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TUBULAR LAVA STALACTITES AND OTHER RELATED SEGREGATIONS

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Tubular lava stalactites are found in many lava tubes. Field observations, sample analysis, and comparative studies indicate that these are segregations extruded during cooling from partially crystallized lava at about 1,070° to 1,000°C. Retrograde boiling within the lava creates a vuggy fabric and provides a mechanism to expel the interstitial liquid. In addition to tubular lava stalactites, a variety of other lava formations can also result.

The study sites for this paper are four lava tubes totaling approximately 71 km of mapped passages on Kilauea Volcano, Hawaii (Fig. 1). Here, as in other well preserved lava tubes that we investigated in Hawaii and the western United States, interior surfaces are commonly coated with "a thin, smooth, vitreous surface" known as glaze (Larson 1993). This is underlain in places by a variable layer of dark rock, on either broken or smooth surfaces. Where thick, the dark deposits are usually associated with slender vermiform lava stalactites. Larson (1993) described these as follows:

"A tubular stalactite [is] composed of lava. Most are slightly and uniformly tapered. Their diameter, averages about .7 cm and often decreases slightly toward the tip, but extremes from .4 to 1 cm have been noted. Lengths range from the perceptible to a meter and more. The tip may be hemispherical, or open for a considerable distance, but the interior is usually an entrainment of elongated vesicles and septa, the outer surface may be macrocrystalline and partially or completely marked with shallow annular grooves thought to be growth increments. They often serve as conduits for considerable quantities of fluid lava; stalagmites of 100 times the volume of corresponding tubular stalactites are not uncommon.

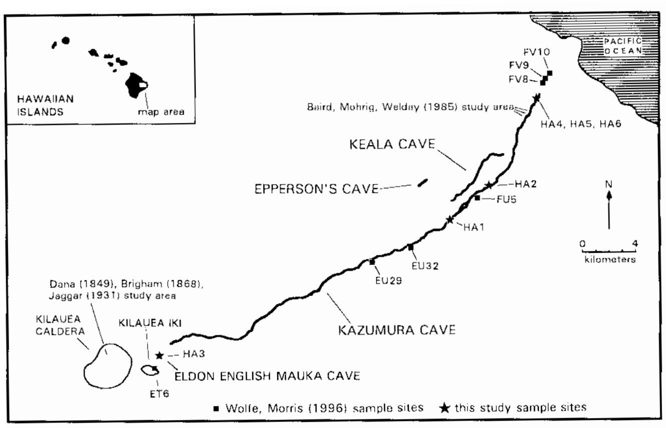


Figure 1. Study area showing sample sites. Keala from S. Kempe, (pers. comm.). Eppersons from W.R. Halliday (pers. comm.). Kazumura and Eldon English Mauka Caves after Hawaii Speleological Survey (NSS) files. Bulk rock samples from Wolfe and Morris (1996).

Figure 2. Runners and eccentric tubular lava stalactites, Eppersons Cave. Photo by K. Allred.

Frequently occurring in combination with lava helictites, they may be crooked, straight, branching, botryoidal, deflected, twisted, even deflated, or combinations of the above."

Previous investigators have theorized that these stalactites originated from (1) water vapor (Dana 1849; Brigham 1868; Dana 1889); (2) remelt (Jaggar 1931; Hjelmqvist 1932; Perret 1950; McClain 1974; Baird, Mohrig & Welday, 1985); and (3) other means (Williams 1923; Harter 1993; Favre 1993; Ogawa 1993; Allred 1994).

Some tubular lava stalactites and related lava formations clearly reveal that their fluids originated from within the rock itself. Most tubular lava stalactites that we found tended to be most eccentric and kinky nearest their ends (Fig. 2 & 3). Others had formed only as an incipient coralloidal shape (Halliday 1994). Tubular lava stalactites are called runners where they lie along a surface (Larson 1993). If runners flow down a tubular lava stalactite, the original free-dripping part can be identified by its horizontal grooves (growth rings).

Inasmuch as less dripping seems to have occurred in eccentric stalactites, matching eccentric stalagmites are not common. The droplets of the stalagmites tend to be more runny at the bases where they drained first (Fig. 3). The stalagmites were usually deposited after the lava stream had stopped moving (Fig. 4). Rarely, a line of driblets has fallen on a slowly

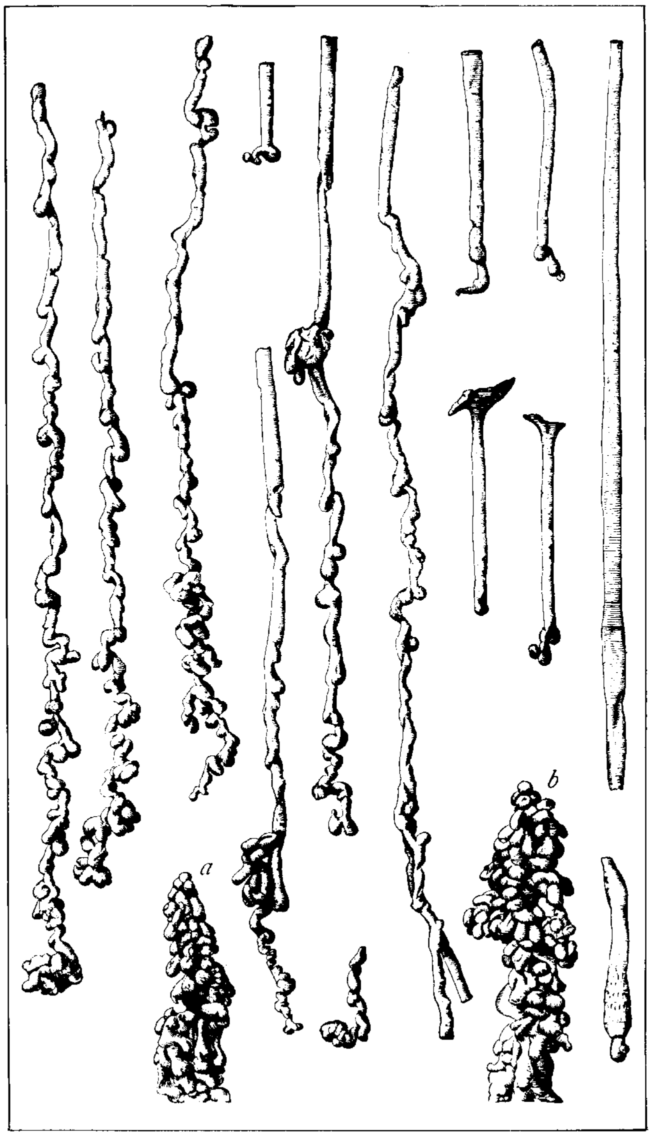


Figure 3. Tubular lava stalactites and lava stalagmites thought to be from Kaumana Cave near Hilo, Hawaii (Dana 1889). The lower ends of the stalactites tend to be more eccentric. As is typical, stalagmites show signs of more fluidity nearer their bottoms.

