Floor Modifications in Small Lava Tubes

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Abstract

Molten lavas are thixitropic liquids: they have a lower viscosity while flowing than they have when stationary. This characteristic affects the passage shape and the floor structure of the resultant tube. The viscosity effect is also responsible for the existence of a relationship between the slope of the ground and the depth of the lava required to flow over it.

Numerous studies by Shaw *et al.* (1968, *et seq.*) on Hawaiian lavas have demonstrated that lava viscosity thins with increased motion. The highest viscosity is demonstrated by lavas that are not in motion. This assumes, of course, that other features of the flow such as temperature and dissolved gas content are held constant. A fluid with this quality of flow-related thinning is called a "thixitropic liquid." Other names applied to these liquids are "non-Newtonian fluids" and liquids that behave like Bingham bodies. The details of thixitropic fluids as applied to lava flows was investigated by Hulme (1974).

Another way of describing this peculiar behavior is to say that as lava moves faster, it becomes more fluid, which enables it to move faster, which makes it more fluid, which enables it. . . Of course there is a limit to all this. The effect is most pronounced in slow speed and stationary fluid.

Two interesting characteristics of this thixitropic behavior are exhibited in lava flows. One is that once stopped, the lava can remain molten without starting to flow again as long as it doesn't cool and crystallize. If a change comes, such as a surge of lava from up slope, the lava can remobilize and start flowing again. The other is that there is a critical depth-to-width-to-slope relationship that determines whether or not the lava will flow. Hulme derives ratios between flow width, flow depth, and levee width and relates them to the slope of the land and the physical characteristics of the lava flow.

One obvious relationship between the slope of the land and the lava flowing over it is that when the lava flows over a section of steep slope it will flow faster and become thinner. The thickness of the flow will become less and the cross section of the conduit necessary to transport a given rate of flow will also become less. The converse is also true. When the slope is flatter, the flow will be (must be) deeper in order to maintain motion. This is a more subtle point, but is borne out by field observations in Hawaii.

It was stated earlier that liquid lava can stop flowing and set up even though it has not crystallized into a solid. This is the phenomenon that gives rise to the original channel levee development. The flow moves over the land and to a lesser degree spreads laterally. As was mentioned before, there is a critical thickness required for a thixitropic fluid to flow down a slope. The flow thins in the direction of movement unless there is a replacement of lava from upstream. The lava at the sides of the flow will thus move until it becomes too thin for movement. Then it will pause and gel. The lava behind the levee will pile up until it is thick enough to move again. This required thickness will be least in the steepest down slope direction. The lateral levees will remain stationary as long as the lava volume doesn't increase and slowly crystallize. Surges or decreases in the quantity of lava being discharged that come after the levees have stabilized take the form of thin overflow layers that build up the levees or of lower ledge levees that form inside of the first-formed levees.

Small surface tubes often form near the front of the flow, branching and rejoining, a behavior that is called "anastomosing." This spreads lava out over the width of the flow front. These surface distribution tubes often have a flattened, half-ellipse cross section. They are comparatively small and shallow, and are often near the lower depth limits that permit lava flow. Their "distributiveness" results from the small quantity of lava that produces them. The relatively short duration doesn't lead to depth, a significantly flow-modified shape, or the extensive lining and overflow features that are associated with major conduits.

The surface tube often has a smooth floor and is marked by solidified flow features along the floor and lower parts of the walls. As the lava supply dwindles, the level frequently fluctuates with minor surges and recessions. These fluctuations leave ridges of accretion (lava buildup) along the walls. When the flow falls below the critical thickness necessary for motion, the flowing slows and stops. This phenomenon is related to the thixitropic behavior of the lava and is not a primary response to the cooling and crystallization of the lava. The size of the lava conduit is related to the characteristics of the lava and the slope that it travels on. The depth of the liquid lava within the conduit when flow ceases is also a factor of the slope.

Lava flowing on a very flat slope must (according to Hulme's width-depth-slope interrelationship) be relatively thick in order to maintain motion. The roof layer of a surface tube formed in such a flow will often be about 30 centimeters thick. The flow through the conduit will be slow and the cross section of such a tube will often be significantly wider than high, with ratios of 3:1 to 4:1 occurring commonly. The appearance of the cross section is a little like the top half of an ellipse.

Such a slow-flowing surface tube often shows a strong tendency towards stream braiding. If the braids are short and close together, pillars form in the middle of the passage. Sometimes the only indication of a braid that didn't quite develop is a lowered ceiling in the middle of the passage.

