Although the cross section (Figure 3) shows segments of the tube still intact, an alternate possibility exists — the entire tube system may have collapsed. In that event, the tubes would consist of channels filled with the debris of the collapsed roofs. According to R. J. Deacon (Shannon and Wilson 1968), the "rubble-filled channels" beneath the hospital site were masked by undisturbed layers of ash and silt. This indicates that the roof of the two tubes at that location may have fallen in before the ash and silt were deposited. If this alternative is valid, it has important engineering implications: those structures such as Catlin Gabel School, that directly overlie the projected course of the tubes, would be in less danger of collapse.

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PROCESSES OF DEVELOPMENT OF LAVA TUBES AT MAUNA ULU, KILAUEA VOLCANO, HAWAII

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ABSTRACT

During the prolonged eruption of basaltic lava at Mauna Ulu from 1969 to 1974, many lava tubes developed. Conditions frequently allowed close and systematic observations, which greatly improved understanding of the processes involved.

A basic requirement for a lava tube to form is a prolonged flow at a steady rate, during which the flow becomes confined to a discrete channel. Chilling of the upper surface of the flow results in the development of thin, scum-like crust on the molten surface. Such crusts commonly adhere to the margins of the channel, and during extended flow, the crust grows outward from the margin across the flow surface. If the level of the surface remains constant, the crusts growing from opposite sides of the channel merge in the center. This initial roof is thin and weak, and either a rise or fall of the lava surface will cause it to break. But if the flow rate remains constant, continued cooling allows the crust to become thicker and stronger, and

Figure 1. Lava stream emerging from an earlier-formed tube and flowing toward the camera. A thin crust is accreting to both lateral margins of the stream and growing across the surface of the flowing lava. A few days later the crust had grown completely across the stream, forming a roof and creating a new lava tube. August, 1970.

Figure 2. Lava stream flowing from right to left, emerging from beneath a newly formed crust. On the right, the crust has been growing completely across the surface, and it is accreting downstream toward the left. Slender, flexible fingers of crust extend from the downstream edge; they gradually thicken and merge laterally and new fingers then develop along the advancing edge of the crust. The downstream growth rate may reach as much as several meters an hour. February 13, 1971.

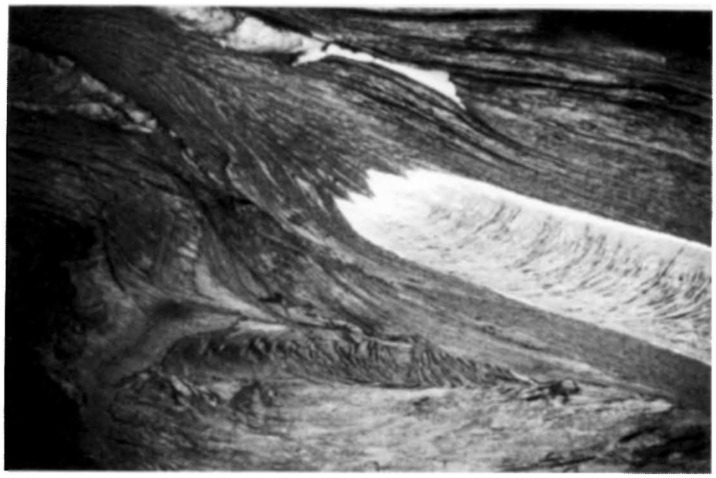

Figure 3. *Aerial view of a crust forming across a stream flowing from upper left to lower right. Crust is growing both laterally across the surface from the banks and downstream from the bridged crust. Open stream is about 4 meters wide. When rate of flow remains constant, the crust continues to thicken as solidifying lava accretes to the underside of the roof. The crust is soon strong enough to support itself if the stream drops to a lower level. It also thickens if new lava flows over its surface, as seen in the upper part of this view. If the rate of flow declines abruptly before the crust has strengthened, the roof collapses and the embryonic tube is destroyed. September 26, 1972.*