Figure 4. Tubular lava stalactite and lava stalagmites, Eppersons Cave. Photo by W.R. Halliday.

moving floor before a stalagmite was finally formed.

Other kinds of lava formations result from extrusions similar to those described above. Dripped "lava roses" (Larson 1993) can form by falling masses and sheets of lava originating from within ceilings. "Miniature volcanoes" (Jaggar 1931), or "small spatter cone[s]" (McClain 1974) were forced upward from ledges or floors. Those we observed had rounded caps (Fig. 5) and runners around their robust perimeters. These stalagmite-like forms may be classified as a form of "squeeze-up" as described by Larson (1993). Lava blisters are associated with some tubular stalactites and the squeeze-ups. Jaggar (1931) described "barnacle stalactites". We found these stretched, grooved, barnacle-like forms associated with tubular lava stalactites behind slumped ceiling linings (Fig. 6). They are also common around contracted perimeters of subsided plunge pools.

Unlike tubular lava stalactites, tapered "shark tooth" or "teat" stalactites (Larson 1993) grow where fluctuating lava adheres to ceilings (Fig. 7). As a result, these pendants and the surfaces between them are typically veneered with subsequent coatings and are, therefore, similar in composition to typical lava tube linings (stratified coats from lava flowing in the tube).

METHODS

Some tubular lava stalactite and ceiling lining samples were crushed and then tested for grain density using kerosene as a displacement medium. Eight thin sections were made of stalactite and ceiling lining samples, including one shark tooth stalactite. X-ray analyses for modal composition were done on a Philips X-ray diffractometer. Chemical analyses of 69 elements were made of a group of small tubular lava stalactites

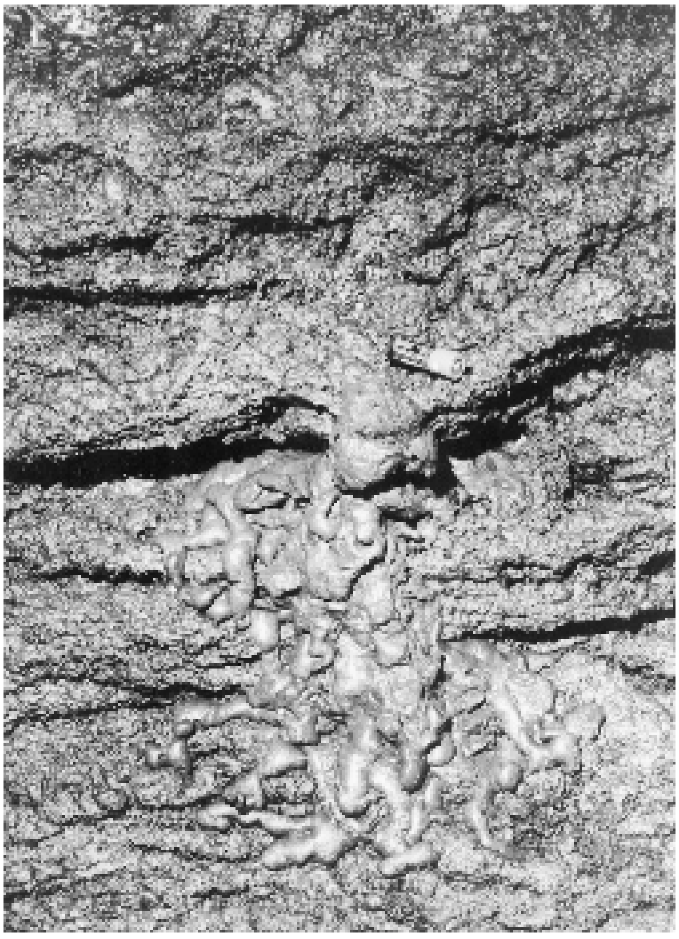
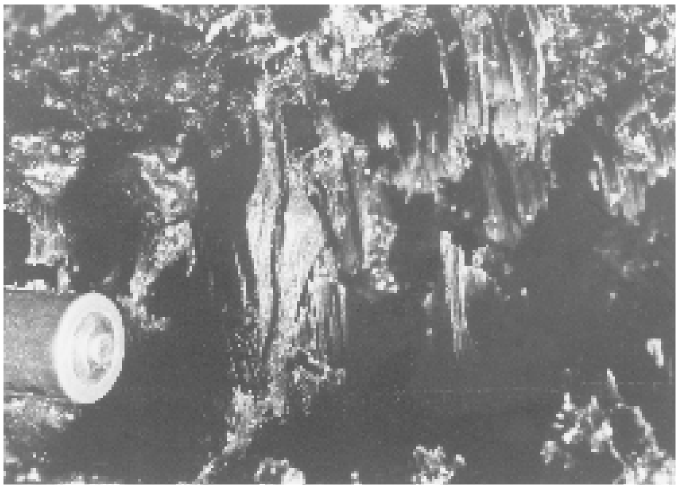


Figure 5 (above). Squeeze-up, Keala Cave. This erupted lava is suspected of being extruded in a similar fashion to tubular lava stalactites. The battery above the rounded cap is 5 cm long. Photo by C. Allred.

Figure 6 (below). Barnacle-like stretched lava, Kazumura Cave. Lava forming these features was extruded as the crack widened. If the lower part falls away, only the "stalactite" portion remains. The battery end is 14 mm in diameter. Photo by C. Allred.



