old Station ceased and lava drained out of the tubes, tell-tale evidence of the past was left. Benches or lava terraces remained locally where part of a flow had congealed against the cooler tube wall before the lava river suddenly subsided, due, perhaps, to a spurting toe. Two benches showing different levels of the ancient lava river may be seen in one tube half a mile northeast of Christmas Tree Cave. The solidified surface of the flows themselves still remain on the cave floors, and here and there congealed lava driplets hang from the ceiling. In Subway Cave vertical flow lines were left on the tube walls when fluid lava from the last river ran down the sides of the tube.

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Hat Creek Lava Tubes as Fallout Shelters

. . . by Tom H. Gaines*

Before the dawn of human civilization, man sought shelter in caves against the natural elements. Now, in the mid 20th century, man might well turn to caves again, this time to protect himself from the dangers of nuclear explosions.

A direct mission of the Civil Defense Office is to plan for adequate fallout shelter – protected living space, available immediately after any nuclear explosion, in which people can survive for at least two weeks until radioactivity abates.

Enormous tonnages of fallout are produced when the "fireball" of a nuclear explosion actually touches the earth's surface. Pulverized earth and debris, fused with fission products by intense heat, are hurled and sucked miles high into the air by the explosion. It is from this gradually settling, all but invisible, cloud of radioactive death, covering thousands of square miles, that men must seek to escape in fallout shelters.

Many unpredictable factors affect the level of danger from fallout: size, location, height, and number of explosions; "clean" or "dirty" devices; wind force and direction; and possible precipitation.

A study of the Hat Creek lava tubes was started early in 1962 by Shasta County's Civil Defense Office, to determine their possible use as fallout shelters for the County's 65,000 citizens. The study was spurred by results of previous surveys for fallout shelter capability in the County which showed that there was space for only an eighth of the people. Results, from the investigation of only five of the Hat Creek tubes, indicate possible shelter space for 8000 people, and suggest an important role for lava-tube caves in the Civil Defense Program.

Criteria for Using Caves as Shelters

Many factors must be considered in studying the suitability of the Hat Creek lava tubes as fallout shelters. Intense planning and preparation would be necessary to solve the many difficulties in just sustaining life in the caves, under bare survival conditions. Criteria for considering existing structures for use as fallout shelters are listed in California Disaster Office Letter No. 8, of the National Fallout Shelter Survey: accessibility, structural stability, shielding, space requirements, ventilation, and illumination. Additional factors are considered under habitability and survival.

*Civil Defense Coordinator, Shusta County.

Accessibility

Hat Creek Valley is about 1½ hours drive from Redding under ideal weather and highway conditions, by either U.S. Highway 299E or State Highway 44. Evacuation under potential panic conditions of the 45,000 who live within 15 miles of Redding would be a tremendous traffic control problem. The Shasta County Civil Defense Office is cooperating with state and local government agencies to estimate the time needed for evacuation of large numbers of vehicles over these highways, and to plan to solve potential problems. Evacuation by night or in stormy weather would need further special planning. Level parking space is abundant near Old Station, and nearby along State Highway 89.

Structural Stability

Although Letter No. 8 approves the structural stability of "natural caves or caverns" for shelters because they have stood for long periods, improvements would be needed for reasons of safety and comfort. Fallen rock would need to be removed, to gain space and improve access. Loose rocks or weak sections in the overhead would need support, particularly near entrances and caved places.

Shielding

For the tubes to be considered safe from fallout radiation, by common Civil Defense standards, the basalt roofs should be thick enough to reduce gamma radiation at least 1000 times. From its specific gravity of 2.25, Hat Creek basalt is determined to have about the same shielding factor as normal concrete. About 2 feet of Hat Creek basalt gives the required minimum absorption factor of 1000. The 11 to 22 foot thick roofs of the caves would reduce radiation to a thousandth or less, of that safe minimum.

Fallout would have to be prevented from washing from the ground surface into the caves as silt through the entrances, or as fine particles in water seeping through the ceiling. All cave openings would require effective shields to prevent rain from washing fallout in. Special air-tight closure would be needed in case of chemical or biological weapons.

Uncomfortably prophetic, this mushroom cloud was one of the results of the great eruption of Mount Lassen on May 22, 1915. The cloud was more than 7 miles high; this photograph was taken by B.F. Loomis, from Anderson, fifty miles away.

