Geology and Mineralogy of Lava Tube Caves in Medicine Lake Volcano, California

Bruce W. Rogers
Cave Research Foundation and U.S. Geological Survey
37899 Los Arboles Drive, Fremont, California 94536-6635

Patricia H. Rice
Cave Research Foundation and U.S. Geological Survey

Medicine Lake Volcano is a large shield volcano that lies in the northeast corner of California, just south of the California-Oregon border. This Pleistocene to Holocene volcano is located in the southeastern portion of the Cascade Geomorphic Province. The volcano has developed as a large shield over 33 kilometers in diameter which attains an elevation of 2,417 meters. The north slope of the mountain is covered with bunch grasses and sage at the lower elevations adjacent to highly alkaline Tule Lake. Further up slope a mixed sage and pinyon-juniper woodland is present while a ponderosa pine forest covers the upper third of the volcano. The southern slopes of the mountain are cloaked in mixed ponderosa and hardwood forest. Except for Medicine Lake, a caldera lake, and short-lived ephemeral streams, the volcano lacks permanent surface water. The eruptive rocks range in composition from basalt to rhyolite. More mafic flows and breccia comprise the bulk of the volcano with a thin covering of more silicic pumice, ash, and obsidian flows. The basaltic lavas have compositionally changed throughout their eruptive history such that the earliest lava is more silicic (approximately 53% SiO_2) and the latest more mafic (approximately 47% SiO_2). This results in lava fields which change composition along their length.

In a zone on both the northern and southern flanks at approximately 1,370 meters in elevation are many cinder and composite cones from which long, tube-bearing lava flows emanate. A wealth of volcanic features of special interest to speleologists and cavers are present in these areas. Many of the tube systems' roofs failed shortly after their draining. The resulting landforms can be divided into three types of collapse features: long, sharp-edged

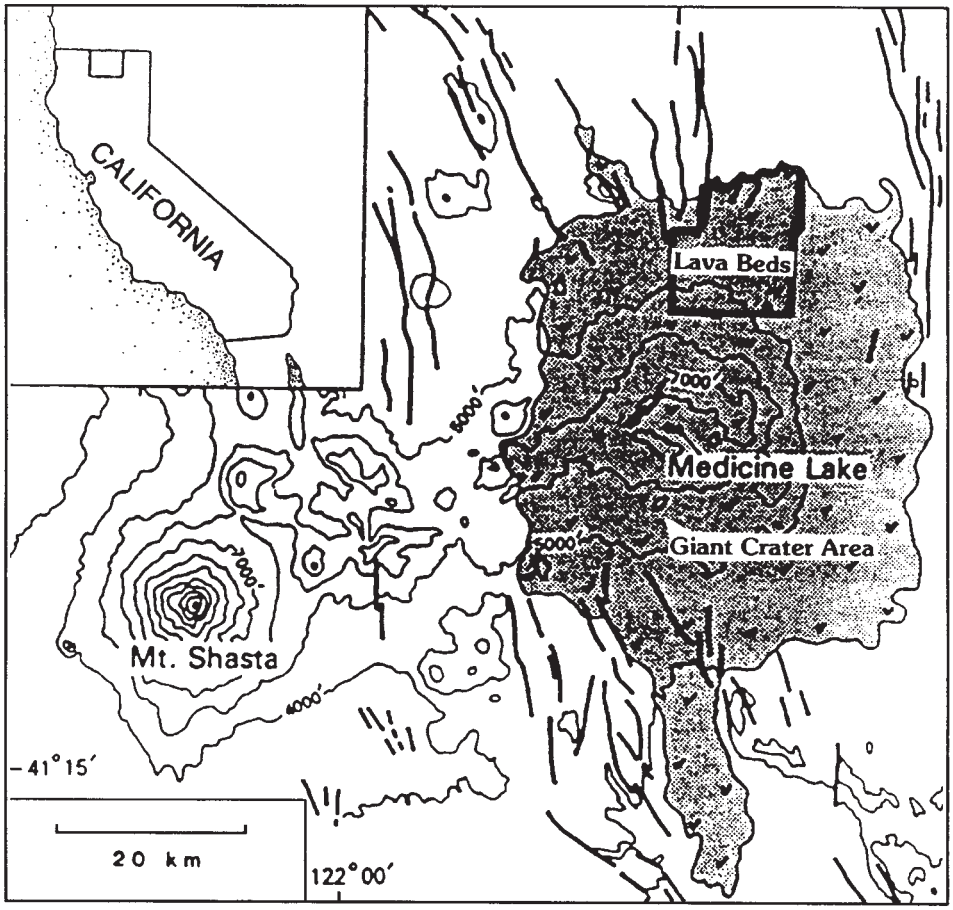

Figure 1—The location of Medicine Lake Volcano. (Figure modified from J. Donnelly-Nolan, 1987)

Figure 2—The profile of Medicine Lake volcano as seen from the margin of Tule Lake located at the north base of the volcano. Notice the many smaller cinder cones on the main shield of the volcano. These cinder cones mark the 1,370-meter-high zone of cave-bearing basaltic lava flows. Mt Shasta is visible in the upper right background.