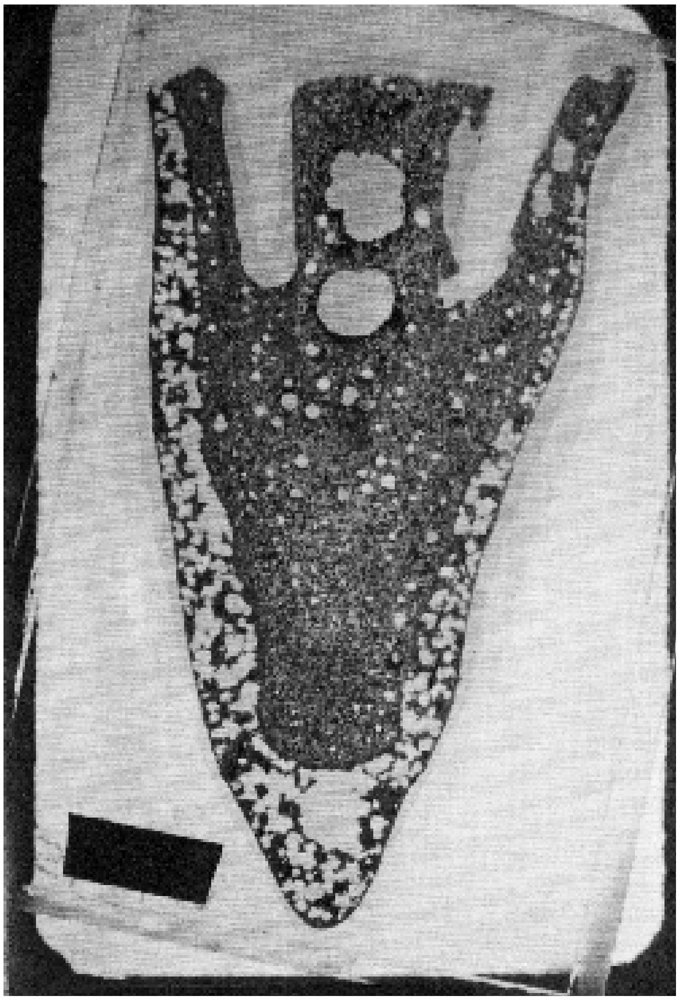


Figure 7. The HA1 shark tooth stalactite thin section. Eight linings are visible with magnification. The light voids are vesicles. The sample is 66 mm long. Photo by M. Palmer.

and the parent lining 1 to 3 cm above the stalactites. This was done primarily by ICP-AES (inductively coupled plasma atomic emission spectrometry), INAA (instrumental neutron activation analysis), ICP/MS (inductively coupled plasma-mass spectrometry), and XRF (X-ray fluorescence spectroscopy).

Cave observations of 1995 and 1996 were correlated with paraffin models used to simulate tubular lava stalactite growth. A caldron of liquid paraffin drained through a coarse filter, valve, and tube, into a small cooling reservoir. It then seeped through a sponge filter and out a final tube. The paraffin temperature was monitored with thermometers in both containers.

DISCUSSION

The extreme temperature of active lava tubes makes direct observation of forming tubular lava stalactites difficult, if not impossible. Hon (pers. comm. 1996) reported seeing a slowly dripping tubular stalactite from the vantage point of a nearby skylight, but we are still forced to puzzle out their origins by studying cooled lava tubes.

CONCEPTS OF FILTER PRESSED SEGREGATION

Wright and Okamura (1977) explained that lava can "segregate" from a partially crystallized melt at temperatures between 1,070° and 1,030°C. This results in veins of "relatively coarse grained, glassy, vesicular rock" differing in composition from the main body of lava. This process is called filter pressed segregation, and occurs in lava lakes of Kilauea Volcano. They describe it as follows:

"The crystal framework of the crust behaves as a filter, through which the liquid fraction moves into the open fracture. The efficiency of the filtration process is variable. Some segregations carry in crystals, so that the bulk composition of the segregation does not lie on the liquid line of descent for the lake as a whole, whereas other segregations are virtually free of early-formed crystals".

Wright and Helz (1987) concluded that highly differentiated segregations can occur in contraction cracks of these lakes between temperatures of 1,060° and 1,000°C, even when interstitial liquid equals 10% or less. The entry into the cracks was inferred to be gas-driven.

We submit that tubular lava stalactites and other related forms are segregations extruded by expanding gas into cave passages. Like the cracks in the cooling lava lakes of Kilauea, some open lava tube contraction cracks have been injected with interstitial liquid from both opposing surfaces after they split apart. This material did not come from flowing parent lava of the lava tube. Where cracks were widening during the extrusion, stretched barnacle-like forms grew (Fig. 6). It is important to note that the majority of lava tube cracks lack segregations, because of improper conditions, or they may have opened nearer to or below the solidus, given as 980°C by Wright and Okamura (1977). Not all extrusive phenomena are filter pressed. For example, settling of crusts may extrude some parent lava as squeeze-ups.

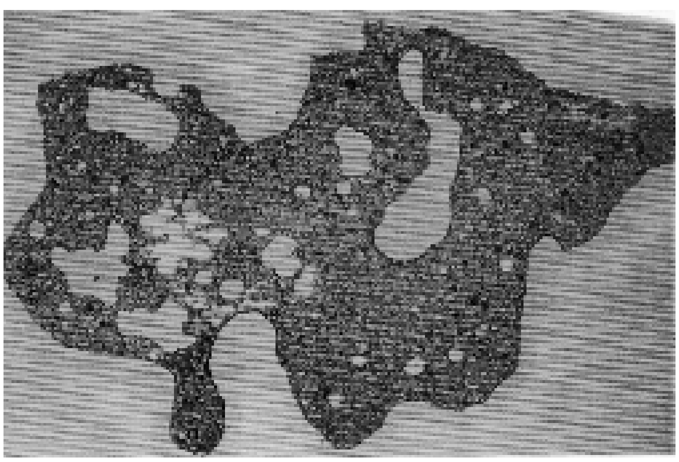


Figure 8. Vuggy fabric in HA2 lining above a small darker tubular lava stalactite. The stalactite is 8 mm long. Photo by M. Palmer.

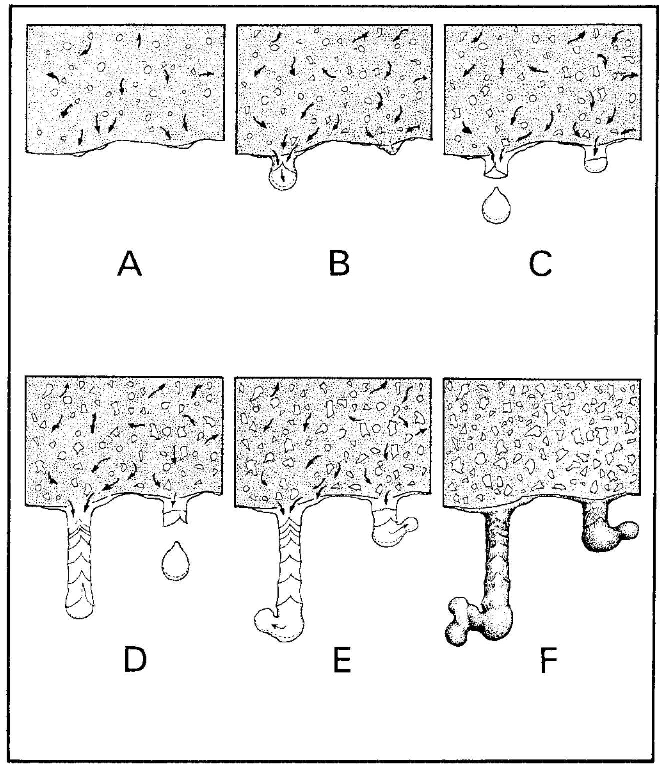


Figure 9. Proposed extrusion of tubular lava stalactites. A. Retrograde boiling in the lining creates vugs and begins extruding a thin discontinuous layer of residual melt. B. Continued residual outpourings collect in some discrete points. C. Incipient tubular shapes become more apparent, and vugs continue to form in the lining. D. Continued addition of drip segments creates growth rings. Splitting of the newest skin is perpetuated to additional segments as new driblets emerge. E. Cooling promotes crystallization of the bottom part of emerging driblets, forcing the liquid to the side or upward into eccentric shapes. Vesicle surfaces have become honeycombed by vuggy fabric. F. Cooled stalactites.

