LONG, PAIRED A'A/PAHOEHOE FLOWS OF MAUNA LOA: VOLCANOLOGICAL SIGNIFICANCE, AND INSIGHTS THEY PROVIDE INTO VOLCANO PLUMBING SYSTEMS

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Martian lava flows of Olympus Mons and the Tharsis volcanoes are an order of magnitude longer, wider, and more voluminous than any single lava flows on Earth (cf. Carr, 1981). The long lava flows of Mauna Loa, Hawaii have been cited as Earth's closest analogs to the large Martian flows (Carr, 1981). It is therefore important to understand the flow mechanisms and characteristics of the Mauna Loa flows and to make use of these in attempts to gain insights into Martian eruptive processes.

A number of workers (Walker, 1973; Malin, 1980) have made attempts to find regular relationships between flow characteristics such as flow thickness, length, and area with physical controls of lava flows such as underlying gradient and average eruption rate. Assumptions regarding lava rheology can then be made if a quantitative method of analyzing the found relationships exists.

The careful mapping of selected Mauna Loa flows has revealed the unexpected relationships that lavas with very different flow mechanisms can have very similar volumes, areas, and lengths. The division of Hawaiian lavas into pahoehoe and a'a (cf. Macdonald, 1953) is a fundamental one and is useful for many reasons. The common down-flow change from pahoehoe to a'a due to degassing, cooling, and shearing (Emerson, 1926; Peterson & Tilling, 1980) is well established; what is not so well known is that flows having similar lengths (up to 47 km) and volumes (up to 200×10^6 m^3) can consist of pahoehoe or a'a in their entirety.

Our mapping has revealed the existence of several paired lavas, each consisting of an earlier a'a member and a later pahoehoe member erupted in the same eruption, the two members of a pair having similar lengths and volumes and, so far as we know, identical initial viscosities and chemical compositions.

The 1859 and 1880-81 lavas of Mauna Loa are particularly striking examples of paired a'a/pahoehoe flows. Historical accounts allow us to piece together the characteristics of the eruptions, which we can then relate with features of the eruptive products analyzed in the field and in air photos. An important relationship which we find for these two eruptions is the close correlation of erupted lava type with discharge rate; channel-fed a'a formed at a time of high discharge rate and tube-fed pahoehoe formed at a time of low discharge rate. Eruptive style is also closely related to discharge rate; high gas-driven fountaining accompanied the high discharge-rate activity, and little or no fountaining accompanied the low discharge-rate activity. A similar relationship was noted on Kilauea during the Mauna Ulu series of eruptions (Swanson, 1973; Swanson et.al., 1979), and is at present being demonstrated by the 1983-1986 Puu O'o and "C-fissure" (Ulrich et.al., 1986) activity.

At a time of high discharge, lava is strongly channelized and the high flow velocity precludes the roofing-over of significant lengths of the main channels. The loss of heat from open channels is very rapid, and a significant viscosity increase occurs in the channelized lava. Because of lateral velocity gradients, any portion of chilled lava crust is subjected to a torque due to traction by the underlying lava, and because of this torque adjacent portions of skin tend to be torn apart. If the underlying lava is too viscous to well up and heal the tears, then the torn-apart portions of skin become rubble fragments (Macdonald, 1953) and the lava flow becomes a'a.

In contrast, at a time of low discharge, flowage of the lava through tubes under the surface crust is favored. A labyrinth of small single-flow-unit tubes forms, and coalescence or enlargement of these causes master tubes to develop. Heat is very efficiently

conserved in tubes and lava can travel far from the vent without cooling significantly (Swanson, 1973). These eruption conditions favor the extreme subdivision of the lava into flow units, and these units are individually so thin that flowage has almost ceased by the time that the lava viscosity has reached a value appropriate (in rapidly flowing lava) to the formation of an a'a surface. A'a does not therefore form and the lava is predominantly pahoehoe right to its distal limits.

