

GEOLOGY OF YOUNG'S CAVE, HORSE LAVATUBE SYSTEM, BEND, OREGON: IMPLICATIONS FOR LUNAR BASE SITING; Stephen L. Gillett, Mackay School of Mines, University of Nevada, Reno, NV 89557; Lawrence A. Chitwood, Deschutes National Forest, US Forest Service, Bend, OR 97701; Cheryl York, Tom Billings, & Bryce Walden, Oregon L-5 Society, Inc., Oregon City, OR 97045-0007.

Description of Geology

The Young's Cave System, near Bend, Oregon, is one of many lava tubes in the Bend area developed in highly fluid basalts erupted on the flanks of Newberry Volcano. It is in the distal, northernmost exposed part of the Horse Lava Tube system, which consists of discontinuous aligned, partly anastomosing lavatube segments that reflect the partly choked distributary system of a single northward-draining flow (1), the Horse Flow. We report a preliminary geologic characterization of Young's Cave for lunar base siting studies.

The Horse Flow is mapped as Pleistocene (2), based on regional stratigraphic relations rather than radiometric ages. On geomorphologic grounds the lavas are obviously relatively young because the topography is highly immature, with many closed basins and no well-developed through-going drainages. The axis of the Horse System also forms a vague topographic high.

Field relations show that the lavatube system had a protracted history of multiple lava flows, roof breakdown, and later re-roofing and re-veneering. "Cupolas", local high areas, reflect early, partial collapse of ceiling layers and are generally re-veneered with fluid lava. In other places, where later collapse has exposed ceiling layers, clasts with early, hardened ceiling veneer have been re-incorporated into new roof layers. The lavatube system is partly plugged by a relatively late flow that did not drain fully, and so caused the present discontinuous nature of the system, with local open areas separated by choked passages.

Roof breakdown is mostly old except very near the cave entrances, where it is ongoing thru frost riving. Modern roof breakdown far from the entrances is rare and probably triggered by occasional large earthquakes. Most breakdown far from the cave entrances is demonstrably very early, occurring before the final flow that partly filled the lavatube system, as distinctive clasts from the ceiling have been buried or swept away by this flow. Moreover, locally lava drips originated within the exposed layers and ran down over the broken surfaces, suggesting that some interstitial melt was still present in the tube walls when the breakdown occurred.

The Horse Flow may be less than a few kilometers wide. Its lateral extent is difficult to determine because: (i) Basalt flows in the area generally cannot be distinguished routinely in the field, as they have very similar compositions and textures and the textures vary significantly within a single flow. (ii) Different age lavas overlap irregularly, and the lower and upper ends of the Horse Flow apparently are covered by younger lavas (1). (iii) The flows are not topographically expressed consistently due to "lava inflation" as discussed below.

In highly fluid flows spreading slowly over a relatively flat area, the flow front advances as a set of thin pahoehoe lobes, which are fed internally by small tubes within the chilled outer skin. Intermittently, the lobes will stop advancing because they have spread out enough to cool. Further injection of lava then merely inflates the flow behind, such that several meters of relief can be generated. If enough lava is injected, the inflated flow will eventually rupture, and a new cycle of spreading and cooling can occur. Obviously, this process leads to large lateral variations in thickness in the same lava flow, so that lateral distinction of flows is difficult; indeed, multiple flow fronts can result from a single flow, as the flow inflates, bursts out, spreads out over a new area, and inflates again.

Lavas inflating has been observed in the distal parts of modern basalt flows from Kilauea on nearly flat surfaces (3). The flow front advances slowly, on the order of 1-10 m/hr, and electrical conductivity surveys on the flow show that the small feeder tubes under the initially separate advancing lobes coalesce behind the flow front to form the main lavatube(s) under the inflated surface (4). These tubes commonly anastomose, and are also at least in part hydrodynamically maintained. Later draining of such lavatubes, so that they can be preserved as subsurface voids, is probably uncommon; it would require that the advancing lobes be breached without a major injection of new fluid lava. Breaching of the flow front by its dropping over a topographic break might be one way to drain such tubes.