SEGREGATION EMERGENCE

Why and how did the lava tube segregation extrusions occur only after the lava had reached an advanced stage of crystallization? Rounded bubbles, or vesicles, are formed from volatile exsolution at a time when only a small percentage of lava has crystallized. When 50 to 55% of lava crystallizes at about 1070° to 1065°C, it ceases to flow (Wright & Okamura 1977; Peck 1978). This transition is called the crust-melt interface. With more progressed crystallization, interstitial liquids can effervesce between crystal faces to form irregular vugs (Peck 1978). This is because, as crystallization becomes more advanced, volatiles (chiefly H_2O) are concentrated in the residual melt and retrograde boiling occurs (Best

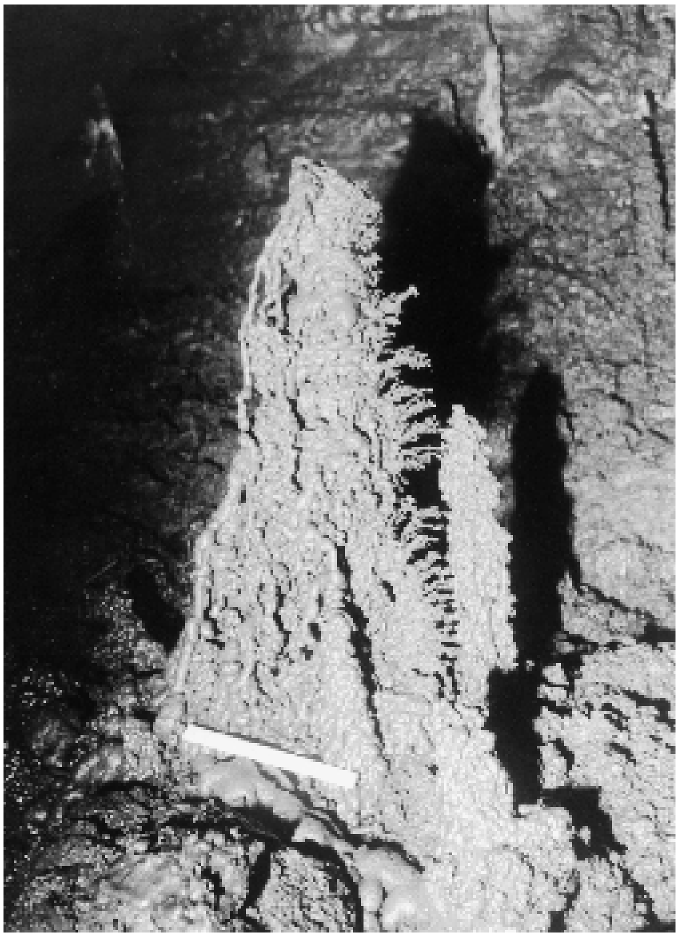


Figure 10. Lava coralloids (second-order segregations) extruded from a large lava stalagmite, Eppersons Cave. The coralloids formed during the cooling of the lava tube on the upstream side, and probably leeward of a breeze. The scale is 15 cm long. Photo by K. Allred.

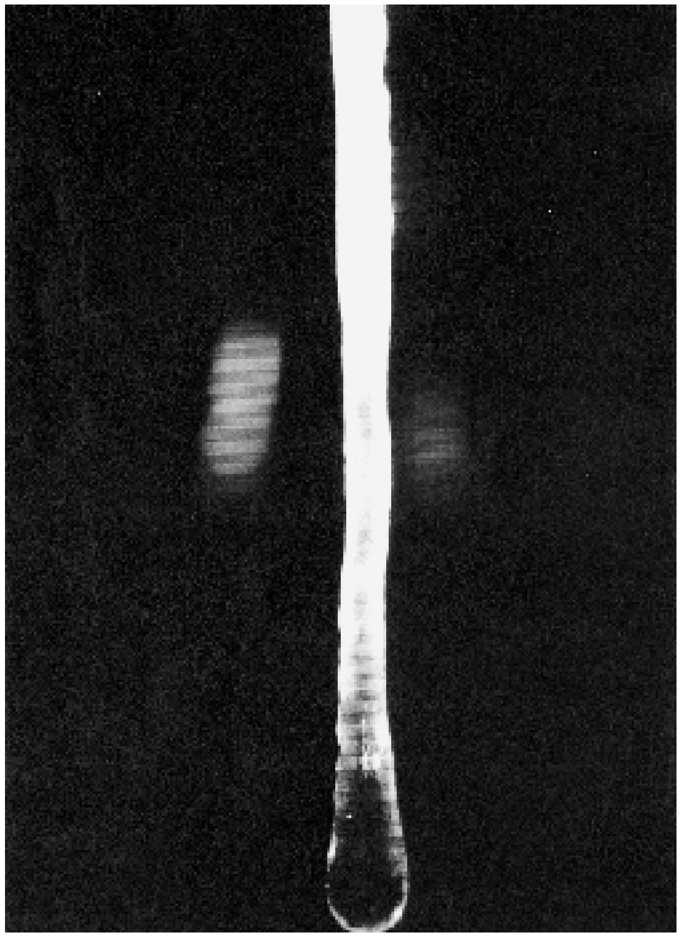


Figure 11. Tubular paraffin stalactite during growth. The stalactite diameter is 3 mm. Photo by C. Allred.

1995: 246, 292). We observed a more intensely vuggy fabric in linings having higher concentrations of tubular stalactites and other segregations (Fig. 8). In such a fabric, vesicle surfaces become honeycombed with vugs until only their general spherical shape remains. At least some of the interstitial melt is forced out into the cave to form tubular stalactites (Fig. 9).