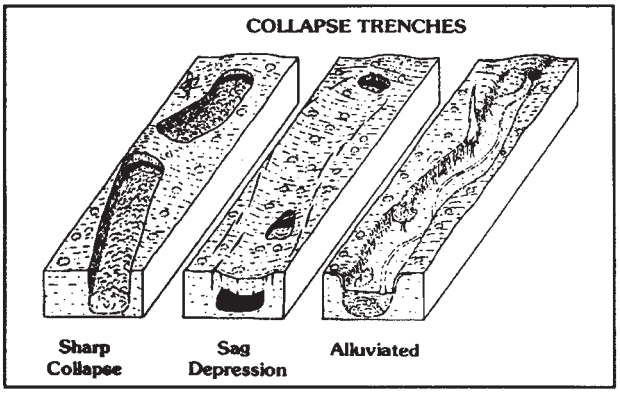

Figure 3—Of the three types of collapse trenches present on Medicine Lake volcano, sharp-edged trenches are most common.

collapse trenches; shallow sagged, partially collapsed, partly squeezed down tube-cum-trenches; and alluviated trenches. The sharp-edged trenches have clean walls and partially preserve cave passage profiles under overhanging trench edges and in reentrants. The shallow sagged trenches have not undergone chaotic collapse but have plastically sagged, either closing or leaving very low passages. Alluviated trenches are uncommon. These features have had their floors thinly veneered with sediments and subsequently vegetated. These trenches appear to be either sharp-edged or sagged in origin.

Spatter cones or rootless vents (hornitos) are present along the axes of portions of the tube systems. These hornitos range up to 20 meters in diameter and 10 meters high and, in some cases, allow access to otherwise sealed cave segments.

During the eruptions of the past 11,000 years, the pre-existing soil and basalts were covered with volcanic debris. Channels cut into this debris were quickly lined and extended upwards as overflowing lavas built up the edges of the channels. Some erosion downward into the lava deepened the channels and tubes. Succeeding overflows built up the channel until it finally roofed over. As the main flows ceased, minor lobes congealed, leaving flat floors and thin linings. Collapse in the tubes, soil formation at the ground surface, and minor speleothem deposition were the final modifications to the surviving tubes.

Approximately 18% of these tubes are preserved as accessible caves. The slope along the length of many of these caves commonly averages three degrees although sudden drops over the controlling underlying topography are present. Over 300 caves are known from these flows. The caves range from short grottos under ten meters long to braided systems nearly seven kilometers long. Passage

Figure 4—Scott Fee standing at the entrance to Skull Cave provides scale to the size of a typical sharp-edged collapse trench in Lava Beds National Monument. This trench leads into both Skull Cave, a deep ice cave with very large (18-meter diameter) passages and sub-fossil animal and Native American bones as well as into Inclined Cavern, a smaller (10-meter diameter) passages ice cave.

Figure 5—Big Bertha's Chimney, named after pioneer settler Bertha Heppe, leads into a short segment of lava tube at the vent through which the Valentine Cave andesitic basalt flow erupted.

sizes range from 0.25-meter high crawlways a meter wide to "dirigible passages" up to 25 meters in diameter. Vertical pits up to 20 meters deep are common where passages either stoped their way to the surface or collapse between overlying levels occurred. While breakdown is pervasive, small to large areas of original pahoehoe floors with differing surface textures are found in nearly every cave. Wall and roof decorations of lava glaze are very common even in the smallest of surface tubes. However, in many of the moderate- to large-sized caves, consecutive collapse of the linings have removed most of the tube's original glaze. Hardened cascades and lava falls are common in the caves as are frozen lava lakes and pools. Rafted blocks of lava and lava balls encased in the pahoehoe floor are scattered along the length of many tubes.

