THE 1984 MAUNA LOA ERUPTION AND PLANETARY GEOLOGY

Henry J. Moore, U.S. Geological Survey, Menlo Park, CA., 94025

In planetary geology, lava flows on the Moon and Mars are commonly treated as relatively simple systems. The purpose of this abstract is to illustrate some of the complexities of actual lava flows using the main flow system of the 1984 Mauna Loa eruption. The outline, brief narrative, and results below are based on a number of sources [1,2,3].

This flow system developed in four distinct stages that overlap in time: (1) rapid advance of a narrow aa sheet, (2) development of a channel within the aa sheet that conducted lava from the vents to the lower reaches, (3) formation of blockages and obstructions in the channel that produced overflows, levees, and lava ponds on the aa sheet, and (4) waning stages during which the lava channels drained and the distal parts of the flow thinned and spread. Blockages, obstructions, and overflows progressed upstream with time. There were also significant variations in the lava flowing in the channel from the vent toward the toe: (1) densities of samples from the flowing lava increased from less than 530 to more than 2,400 kg/m^3, (2) tempertures of the most fluid lava decreased from 1140°C to as low as 1086°C, (3) concentrations and sizes of warm to incandescent objects increased, (4) apparent viscosity increased dramatically, (5) the rheology changed, and (6) the volume flow rates decreased.

On the afternoon of March 25, lava was issuing from fissure vents at the 2850-m elevation that became the principal sources of lava for the remainder of the eruption. Three southerly flow lobes fed by the vents stagnated by March 27, but the main flow was fed at a fairly constant volume-flow rate (560 m^3/s). Constant-volume flow rates were sustained from March 30 to April 7; after April 7, flow rates declined. The main flow (flow 1) advanced rapidly as a narrow aa sheet, elliptical in profile, to the 910-m level, 25 km from the vents. The sheet flow evolved into (1) a channel zone within the sheet flow below the vents, (2) a transition zone farther downstream, and (3) a dispersed-flow zone led by the advancing toe. The lava channel had developed in the sheet flow by March 29. Also on March 29, obstructions and blockages near the 1740-m level caused a channel overflow or breakout that cut off the lava supply to flow 1 so that it moved about another km in a day. Lava from this breakout gave rise to flow 1A, which advanced rapidly along a course sub-parallel to and north of flow 1. A series of overflows that progressed upstream beginning April 3 produced levees and lava ponds that were superposed on the aa sheet. Blockages and collapse of lava-pond walls gave rise to surges, ebbs, and small overflows that reduced the lava supply to flow 1A. On April 5, a breakout occurred at about the 1980-m level and cut off the lava supply to flow 1A, which stopped

about 27 km from the vents. The April 5 breakout gave rise to flow 1B, which moved toward the northeast. Repeated channel blockages and overflows continued progressively upstream from April 5 to April 8. On April 7, lava production at the vent began to dwindle; subsequently, the flow system stagnated, vent activity ceased, and the channels drained.

The appearance of lava during the eruption correlated with changes in the apparent viscosity of the flow. At the vents and 3 km away, the flow was composed of sparse cinders and clinkers in a matrix of molten lava confined in a channel 20 m wide. Flow was laminar and steady; velocities were 15 m/s (vents) and 5.3 m/s (3 km from vents). At 9 km from the vents, the flow was composed of dark cinders and clinkers, and incandescent clots in molten lava. At 15 km from the vents, the flow resembled a slowly moving mass of debris confined in a rubbly, leveed channel 57 m wide; the flow included warm to incandescent fragments that were block size and smaller, and molten lava. Movement occurred by displacement of discrete, intact units with boundaries that paralleled the crests of the levees. Flow was laminar but unsteady, with surges and ebbs; velocities ranged from 0.1 to 0.3 m/s.

Apparent viscosities of the lava were calculated from observed velocities, assumed densities based on samples from the flowing lava, and flow dimensions along the main flow. On a given day, apparent viscosities increased downstream. On April 2, they were about 10^2 Pa·s at the vents, 10^3 Pa·s at 3 km from the vents, 10^5 Pa·s at 15 km from the vents, and near 10^7 Pa·s at the toe. These increases in apparent viscosity were probably related to (1) increases in the concentrations of solid debris, crystals, and plastic clots, (2) reductions in gas and bubble contents, (3) decreases in temperatures, and (4) decreases in stresses and shear rates.

Flow laws probably varied along the length of the flow from Newtonian, through Bingham, to pseudoplastic fluids [e.g. 4]. Other fluid models may also apply [5]. Estimated stresses and shear rates for the lava compare favorably with laboratory data at similar temperatures (1120-1140°C) [4].

Volume-flow rates at the vents on April 3 were near 560 m^3/s, about 12 times higher than at 15 km downstream. Mass-flow rates, calculated with the densities assumed in calculations of apparent viscosities, indicated a mass loss along the flow that could not be accounted for by the observations, ponding, overflows, or gas loss. With certain assumptions, conservation of mass requires a lava density at the vents about 220 kg/m^3, implying a mass-flow rate near 1.2×10^5 kg/s. If these masses were deposited with an average bulk density of 2,200 kg/m^3, the volume-flow rate would appear to be 56 m^3/s.

The implications of the above results to planetary geology are clear. Volume-flow rates during an eruption depend, in part, on the volatile content of the lava. These differ from the volume-flow rates calculated from post-eruption flow

dimensions and the duration of the eruption [6,7] and from those using models that assume a constant density [8,9]. Mass-flow rates might be more appropriate because the masses of volatiles in lavas are usually small, but variable and sometimes unknown densities impose severe restrictions on mass estimates. Lava flows cannot necessarily be modeled as simple flow units because they may develop in time-dependent stages. All rheological properties probably vary with time.

Despite these complications, planetary geologists should persist in their endeavors to understand lava flows on Earth and other planetary bodies [8,9,10,11,12].

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