The occurrence of coarse grains in segregations is evidence of increased diffusion of atoms because of high H_2O content. Low viscosity of residual liquid results from water molecules breaking some chains of SiO_4 tetrahedra. Addition of K_2O and Na_2O to silicate melts plays a similar role (Best 1995: 232, 293). With this in mind, we observed a tendency of brownish segregation material to have once been very fluid and to have almost none of the magnetite prevalent in the more common dark gray samples. This may indicate extensive oxidation to hematite under high H_2O conditions that would cause retrograde boiling. Vesiculation in segregations (Anderson *et al.* 1984) is further evidence that the driving force was retrograde boiling. Even later retrograde boiling can form vugs in tubular lava stalactites and stalagmites to extrude helictites or coralloids (Fig. 10). None of these second order segregations have yet been analyzed.

COMPARISONS WITH PARAFFIN MODELS

To help understand the origin of tubular lava stalactites, we were able to simulate their growth using colored paraffin of approximately 65° to 70°C. The most effective way of regulating paraffin flow was by inserting a sponge plug into the drainage tube which fed the stalactites. This is similar to the process of filter pressed segregation in lava, but where gravity takes the place of gas pressure. The resulting paraffin stalactites were 3 to 4 mm in diameter, and up to 15 cm long. As driblets drained quickly through a stalactite and dripped from the growing tip (Fig. 11), a thin flexible skin extended in segments. We sometimes observed the skins of newest segments splitting open and closing repeatedly parallel to the axis during cyclic driblet movement. This segmenting and splitting is reminiscent of growth rings and linear seams on some tubular lava stalactites.

Paraffin stalactites can be diverted into eccentric directions. The paraffin has a high solidification contraction of about 15%

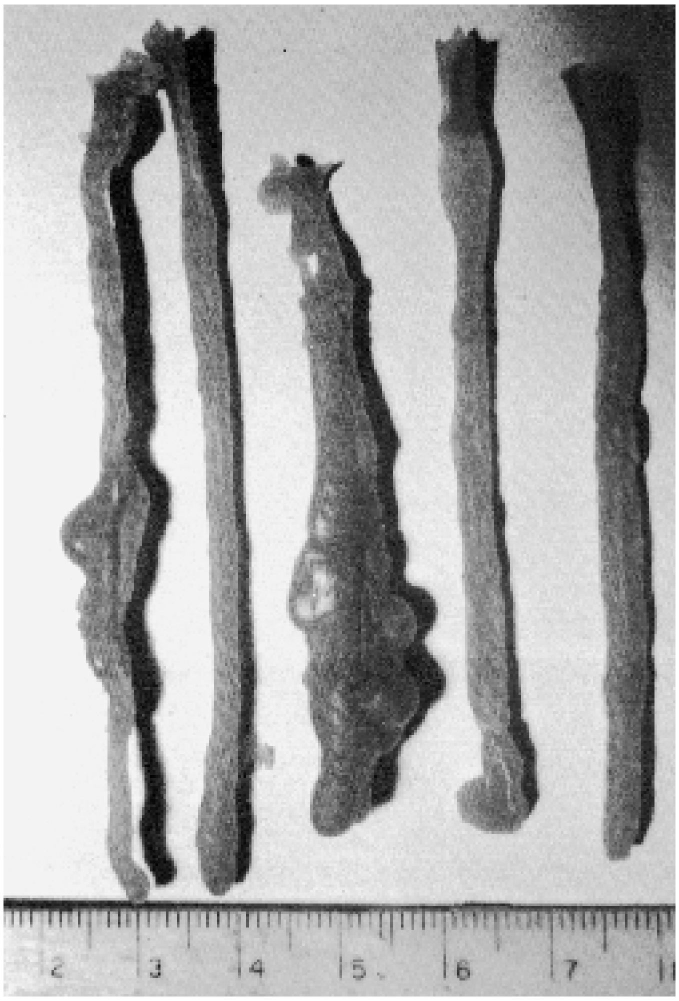


Figure 12. Some tubular paraffin stalactites. The scale is in centimeters. Photo by C. Allred.

volume. Since the solids are heavier, they tend to congeal at the bottom of the emerging driblet. The driblet is held to the preceding segment by surface tension, and the skin is thinnest around the sides of the driblet where spreading occurs. If the drainage is allowed to cool sufficiently (due to convection farther down the stalactite, or from diminished flow), pressured liquid pushes out or upward from the side of the driblet, beginning an eccentric form. These breakouts also can occur nearer the attachment point of a stalactite, resulting in a compound form. If a breeze is present, preferential growth is leeward. We suspect a similar process is involved in the formation of eccentric tubular lava stalactites, because lava contracts about 13% (Daly 1944) (compare Figs. 3 & 12).

If the paraffin temperature was too hot, a stalactite could not form, and all of each driblet fell to build puddles below. Only rudimentary stalagmites were possible with paraffin because of its extreme fluidity. This would indicate that paraffin is not a perfect model, even though mechanisms are comparable.

We also attempted to simulate stalactite formation according to the popular "remelt" hypothesis. We repeatedly flash heated a horizontal, flat, paraffin "ceiling". This only produced driblet projections less than 3 mm long. Any larger projections were quickly melted away when exposed to the heat. After experimenting with the paraffin, it became clear to us that tubular lava stalactites must necessarily develop from low viscosity cooling lava dripping from their tips.

Table 1. Modal compositions (volume percent). Segregations are shaded. 1, from Hjelmquist (1932); 2, the outer crust of the stalactite, and includes both hematite and magnetite; 3, all glass; 4, undetermined amounts of zeolite were detected in the glass; 5, uncorrected modes (Wright and Okamura, 1977, Table 14); 6, includes minor amounts of clay deposited on the exterior surfaces of stalactites after they were formed; *, olivine was visible in lining and may have been included in point counts for pyroxene.

	Sample	Olivine	Pyroxene	Plagioclase	Ilmenite	Magnetite	Hematite	Glass, Zeolite[4]	Apatite	Total
HA1	shark tooth stalactite composed of 8 linings	?	36.04	31.39	1.16	12.79	1.16	17.44		99.98
HA2	lining portion directly above tubular stalactite		29.16	30.55		15.27	5.55	19.44		99.97
HA2	tubular stalactite portion of sample		16.00	25.00	2.00	19.00	11.00	27.00[6]		100.00
HA3	both tubular stalactites & portion above are segregations		12.24	16.32		23.46		47.95[6]		99.97
HA4	stalagmite, transverse cross section		32.46	23.37		29.87	3.89	10.38		99.97
HA4	stalagmite, axial cross section		28.41	15.90	1.13	32.96	2.27	18.17	1.13	99.97
HA5	outer portion of HA6, directly above a small tubular stalactite	*	49.99	30.48		12.19	1.22		6.09	99.97
HA5	small tubular staltcite of HA6		39.60	22.77		24.75		8.91	3.96	99.99
HA6	lining from which tubular stalactites had grown	*	66.66	16.00		10.66	2.66		4.00	99.98
Hj[1]	tubular stalactite, Raufarholshellire Cave, Iceland		19.00	19.80		7.90	17.90[2]	35.40[3]		100.00
MLL[5]	Chemical mode for average Makaopuhi basalt	6.50	39.80	42.50	4.20	1.00		5.40[3]	.60	100.00

PETROGRAPHIC ANALYSIS AND DENSITY

Our sectioned samples (Table 1) were generally similar to tubular stalactites of previous petrographic studies (Dana 1889; Hjelmqvist 1932; McClain 1974; Baird *et al.* 1985). The segregations are darker, more coarsely grained, and are higher in magnetite and glass content, than the linings from which they extruded. We found that many tubular stalactites can be picked up easily with a magnet, due to high magnetite content throughout.