Fourteen minerals, mineraloids, and rocks identified by x-ray diffraction are found as speleothems in the tubes. The sources of these minerals are varied. The silicates appear to have been leached from the unstable pumice and glassy ashes. The calcite, gypsum, barite, and unnamed salts have drawn their carbonate and sulfate from the wind-blown dust derived from the largely carbonate lake margins. The oxide and hydroxide minerals (exclusive of ice) have been derived by weathering of the relatively deeper soils of the upper, well-watered and vegetated slopes of the volcano. Ice is present as permanent deposits in at least 20 caves and appears as seasonal decorations in a great number of caves. There is a rough zonation, controlled by elevation, of the secondary mineralization in the lava tubes. This zonation appears to follow the availability of ground water, soil composition, and vegetation patterns. On the flanks of the volcano the less mobile oxide, hydroxide, and miscellaneous "minerals" form in the caves higher on the volcano where soils are well developed and

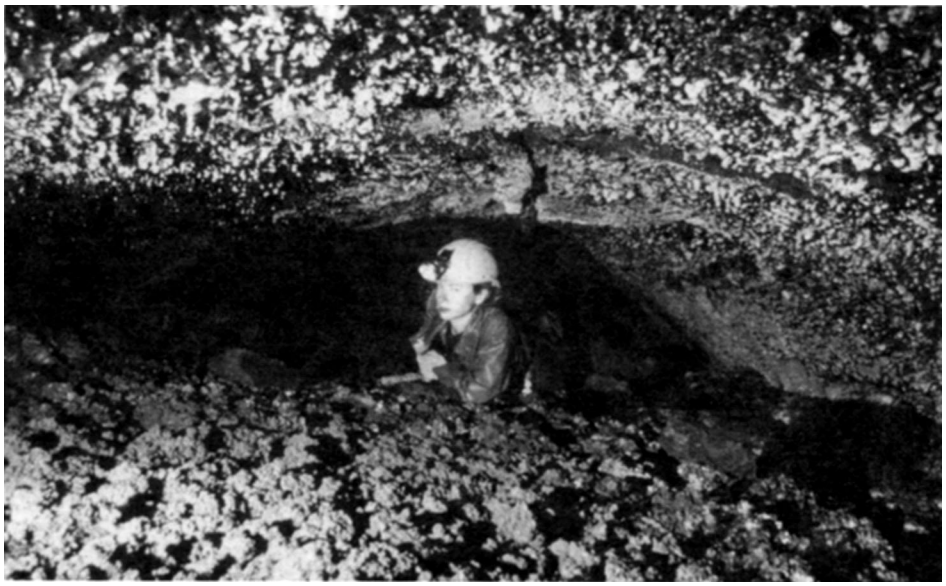

Figure 6—Charmaine Legg relaxes in a 0.6-meter-high crawl in Mammoth Cave. Note the near-aa textured cauliflower lava floor and sharks tooth lava stalactite ceiling, both of which make travel into these parts of the cave unpleasant.

Figure 7—A scanning electron microscope photograph of a moonmilk found in Catwalk Cave. The granular background is fine-grained calcite, calcium carbonate; the square tabular crystals in the foreground are gypsum, hydrous calcium sulfate; and the bladed crystals at the top are barite, barium sulphate. Scale bar at lower left is 20 microns—0.000,000,020 meter—long.

ground water abundant. The more mobile silicate, carbonate, and sulfate minerals are found further down slope in areas of thinner soils and less ground water. Ice and basalt speleothems are found throughout the elevational range of the caves studied. The minerals found inclued:

ice	H_2O	common, especially seasonally
goethite	$FeO \cdot (OH)$	rare
pyrolucite	MnO_2	rare
romanechite	$BaMn^{+2}Mn^{+4}{}_8O_{16}(OH)_4$	rare
gypsum	$CaSO_4 \cdot 2H_2O$	uncommon
barite	$BaSO_4$	rare
calcite	$CaCO_3$	very common
unnamed	$Na_2SO_3 \cdot 7H_2O$	rare
unnamed	$Na \cdot SO_4 \cdot CO_3 \cdot nH_2O$	rare
cristobalite	SiO_2	very common
silhydrite	$3SiO_2 \cdot H_2O$	rare
amorphous silica	SiO	moderately common
basalt and andesitic basalt		ubiquitous

Figure 8—Ice stalactites in Crystal Ice Cave in Lava Beds National Monument are comprised of 0.3-meter-long stacks of 2-centimeter-diameter hexagonal ice plates. Many other unusual ice speleothems are present in this ice cave. In some locations very finely powdered gypsum is found on the surface of ice stalagmites and floors. The powder has been literally squeezed out of the mineral-charged waters as the water froze.

Mineral Groups Found as Speleothems					
Stalactites	●		●	●	
Spathites			●		
Flowstone	●		●	●	●
Crusts	●	●		●	●
Coralloids	●		●		
Moonmilk		●			
	CO_3	SO_4	SiO_2	O_2	NO_3

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Figure 9—Typical eight-meter-diameter passage in Gelsies Grotto, an over-700-meter-long tube. Note extensive collapse masking original floor and large amounts of calcite and cristobalite speleothems on the walls. In another portion of this cave one can see where a later lava stream coursing through the cave heated, deformed, and finally eroded down nearly 1.5 meters into the solid basalt floor of the cave.

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