Quieter types of fissure flows from volcanic centers north of Mt. Lassen produced the lava tubes, now being considered as shelters.

Space Requirements

The space required per person depends on the amount of available ventilation: if 3 cubic feet of fresh air can be provided per minute per person, the factor is 10 square feet of floor space per person. If less fresh air is available, the factor is 500 cubic feet of space per person. Minimum storage and utility space required is 1 cubic foot per person, to be used for medical supplies, food and water, sanitation, fuel, clothing, communications, and emergency equipment. There should be 6½ feet of headroom for at least 50 percent of the people, and at least 4 feet for the rest.

On this basis, Subway Cave has room for at least 4000 people, and Christmas Tree Cave for at least 2000.

Ventilation

Ventilation is considered adequate if 3 cubic feet of fresh air can be provided per person per minute. Fans would help move fresh air into and through the caves; filters would be needed to remove fallout particles from outside air.

Subway Cave would have adequate ventilation if a 1-foot diameter ventilation hole were drilled at the north end of Caved Caverns, and another a few hundred feet north of the Cave In. Circulating fans would be needed at the entrances to the Mushroom, and to the Witch's Crown and Bigfoot Chamber.

Christmas Tree Cave would need a 1-foot ventilation hole in the extreme south chamber, and another midway between it and the cave opening.

Air temperature and humidity would need to be controlled. In winter, cold air settling in the tubes would need to be heated and circulated. In summer interior air might need cooling. Body heat would greatly increase temperature and humidity. Moisture may condense and freeze on the ceiling, or it may drip constantly from the many lava projections. Dehydration of human bodies may be a problem at times.

Each cave would need a lighting system capable of at least 2 foot-candles at floor level. Each tube would need at least one generator, with fuel, distribution system, repair equipment, and all necessary elements of a reliable, safe, power system. Air intake and exhaust systems of diesel or gas generators would be special problems. Whitewashing the dark tube walls would improve the efficiency of the lighting system. Entrances, emergency areas, and constricted places would need special lighting.

Habitability and Survival

To assure physical survival in the caves, other preparations are needed, including food and water supplies, radioactivity monitoring equipment, medical supplies and hospital space, sanitation and waste disposal, fuel supplies for generators and stoves, kitchen gear, emergency and survival equipment of all sorts, bedding and clothing, and shop and repair facilities.

Human factors require planning for emergency education, resistance to claustrophobia, recreation, communications both internal and external, spiritual needs, intelligent organization, and legal orderly conduct.

References

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NEW REDDING SHEET

The Redding Sheet of the Geologic Map of California is now available from the Division of Mines and Geology. The map indicates the areal extent of geologically distinguishable rock units (including the Nomlaki tuff) in the region delimited by Shelter Cove on the southwest, Arcata Bay on the northwest, Shasta Reservoir on the northeast, and Red Bluff on the southeast. The map was compiled by Rudolph G. Strand, with the assistance of Salem J. Rice, Philip A. Lydon, Quintin A. Aune, Melvin C. Stinson, and James R. Evans, who did some mapping to fill in unknown areas. Chief among the other contributors are William Porter Irwin and Donald Tatlock of the U.S. Geological Survey who in recent years have made a reconnaissance map of a vast area in the northwestern part of the state. In addition, many other geologists who have worked in the area provided information to help make this as reasonable a portrayal of the geology of the region as is now possible.

This map covers the Eel River Basin and the northern Sacramento Valley gas producing areas, the East and West Shasta copper-zinc mineralized areas, the Shasta-French Gulch gold producing areas, and several resort and timber regions. Geologically, there are still numerous undeciphered problems, some of which are obvious on the map.

You may obtain your copy of this attractive map (which is lithographed in color) from any of the offices of the Division of Mines and Geology or by sending $1.50 (plus 6¢ tax for California residents) to the Division at the Ferry Building, San Francisco 11, California. Uncolored copies of the map, suitable for special scientific undertakings, are available for 50¢ each.

R.G.S.