Glaze is a <50 µm magnetite skin, which has a characteristic silver luster from light reflecting off facets of tiny octahedrons. This magnetite ornamentation seems to have grown after the greenish pyroxene-rich surface had begun to crystallize on most lava tube surfaces. We found rare sites of greenish linings and tubular stalactites lacking much of the magnetite ornamentation. A reddish color can result when glaze has been oxidized to hematite. The magnetite indicates low temperature crystallization between 1030°C and the solidus (Table 2a). Thus, we question the prevailing assumption that glaze is evidence of remelting (Jaggar 1931; Peterson & Swanson 1974; Harter 1978; Allred & Allred 1997). The darker, coarsely grained layer under some glaze of our samples is segregated material.

We found that under magnification, the thin section of the shark tooth stalactite sample HA1 (Fig. 7) consists of eight distinct coatings (linings) ranging from 5 µm to 2.5 cm thick. In lining and tubular stalactite samples, the transitions between the linings and segregations are much less distinct than between the separate linings of the shark tooth stalactite. In the lining and stalactite samples, pyroxene crystals and laths of plagioclase commonly extend deep into either side of the transition zone, indicating segregation drainage through the crystalline framework.

Thin sections of the HA4 stalagmite show the distinct outlines of individual driblets (Fig. 13). Each has a finely crystalline pyroxene and magnetite rind with a well defined 50 µm magnetite glaze. The globs that fell onto this particular sample had congealed enough so that subsequent impacts did not deform them.

Some samples contain pseudomorphs from pyroxene partially altered to magnetite. Other identified minerals were a zeolite and probably sepiolite (M. Palmer, pers. comm. 1996).

Some hollow parts of tubular stalactites were partially filled with a delicate frostwork of pyroxene crystals and plagioclase laths and plates. Naughton (1975) suggested that the frostwork may be all that remains after interstitial liquid effervesced out.

The lava tube segregations generally follow the mineral paragenesis of Makaopuhi Lava Lake on Kilauea (Table 2a, Fig. 14). Wright and Fiske (1971) defined three stages in the crystallization sequence of nearby Alae Lava Lake. Filter pressed segregations occur in the third stage (Table 2b).

Table 3 shows the major and minor chemical compositions of segregations and average parent basalts. Makaopuhi data is included for comparison. When the crystallization of lava progresses beyond the crust-melt interface, the residual melt commonly becomes more enriched in Fe, Ti, Na, K, P, and Si, relative to Ca and Mg (Best 1995: 262, 292). Higher percentages of Ca and Mg are utilized in the earlier formed minerals. We expected the segregations to contain no earlier formed crystals of olivine if the filtering had been effective. This seems to be the case with the segregations in our thin sections, whereas olivine and olivine pseudomorphs are visible in at least some of the lining samples. The tubular lava stalactite samples of Table 3 are plotted on variation diagrams of Fig. 15 showing the liquid line of descent of Alae Lava Lake, Hawaii. All three analyzed lava tube segregations plot near the crust-melt interface. However such segregations may also occur at much lower temperature (Wright & Fiske 1971; Wright & Helz 1987). Bulk compositions that are higher in MgO than in the Alae Lake liquid line of descent (for example, HA6) may have segregations that occurred at slightly lower temperatures relative to that MgO scale.

Table 2. Crystallization of basalt, Kilauea Volcano.

a. Mineral paragenesis, Makaopuhi Lava Lake. Filter pressed segregation range is shaded (after Wright & Okamura 1977).

Mineral	Composition	Temperature (±10°C)	Glass (weight percent)
Olivine	Fo_{80-85}	1,205	100
Augite	$En_{47}Fs_{13}Wo_{40}$	1,185	94
Plagioclase	An_{67}	1,180	92
Ilmenite	$Ilm_{89}Hem_{11}$	1,070	44
Olivine	Fo_{55}	1,050	17
Pigeonite	$En_{61}Fs_{32}Wo_{7}$	1,050	17
Magnetite	$Usp_{63}Mag_{37}$	1,030	9
Apatite		1,020	7
Solidus		980	4 (residual glass)

b. Change of liquid composition during crystallization of Alae Lava Lake. Filter pressed segregation range is shaded (after Wright & Fiske 1971).

Stage	Temperature range (degrees C)	Minerals Crystallizing	Change of liquid composition with falling temperature
1	>1185	Olivine	Increase of all constituents except MgO and 'FeO'.
2	1185 - 1070	(Olivine) = Augite = Plagioclase (= Pigeonite? in prehistoric lavas)	Decrease of MgO, CaO, and once feldspar begins to crystallize, Al_2O_3. Decrease or no change in SiO_2. Increase in Na_2O, K_2O, FeO, TiO_2 and P_2O_5.
3	1070 - 1000	Augite = Plagioclase = Pigeonite = Ilmenite (= Magnetite at lower temperature)	Decrease in Al_2O_3, MgO, CaO. Increase in SiO_2, Na_2O, K_2O, P_2O_5. Increase in TiO_2 and FeO to a maximum and then decrease as Fe-Ti oxides crystallize in greater quantity.