Flow on a gentle slope requires a deep layer of lava. When the supply dwindles and the level of lava in one of these tubes starts to decrease, it can easily drop below the critical value needed to maintain flow and lowered viscosity. There will still be molten lava on the floor of the tube, possibly even to a depth of a few meters – it just won't be flowing. This phenomenon can be seen in the deep contraction cracks on the floors of some of these tubes (3 centimeters wide by 75 centimeters deep). Another indication is that a cross section through the tube looks like an ellipse that was partially filled from the bottom, often with acute angles between the floor and walls. In the Trout Lake cave area in Washington, Resurrection Cave and many of the small caves in the eastern end of the valley, such as Masseys Barn Cave, are very clear example of these cave-forming dynamics.

A situation that is often found in small anastomosing caves on steeper slopes is that some passages are much less sloped than others. The situation described above also applies here; small overflow tubes and side branches will often be partially filled with the remnant of their flows. Although connected to the main conduit, they fail to drain fully because the thixitropic nature of liquid lava means that the shallow overflows and side branches gel more easily.

The gradation between surface (distribution) tube and large main (primary) conduit is gradual and reflects the different function of each. At the flow front, lava tends to push out in all directions, feeding a fan-shaped lobe. The conduit tends to form a wide, shallow shape and the depth of the lava below the conduit is thin and close to the minimum necessary to enable flow. As the front of the flow passes downhill, the side branches of the lobe stop moving and eventually crystallize, while the interior shape of the tube becomes more regular as the thickness of the flow increases.

While the walls are largely gelled motionless, surges will easily remobilize portions of the walls making branching passages easier. Once the walls crystallize, surges will tend to coat the walls with linings and cover the cave roof with overflows. These activities lead to the formation of a more regular passage shape. All of the internal modification factors combined will result in a passage that is proportioned 1:1 or often even higher than it is wide.

A seal and plug in a lava conduit can form in several ways. After the cave-forming flow stops, extensive cooling of the ceiling occurs. The development of contraction cracks in the solidified basalt of the ceiling may cause a collapse which blocks the lava conduit. The connection between New Cave and Wildcat Cave, and between Jug Cave and Mikes Caves, are the result of such plugs. The last dregs of lava which move down the tube pond up behind this blockage. A little bit of lava may still flow through the dam, as can be seen in Lava Brook Cave at Lava Beds National Monument in California.

Another scenario is responsible for the formation of a true lava siphon. As the lava flows over a short level place, the channel conforms to the ground contours. After roof formation is completed, some portions of the roof thicken more than others and jut lower over the lava stream. A lowering in the flow level occurs during the late eruptive stages. If the depth-to-flow ratio passes the critical depth for which motion takes place, the lava stops and gels. Very often the floor where this occurs in a lava tube will show the very deep, narrow contraction cracks characteristic of the massive cooling of a one-meter or more thickness of lava. New Cave, just down-slope from the middle entrance, shows a good floor which, if a little higher, would make a great siphon seal. The lower end of JaR Cave at Trout Lake is probably a true siphon, though no caver skinny enough has been found to verify this. If there is some movement of lava through the siphon before full solidification sets in, the result will be ripples of crystallized scum building up in the lake. They soon harden into a passage floor that completely blocks the cave. These features are sometimes referred to as "festoons" and can be seen at the lower ends of Cheese Cave and Davids Den at Trout Lake, Washington.

A rare feature resulting from the thixitropic nature of molten lava can be seen in Wildcat Cave at Trout Lake. This cave exhibits marked shelves along the walls. Wide, deep (3×50 centimeters) contraction cracks indicate that these shelves cooled from one homogeneous unit and are not composed of consecutively built up linings. The surface of the shelf is rough, with a texture that is easily distinguished from the adjacent upper walls. The space in the center of the passage, between the shelves, consists of a vertically sided trench up to three meters deep. The width of the shelves decreases down slope until they become indistinguishable. The tube itself also decreases in size down slope and ends in a lava plug.

The shelves formed when the flow in the tube was halted for a period of time near the end of the eruption, possibly by a temporary breakdown blockage at the cave's lower end. The lava level during the hiatus was not high enough to fill Wildcat Cave completely, hence the space between the top of the shelves and the ceiling of the tube. The thixitropic lava stiffened without solidifying completely. When the flow began again. The lava in the center mobilized first and cut a deep vertical channel in the mass that had gelled during the period of no flow. The concurrent seal that developed between Wildcat and New Caves held while the lava drained away; no new lava came from up cave to affect the final flow. The period of stagnation was long enough, and the slope shallow enough, that the shelves attained enough rigidity to retain structural identity when the passage center drained away. The emplacement of the shelves and lava seals mark the final motion of the lava in this portion of the lava flow.

The thixitropic nature of lava (that property that makes it more fluid while flowing and thicker while stationary) can thus be seen to be an important factor in the explanation of why surface distribution tubes have wide passages, low ceilings, and flat floors, and how such flow-thinning behavior explains some of the internal features encountered in lava tubes.