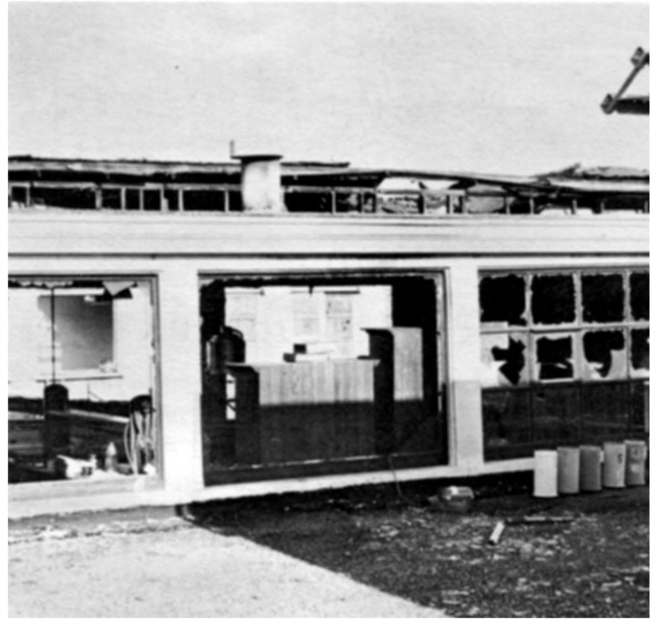
GEOCHEMIST ON DIVISION STAFF

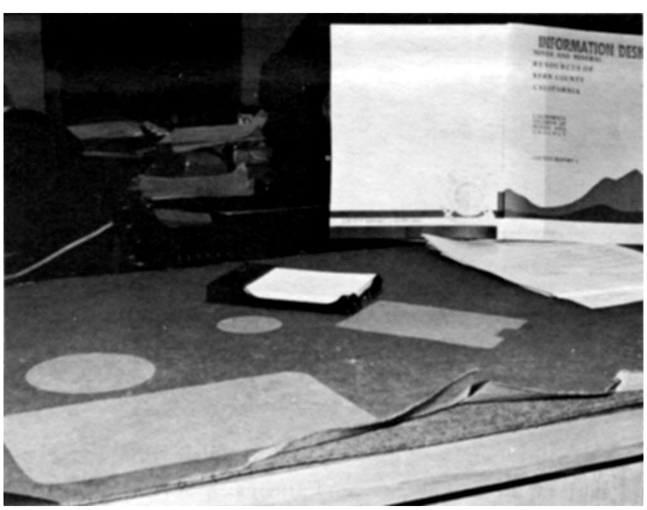
The geochemical research program of the Division has been considerably augmented by the addition of a new staff geochemist, Eugene B. Gross. Dr. Gross, who will be in charge of instrumentation, has had valuable experience with the Atomic Energy Commission, as well as in industry with Food Machinery and Chemical Corporation, where he conducted research utilizing X-ray equipment.

The arrival of Dr. Gross in February makes the complement of geochemists, now two, at two-thirds the presently needed level. Another research geochemist is expected to arrive in March.

OLD FERRY BUILDING AFIRE

On Friday, February 8, fire once again swept the historic Ferry Building. Once again, too, the Division of Mines and Geology was untouched by the fire (although we sustained considerable smoke damage). This was the second fire within a year. Most seriously damaged were the offices of the Division of Parole and Community Services, Department of Corrections, and the Port Authority's Testing Laboratory.





Above. View of the second floor offices of the Division of Parole and Community Services (in rear) and the testing laboratory of the Port Authority (in foreground).

Center. Interior of the testing laboratory, which was a nearly complete loss.

Left. Damage to the Division's offices was chiefly by grime and smoke. On the information counter, the patterns made by objects may be easily discerned on the smoke-blackened counter. The library was extensively smoked, as was the museum.

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NEW REPORT ON JOSHUA TREE MONUMENT

A new report on a part of a scenic area in the southern desert has just been released by the Division of Mines and Geology. Issued as Special Report 68, the new report is entitled "Igneous and metamorphic rocks of the western portion of Joshua Tree National Monument, Riverside and San Bernardino Counties, California". The author is John J.W. Rogers, now of the Department of Geology of Rice University.

Special Report 68 is priced at $1.00, plus tax. It is bound in a light blue paper cover, and includes a geologic map on a scale of about 4 miles = 1 inch in a pocket in the back.

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