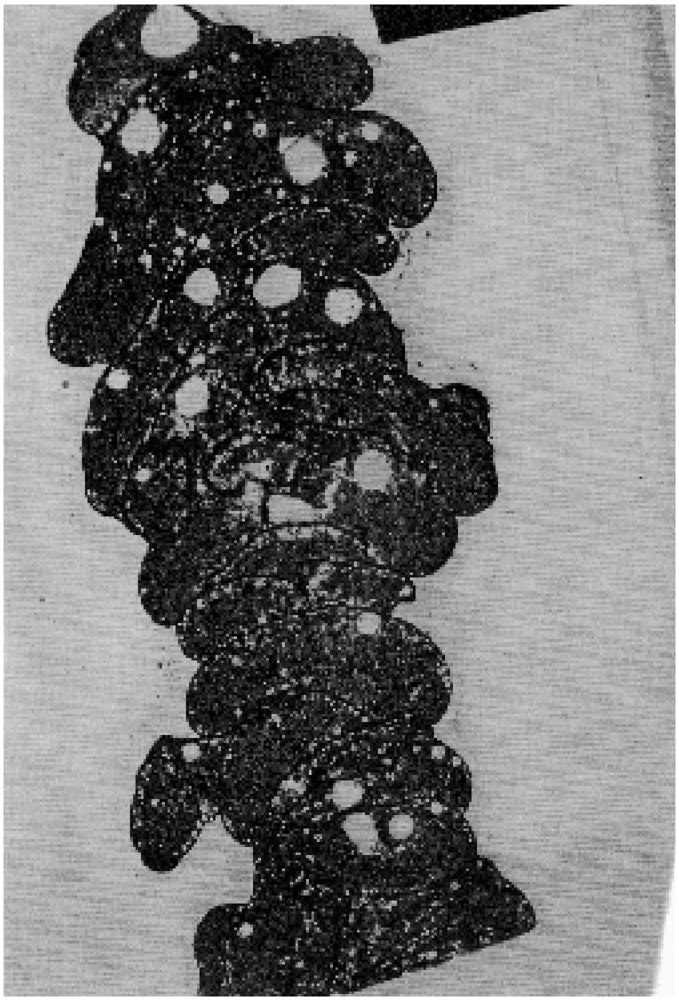


Figure 13. A thin section of lava stalagmite HA4. The light voids are vesicles. Sample is 56 mm long. Photo by M. Palmer.

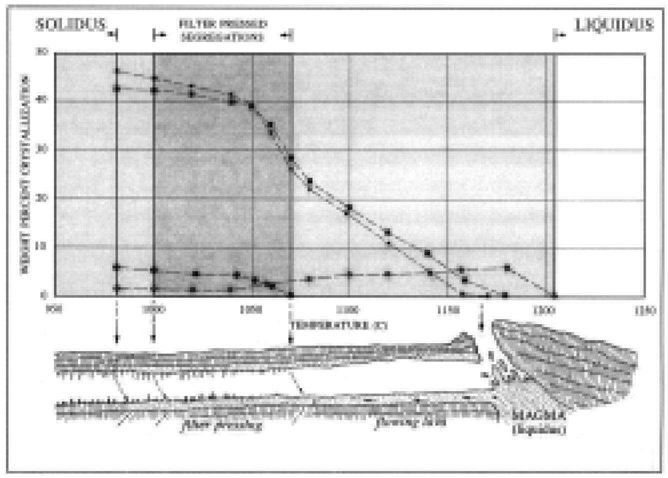


Figure 14. Crystallization of Makaopuhi Lava Lake basalt (data after Wright and Okamura, 1977; Wright and Hilz, 1987) compared with the inferred solidification and segregation range of a Kilauea lava tube. Approximately 4% of the olivine precipitated at higher temperature is later resorbed. Deflected temperature boundaries through the lava tube are due to a cooler conductive ceiling above the lava river. An eruption temperature of 1165ºC was chosen from Swanson (1973). ○, olivine; ■, pyroxene; ▪, plagioclase; ●, Fe-Ti oxides; ⁂, partially crystallized lava.

Many trace and rare earth elements are incompatible with the crystallization phases, so tend to remain in residual liquids. They are, therefore, more concentrated in the segregations than in the linings (Table 4). Many of the incompatibles in the stalactites were approximately double those of the lining. This is further evidence that the segregations occurred at about the crust-melt interface. Ni, Cr, and Co are compatible, and they substitute for MgO in olivine (Krauskopf & Bird 1995).

Table 3. Chemical composition of segregations and Kilauean parent lavas (weight percent). Segregations are boxed. 1, silica dioxide and disodium oxide were designated as SiO_2 and NaO respectively (Brigham 1868); 2, collected from Kazumura Cave (Baird, Mohrig& Welday 1985), total Fe calculated as FeO; 3, from Wolfe and Morris (1996); 4, segregation vein from Makaopuhi lava lake sample 68-2-10 (Wright & Okamura 1977); 5, Wright and Okamura (1977), Table 12; 6, detection limit of 0.01%.

Oxide	Tubular stalactite, Kilauea Caldera (1868)[1]	Tubular stalactites Kazumura Cave. (1985)[2]	Tubular stalactite HA6, Kazumura Cave. (this study)[6]	Parent lining of tubular stalactite HA6. (this study)[6]	Average parent lava of the Kazumura flow. (1996)[3] upper flow	Average parent lava of the Kazumura flow. (1996)[3] lower flow	Segregation vein Makaopuhi Lava Lake. (1977)[4]	Average Makaopuhi basalt. (1977)[5]
SiO_2	51.9	53.3	49.14	48.74	50.70	50.70	50.77	50.18
Al_2O_3	13.4	13.8	12.49	13.70	13.13	13.00	12.27	13.26
Fe_2O_3	15.5		15.33	12.07	12.66	2.87	4.26	1.48
FeO		10.4			--	8.65	10.45	9.86
MgO	4.8	5.5	5.23	8.37	7.85	8.42	4.23	8.27
CaO	9.6	10.9	9.37	11.07	11.33	11.02	8.47	10.82
Na_2O	3.0	2.8	3.05	2.46	2.08	2.10	2.75	2.32
K_2O	1.1	0.5	0.65	0.33	0.38	0.39	1.11	0.54
TiO_2		2.8	3.63	2.08	2.52	2.30	4.49	2.64
P_2O_5			0.35	0.19	0.23	0.25	0.52	0.27
MnO	0.8		0.20	0.17	0.17	0.20	0.20	0.17

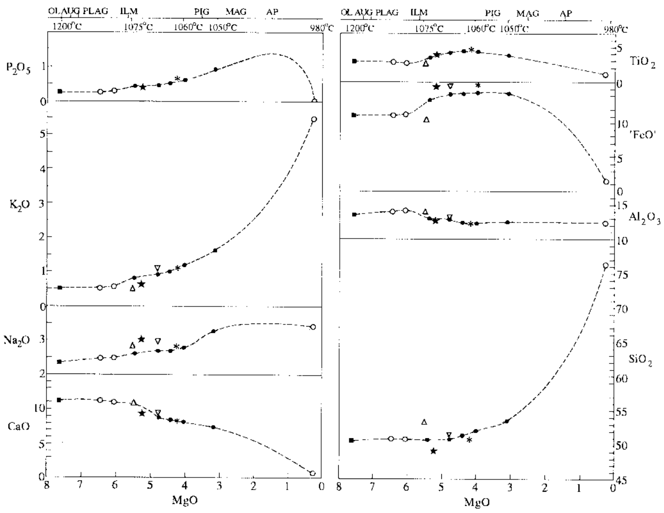


Figure 15. Liquid line of descent, Alae lava lake (Wright & Fiske 1971) with additional plotted lava tube segregations. ■, bulk composition; ○, separated and analyzed glasses; ●, naturally filter pressed oozes; ⩓, tubular lava stalactites, (Baird *et al.* 1985); *, segregation vein sample 68-2-10 (Wright & Okamura, 1977); ⩔, tubular lava stalactites (Brigham 1868); ✱, HA6 tubular lava stalactites.