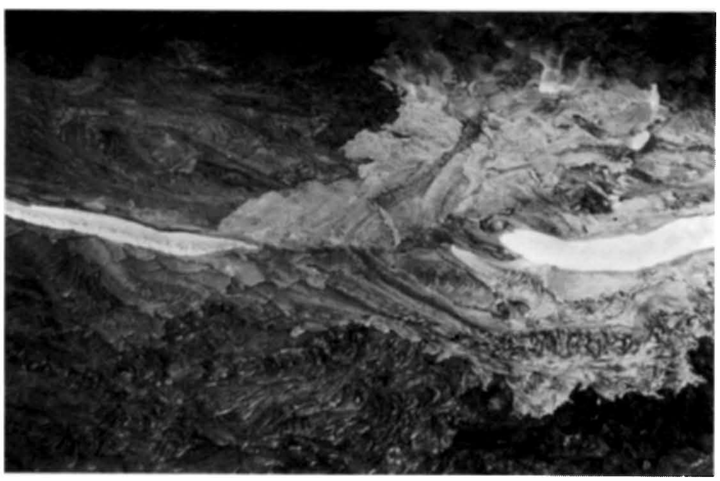

Figure 4. *Aerial view of a lava stream. flowing from left to right, bridged over by a roof in the center of the view to form a lava tube about 30 meters long. A "seam" marks the line along which the crusts form each bank joined together. Downstream from the tube, the stream divides into several branches, each of which is being crusted over where it emerges from beneath the roof. Upstream from the tube, a thin crust has developed and is floating along the central part of the stream as flexible "rafts." The open stream on the right is about 5 meters wide. R. I. Tilling, December 28, 1972.*

Figure 5. *A second process of roof development is illustrated here. Stream, moving from the left, has rafts of floating crust that have piled up against a constriction where the stream enters a roofed-over section. By this process, the roof is extended upstream. November 7, 1973.*

Figure 6. *A third process of lava tube development is shown here. A channelized stream may undergo occasional brief surges, and lava overtops the banks, quickly solidifying when the stream subsides. Each overflow leaves the bank slightly higher. In this view, successive small overflows have built inward-tapering levees about a meter in height; such levees may ultimately meet at the top to form a lava tube elevated above the adjacent land surface. March 5, 1974.*

Figure 7. With sustained flow, the stream within a lava tube may erode its bed to a lower level, leaving the roof unsupported. Thin or weak spots may collapse, forming skylights, which allow observations of the still-flowing lava stream. Here the surface of the active stream has dropped about 4 meters, and the thin edge of the remaining crust is about 15 cm thick. January 9, 1973.

***Figure 9.** The roof at this skylight is nearly 2 meters thick. Cooling of the molten lava as it passes by the skylight causes development of an incipient, floating crust, shown by slightly darker surface in the center of the stream. At the lower right, a crust is growing outward from the bank across the stream; it may ultimately form a complete roof across the stream beneath the skylight, forming a multi-level tube. R. L. Christianson, May 2, 1973.*

eventually it becomes strong enough to support itself. Many variations to this basic process may operate, such as bridging when floating crustal fragments are constricted. Partial collapse of roofs results in skylights, which permit observation of the flowing lava in the tube, further verifying the processes.

The roof serves as a heat insulation, and once the channel has been enclosed, the lava beneath retains its fluidity, allowing it to flow for long distances. The strong tendency for tubes to develop is a significant factor causing the gentle slopes of shield volcanoes.

***Figure 8.** View into skylight showing terraces on the wall marking levels of the surface of the stream as it dropped successively lower. Lava stalactites hang from the ceiling, formed when the incandescent coating of the tube interior achieved enough fluidity to flow. Tube diameter about 3 meters. September 11, 1972.*

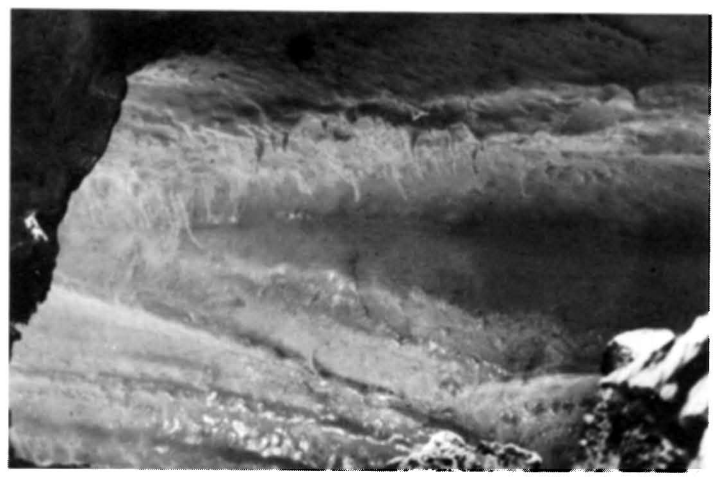

***Figure 10.** Lateral view through skylight into a tube with a sloping roof (see Fig. 6). Successive terrace levels are seen on the incandescent walls. Growth of stalactites was arrested because of cooler temperatures that resulted when the skylight formed, but some are bent toward the opening, evidently the result of hot air surging out of the opening while the stalactites were still pasty. Tube diameter about 2 meters. September 19, 1972.*

Photos by the author unless otherwise noted. (No paper received for publication)