**Hawaii Volcanoes 4**

1. We have arrived now at the last topic related to lava – lava types. Although there are fundamentally only two types of basaltic lava, the variety of forms these can develop is amazing and provides a beautiful example of chaos theory applied to natural systems.
2. Simply stated, chaos theory predicts that the iterative application of simple rules can have complex, unexpected outcomes.
3. The simple rules that control lava behavior are most fundamentally based on gravity and lava viscosity. Gravity provides the force to move the lava, but its ability to do so depends on lava viscosity.
4. Steeper slopes and larger volumes of lava will help gravity move lava down slope, while higher temperatures, lower internal shear stress and higher gas contents will all reduce viscosity and thereby encourage down slope motion. By themselves these parameters do not result in the “complex, unexpected outcomes” predicted by chaos theory, ….
5. … but with lava flows (and many other geologic processes) the outcomes of following simple rules become the new initial conditions from which to reapply the rules. This is where the term iterative (meaning repeated over and over) comes into play, because the results of applying the simple rules creates feedback which constantly affects future outcomes. You can see the principle as work in this pahoehoe lava flow. A tongue of lava pours from the base of an active flow, but its path is affected by previous flows. In this way complex, but not entirely random patterns are developed in the flow.
6. A complete explanation of chaos theory is well beyond the scope of this lesson (and my understanding!), but there’s a nice summary here for the interested reader, …
7. … and I encourage you to play around with Conway’s Game of Life where you can see firsthand how the iterative application of simple rules can have complex outcomes.
8. Such complex outcomes can be expressed as mathematically determined patterns known as “strange attractors”. If you would like to explore deeper the fascinating world of chaos theory, I highly recommend downloading “Chaoscope” - the free 3D Strange Attractor rendering software that made all the abstract images seen here.
9. I’m convinced that if you played around with Chaoscope long enough one could find strange attractors that look like many geologic shapes including pahoehoe and …
10. … aa.
11. As we move through the various lava types and patterns, try to see them as outcomes predicted by the larger paradigm of chaos theory and perhaps, by extension, you may catch a glimpse of how it applies to other geological phenomena. First up – pahoehoe.
12. Pahoehoe is a Hawaiian term for basaltic lava that has a smooth, hummocky, or ropy surface. The high fluidity (low viscosity) of pahoehoe generally results from its high temperature …
13. …and high gas content as is evident from this blister on the surface of a pahoehoe flow. Blisters are thin-walled basaltic-glass bubbles formed by the release of volcanic gas from the surface of a pahoehoe flow. Like a glass blower that blows air into molten glass to create a goblet or vase, gas released from lava may inflate the thin glassy crust of a lava flow to form a large bubble or blister. They are found on all types of pahoehoe flows.
14. The most gas-rich, high temperature lava is generally confined to near vent regions and forms a type of lava called shelly pahoehoe. Often this form occurs with overflows from a near vent lava lake, as volumes of gas rich lava pours over confining dikes. As this lava flows down slope it forms huge knaps and rolls covered by a thin, frothy surface skin of basaltic “foam”.
15. Lava may drain out from beneath the solidified froth, …
16. … leaving shelly surfaces that often collapse when walking on the top of the flow.
17. You wouldn’t want to walk across shelly pahoehoe while there is still lava inside! These volcanologists look like they are having second thoughts.
18. Slab pahoehoe has a surface that consists of a jumbled arrangement of jagged plates, or slabs, of pahoehoe that were rafted, sheared, tilted, upturned, overturned and heaped on each other. Slab pahoehoe is also somewhat common in the near vent region, though perhaps not as common as shelly pahoehoe. Slab pahoehoe is the result of fluid lava subjected to high strain rates, although I must admit I could not determine where that strain comes from.
19. I suppose it could be from pouring down steeper slopes near the vent or perhaps from splash-over from especially turbulent lava lakes.
20. Slab pahoehoe is a transitional form to aa and will become aa should the lava’s viscosity increase while high strain rates are maintained. For example: if rapid movement continued while slab pahoehoe cooled, it would turn into aa. The mechanics of that transition will be discussed in greater detail when we cover aa.
21. A pahoehoe flow typically advances as a series of small lobes and toes that continually break out from a cooled crust. These small glowing pahoehoe toes were fed by lava that broke out from a lava tube (out of view) at Kilauea Volcano, Hawai`i.
22. The flow spreads as the small toes grow in size and merge together to form a broader front, …
23. … which in turn inflates with new lava moving through the molten core of the flow. Another series of budding toes will break out, move forward, and start the process over again. (Did you catch the iterative aspect of chaos theory there?) Originally it was thought that pahoehoe was emplaced by stacking these toes one on top of another. Although that certainly happens …
24. … it has become increasingly clear that much of the lava emplaced in massive flow fields is emplaced *beneath* the surface raising it up. This is evidenced by signs and fence lines plucked from the ground and large flexural cracks resulting from the uplift of adjacent slabs.
25. This pickup truck that was abandoned to the lava also shows evidence for flow inflation.
26. Note how the lava flowed around the truck but did not bury it. The truck was then lifted upwards as the flow inflated.
27. Parking violations can have serious consequences in Hawaii Volcanoes National Park.
28. The surface texture of pahoehoe flows varies widely, displaying all kinds of bizarre shapes often referred to as lava sculpture. This is the smooth variety which generally forms where hot lava has recently broken out of a lava tube and flows across unobstructed, gentle slopes such as this road in Kalapana on the east rift zone of Kilauea Volcano.
29. When lava flows down steeper slopes …
30. … like the great fault scarps on the south flank of Kilauea Volcano ….