Thus, such lavatubes do not form by roofing over of an originally open channel, the classical

mechanism of lavatube formation. This alternative mechanism probably accounts for lavatubes formed on very low slopes ($< 2^\circ$). Hence the lavatubes in the Horse Flow probably also formed in the way, as they are anastomosing, poorly drained, and the Horse Flow was erupted over a low gradient [$\sim 0.5^\circ$; (1)]. Moreover, if draining of such lavatubes is relatively uncommon, the absence of extensive lavatubes in the adjacent flows is easy to explain.

The lava is highly vesicular, olivine-bearing diktytaxitic basalt, with a "jackstraw" texture of $\sim 70\%$ plagioclase laths with augite and occasional olivine phenocrysts in a glassy matrix with abundant intracrystal voids. For this reason the lavas are relatively permeable. This texture probably results from vapor exsolution in residual melt in the inflated areas.

Sediment infill in Young's Cave is concentrated near the entrances and is nearly all reworked Mazama tephra that probably was moved episodically in rare but large local floods. The sediment grains are subangular but encrusted with very fine authigenic crystals from chemical weathering; the sediment is thus rounder but dustier than lunar fines.

Implications for Lunar Base Development

The silica undersaturation accounts for the fluidity of the basalt, but its volatile-rich nature also contributes. As lava tubes form only in highly fluid lava, this suggests lavatubes may be rarer on airless bodies. Moreover, for inflated lavas to form, the rate of eruption must be low enough that the flow lobes advance slowly. However, a more important constraint in lavatube formation appears to be the circumstances that allow the lava to drain to leave a void. Again, the Kilauea studies suggest that lavatubes are extremely common in basalt flows, but their draining is relatively rare; note that even the Horse System itself is only partly drained.

Drainage seems to require an average slope of at least 0.5° , and the volume of flow must not be so large the distal end becomes unable to drain thru ponding in a local sump. Lavatubes formed on slightly steeper slopes by the roofing over of an initially open channel, the classic mechanism, also seem more likely to drain than those, like the Horse System, formed by lava inflation on nearly flat surfaces. Hence, on the Moon, away from obvious exploration targets like apparently uncollapsed rilles, low topographic highs on the margins of the maria, which apparently reflect volcanic centers, are probably better exploration targets than the middle of the maria themselves.

Internally lavatubes are not simple, straight cylinders. They are sinuous and do not have constant cross sections nor aspect ratios, but vary greatly laterally in both height and width. For example, the largest passage in Young's Cave is about 6 m across by 5 m high by 60 m long, but elsewhere passages are choked by undrained lava to clearances of centimeters. Talus on the cave floor, from ceiling breakdown, must also be accounted for in any units intended for installation in the tube. The lavatubes may anastomose, however, which could provide more flexibility in the installation.

Once formed, the lavatube is extremely strong. Field relations indicate that most breakdown occurs when the tube is still active, except in the immediate vicinity of an entrance where frost riving is occurring. In the absence of such weathering, the cave should last indefinitely; on the Moon, for example, the only mechanism for destroying a lavatube appears to be direct impact. Such strength and longevity are obviously highly desirable for a lunar base.

Although further work is required to fully characterize the geology of Young's Cave lavatube, it clearly is a useful model for lunar base siting investigations. Further work should include geophysical surveys to test techniques for locating buried lavatubes, and a paleomagnetic reconnaissance to identify separate flow units. The mechanism of formation of lavatubes in inflated lava flows also merits further investigation.

References: (1) Greeley, R., Oregon Dept. Geology Mineral Industries Bull., 71, 1971. (2) Peterson, N.V., E.A. Groh, E.M. Taylor, & D.E. Stensland, Oregon Dept. Geology Mineral Industries Bull., 89, 1976. (3) Kauahikaua, J., T. Moulds, & K. Hon, Eos, 71, 1711, 1990. (4) Jackson, D.B., M.K.G. Hort, K. Hon, & J. Kauahikaua, Eos, 68, 1543, 1987.