Bulk rock densities of segregations average slightly higher than their parent linings. Grain densities of HA6 segregations and linings were 3.16 g/cm³ and 3.0 g/cm³, respectively.

RUNNER CHANNELS

In places, shallow incised "runner" channels extend vertically down the cave walls. Those we observed are up to 20 mm wide, 5 mm deep, and one meter long (Fig. 16). At first we thought these had been melted into the already solidified walls by hotter lava extruded into the cave through tiny holes in the walls. Now we believe the volatile-supersaturated segregations pouring from the orifices reacted with the residual liquid of the hot wall lining. This caused some residual liquid to become less viscous and flow away with the segregations. Best (1995: 234) calls this general process "depolymerization". In such circumstances, previously crystallized olivine and other minerals would be undermined and wash down the channels with the liquid. Exit holes and internal conduits

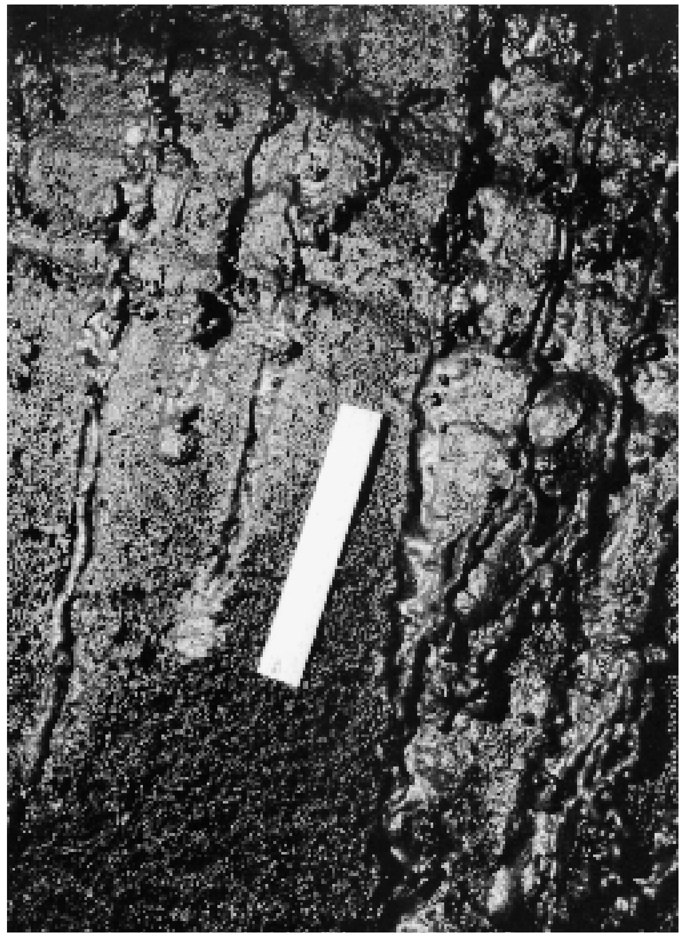


Figure 16. Runner channels with subsequent runners, Keala Cave. The scale is 15 cm long. Photo by K. Allred.

Table 4. Trace and rare earth elements of HA6 lining and stalactites. (-) Indicates below detection limits.

Element	Au	As	Ba	Br	Co	Cr	Cs	Hf	Ir	Rb	Sb	Sc
detection limit/unit	1 ppb	1 ppm	1 ppm	0.5 ppm	0.1 ppm	0.2 ppm	0.2 ppm	0.2 ppm	1 ppb	10 ppm	0.1 ppm	0.01 ppm
HA6 lining	-	2	105	-	45.1	695	-	7.7	-	-	0.4	29.1
HA6 tubular stalactites	8	2	173	-	42.1	351	-	7	-	-	0.7	27.5

Element	Se	Ta	Th	U	W	La	Ce	Nd	Sm	Eu	Tb	Yb
detection limit/unit	0.5 ppm	0.3 ppm	0.1 ppm	0.1 ppm	1 ppm	0.1 ppm	1 ppm	1 ppm	0.01 ppm	0.05 ppm	0.1 ppm	0.05 ppm
HA6 lining	-	0.7	0.7	-	-	8.4	21	15	4	1.43	0.7	1.76
HA 6 tubular stalactites	-	1	1.2	0.5	2	16.9	42	30	7.29	2.46	1.3	3.01

Element	Lu	Sr	Y	Zr	V	Mo	Cu	Pb	Zn	Ag	Ni	Cd	Bi	Be
detection limit/unit	0.01 ppm	1 ppm	1 ppm	1 ppm	1 ppm	2 ppm	1 ppm	5 ppm	1 ppm	0.5 ppm	1 ppm	0.5 ppm	5 ppm	2 ppm
HA6 lining	02.5	308	23	122	270	3	118	14	87	2.4	151	-0.5	25	-2
HA6 tubular stalactites	0.42	431	41	234	390	3	235	-5	129	2.9	58	-0.5	15	-2

above the channels seem to have been enlarged as well. Indeed, it may be that "roots" observed to extend above some tubular stalactites (Harter 1971, 1993) were formed by residual melts depolymerizing along the paths of segregations. As with the other segregated features, the depolymerization occurred during cooling of the lava tube. It is important to emphasize that none of these processes have anything to do with a "remelt" scenario. Although the eventual solidus temperature might be lowered by increased H_2O in residual melts, there is no change from crystalline to melt.

CONCLUSIONS

Based on evidence stated above, tubular stalactites and some other extrusions in lava tubes are filter pressed segregations extruded by retrograde boiling from partially crystallized lava. They occur at or below the crust-melt interface between about 1070º and 1000°C. Segregations differ from their parent linings in density, texture, mineral ratios, and chemical composition. In some cases, segregations depolymerized residual liquid in partially crystallized linings. Besides tubular lava stalactites and their drainages, filter pressed segregation is also responsible for barnacle-like stretched lava, and at least some lava roses, blisters, and squeeze-ups.

Genetically, the outer shells of tubular stalactites function like the insulative linings of the lava tubes in which they grow. The great variety of these and other interesting lava formations is influenced by the composition of the parent lavas, by when the segregations occur, by the efficiency of filtering, and by the complex open environment under which they cool.

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