31. … an unusual variety of lava is formed called entrail Pahoehoe. Named after the texture of an animal's intestines, …
32. … entrail pahoehoe is characterized by especially elongated protrusions of pahoehoe resulting from rapid rates of flow relative to solidification.
33. On the south flank of Kilauea the most striking examples occur where pahoehoe oozed down steep scarps in the Hilina fault system. Entrail pahoehoe also tends to form on steep slopes because the force of gravity is more effective …
34. in causing lava breakouts, which are necessary to form the multiplicity of long, narrow flows characteristic of entail pahoehoe.
35. Lava breakouts may also occur on nearly flat ground at a bend in a lava tube. Note the rake-like marks left in the very smooth pahoehoe here as it flows from underneath the wrinkled margin of the lava tube.
36. A good example of a complex, unexpected outcome from the iterative application of simple rules.
37. Ropy pahoehoe is the most common surface texture of pahoehoe flows. The numerous folds and wrinkles ("ropes") that are characteristic of ropy pahoehoe form when the thin, partially solidified crust of a flow is slowed or halted (for example, if the crust encounters an obstruction or slower-moving crust).
38. Because lava beneath the crust continues to move forward, it tends to drag the crust along. The crust then behaves like an accordion that is squeezed together--the crust is flexible enough to develop wrinkles or a series of small ridges and troughs as it is compressed and driven forward.
39. Because the shape of the ropy crust is determined by how it interacts with adjacent ropy crust, the iterative prerequisite of chaos theory is in full effect. Forms resembling strange attracters …
40. … are especially noticeable in ropy pahoehoe. Lava coils like this are spiral or scroll-shaped features that form along slow-moving shear zones in a flow; for example, along the margins of a small channel. The direction of flow can be determined from a lava coil. Lava on the right side of the photo was moving toward the top of the view relative to lava on the left side.
41. Tumuli can be thought of as pahoehoe on steroids. These elliptical, domed structures on surfaces of pahoehoe flows occur on flat or gentle slopes. A tumulus is created when the upward pressure form of slow-moving molten lava within a flow swells or pushes the overlying crust upward. Since the solid crust is brittle, it usually breaks to accommodate the "inflating" core of the flow. Such fractures generally extend along the length of a tumulus, and are frequently accompanied by smaller irregular cracks down the sides.
42. Lava commonly squeezes out through these fractures, and sometimes drains from the tumulus to leave a hollow shell.
43. Spiney pahoehoe is the most viscous pahoehoe, which with just a little more strain applied (for example flowing over a cliff), can turn into aa. Walking over spiney pahoehoe can be quite unpleasant -- something like walking over an array of swords pointing up with their handles buried in rock.
44. Aa is pahoehoe’s edgy cousin.
45. The Hawaiian term applies to lava flows that have a rough rubbly surface …
46. … composed of broken lava blocks called clinkers.
47. The incredibly rough, jagged and even spinose surface of a solidified aa flow makes walking difficult. One might imagine that the term came from the pained vocalizations made by early barefooted Hawaiians.
48. The clinkery surface actually covers a massive dense core, which is the most active part of the flow. As pasty lava in the core travels down slope, the clinkers are carried along at the surface. At the leading edge of an aa flow, however, these cooled fragments tumble down the steep front and are buried by the advancing flow. Thus aa flows advance much like the tread of a bulldozer -producing a layer of lava fragments both at the bottom and top of an aa flow.
49. Like pahoehoe lava is fed by lava tubes, aa is transported via lava channels. Although aa channels are not completely covered over by solidified lava like lava tubes generally are, the thick accumulations of solidified lava rubble which flank and partly cover aa channels minimize heat loss …
50. … and enable aa to be transported over large distances without solidifying.
51. Despite aa’s high viscosity, it is capable of moving at speeds sometimes even faster than pahoehoe, because its greater thickness helps gravity spill it forward. The aa flows shown here, that surged through the Royal Gardens subdivision from the 1983 Pu’u O’o eruption, were up to 11 m thick and moved at rates as great as 33 m/min. Note the exposed molten core of the flow and vehicles for scale.
52. Although there are many types of pahoehoe, the characteristics of aa are remarkably consistent.
53. This is because strain from flowage and fountaining causes pahoehoe to thicken into aa and the thicker the lava the more strain will be induced upon motion. So a positive feedback loop is established in aa between strain and viscosity which irreversibly leads to the formation of aa. How that happens exactly on the molecular level I could not determine, but I envision (with great uncertainty!) that strain forces silica tetrahedrons (the basic structural unit of silicate minerals) to link together and thereby thicken the lava.
54. If the rate of strain is high, the transition threshold between pahoehoe and aa is reached at a lower viscosity than if the shear strain rate is low.
55. This is the type of thing that happens when effusion rates are high such as with vigorous fountaining, …
56. … or when pahoehoe pours over a cliff. Catching the incipient transition from pahoehoe to aa is a rare and fascinating event,
57. … but not worth risking your life for.
58. Here you can actually see the transition taking place almost instantaneously as this pahoehoe flows over a steep slope. The area outlined in red is shown in the next photo …
59. … where you can see how the lava has lost its elasticity and is beginning to be ripped apart into clinkers.
60. The converse is also true. If the viscosity of the lava is high, a relatively low rate of shear strain may achieve the transition threshold, and the lava changes to aa. For example, a slow-moving pahoehoe flow that has cooled sufficiently may transform into aa as the flow continues to advance.
61. There are many other fascinating lava features that deserve mention like lava trees, …
62. … and lava balls …
63. … but a huge part of the enjoyment of Hawaiian Volcanoes National Park …
64. ... comes from making your own discoveries!