Close monitoring of Kilauea summit tilt during the current (1983-1986) eruptive activity gives an insight into factors relating to the drastically different eruptive characters. In the time prior to each episode of high discharge and high fountaining at Pu'u O'o, the summit reservoir swelled (Wolfe et.al., 1987). The periodicity of eruptive episodes is recorded as a saw-tooth pattern on a tilt angle vs. time diagram (cf. Eaton & Murata, 1960), due to the slow inflation followed by rapid deflation accompanying eruption. This pattern is interpreted to indicate that magma is stored in a summit reservoir between eruptive episodes (Wolfe et.al., 1987). In contrast, during eruptive periods of low or no fountaining (episode 35-B and the current activity), associated with pahoehoe production, little systematic variation in the tilt record is shown; magma is not being stored in the summit chamber and output at the vent equals input from the mantle (Heliker et.al., 1985; Ulrich et.al., 1987).

By analogy, temporal information regarding the 1859 and 1880-81 eruptions of Mauna Loa allows us to constrain volumes of Mauna Loa summit magma chambers as well as supply rates to the chamber. The values are approximately 200×10^6 m^3 and 7 m^3/sec respectively. Dzurisin et.al. (1984, fig. 7) estimate the volume of Kilauea's chamber as ranging between 50 and 200×10^6 m^3. Estimates of the supply rate to Kilauea's summit chamber range from 2.7 to 3.5 m^3/sec (Ulrich et.al., 1986 ; Swanson, 1972; Dzurisin et.al., 1984). Analysis of total area covered by a'a and tube-fed pahoehoe on Mauna Loa by Lockwood & Lipman (1985) indicates that prior to 750 y ago, pahoehoe was the dominant eruptive product while since then, a'a has dominated. This may indicate that since 750 y ago, magma has been stored between eruptions in a summit chamber.

Consider now the reasons for the differences in discharge rate during single eruptions as well as for the episodic behavior of Kilauea between 1983 and 1986, that produced a paired assemblage of a'a and pahoehoe. Three possibilities are considered. One, the primary control for the episodic activity was partial blockage of the conduit (between magma chamber and vent) between eruptive episodes. Eventually (by July, 1986) the conduit attained thermal equilibrium, and continuous unimpeded magma flow became possible. Two, the primary control for the episodic activity was the accumulation of gas bubbles in the magma within the upper part of the magma chamber, and its depletion lower down. Each eruptive episode released gas-rich magma, and was then terminated because the underlying gas-poor magma lacked sufficient bouyancy to rise to the surface. Since then, steady state conditions have been attained, and the magma emerges continuously with a uniform and moderate content of bubbles. Three, high effusion-rate lava is is erupted when strain release on a swelled magma chamber is the mechanism which drives magma upward to shallow levels, where gas bubble expansion rapidly takes place. The later pahoehoe uses the same conduit to reach the surface at a much lower velocity by means of gas bubble-induced bouyancy.

The relevance of this work to the Martian volcanoes is that two fundamentally different kinds of long lava flows can be distinguished on Hawaiian volcanoes. The two kinds may have identical initial viscosities, chemical compositions, flow lengths, and flow volumes, but their flow mechanisms and thermal energy budgets are radically different. One travels a distance set by the discharge rate as envisaged by Walker (1973) and Wadge, (1978), and the other travels a distance set mainly by the eruption duration and ground slope. In the Mauna Loa lavas, yield strength becomes an important flow-morphology control only in the distal parts of a'a lavas. The occurrence of

paired flows on Mauna Loa yields insights into the internal plumbing systems of the volcano, and it is significant that all of the volume of the a'a flow must be stored in a magma chamber before eruption, while none of the volume of the pahoehoe needs to be so stored. We are confident that it should be possible to distinguish between the two kinds of flows on images of Martian volcanoes and hence start to aquire an improved understanding of these huge structures.

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