MODELLING THE MAXIMUM LENGTHS OF CHANNEL-FED LAVA FLOW FIELDS.

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A number of authors [1, 2, 3, 4] have discussed the factors which influence the length to which a lava flow can grow. These factors include: effusion rate, ground slope, lava temperature, lava rheology, planetary gravity, and ambient temperature. For any given set of conditions, there exists a maximum length which can be achieved by an individual flow lobe, and this corresponds to the condition in which no further forward motion of the flow front can occur due to cooling. Flow lobes that achieve this maximum length are termed "cooling-limited" [5]. Pinkerton and Wilson [4] have shown that the cooling limit for flows with a wide range of compositions corresponds to the point at which the Gratz number of the flow falls from an initially high value to a value of ~300. Many lava flows stop advancing before this limit is reached due to cessation of lava output from the feeder vent. These flows are termed "volume-limited" [5].

A cooling-limited lava flow can reach distances from the source vent greater than its basic cooling-limited length if breakouts occur from the region behind the flow front (or the flow front itself) [4, 6]. Such behaviour is frequently observed in the field [6] and results from the fact that it is the progressive cooling of the flow front which limits the motion, not cooling throughout the interior of the flow. As a flow advances, the apparent yield strength of the front and the adjacent levées increases to a point where there is insufficent driving force to cause further forward movement of the frontal material. However, because cooling in the interior of the flow is much slower than cooling at the edges, the lava in the channel not far behind the flow front is still fluid enough to continue flowing after the flow front itself stops advancing. It is this fact which allows breakouts and subsequent further lengthening of the channel to occur. However, some cooling of the channel lava must occur during transport from the vent, and thus there will be an upper limit to how far this material can flow before it has cooled to the point where no further movement is possible. The question addressed here is thus how many times can lava break out from the front of a cooling-limited flow before this condition is reached and, thus, what is the absolute maximum distance that lava can travel from its vent by successive breakouts from the fronts of a series of cooling-limited lobes.

The model: Our current model uses as inputs the viscosity and yield strength of the material forming the frontal levées of a flow, and the ground slope and dense-rock equivalent volume effusion rate from the vent. These values are used to define the width and depth of the channelised flow from equations given by Hulme [7]. The cooling-limited length of the flow (corresponding to a Gratz number of 300) is then calculated and the time taken for the flow to reach this length is found. The amount of cooling experienced by the channel lava during this time is then obtained by assuming that cooling occurs by conduction from the upper and lower surface of the flow at the same rate [8]. In reality cooling will be more rapid from the upper surface than from the base of the flow, and future elaborations of our model will address this issue. However, by varying the chosen ambient temperature it is possible to make some assessment with this simplified model of the effects of the different cooling rates. As long as the channel lava is still hot enough to continue to flow when the flow front stops, a breakout occurs; the model then calculates the cooling which takes place during this and all subsequent breakouts. Once the temperature of the lava falls to the point where breakouts are no longer possible, the program backtracks to find at what point during the emplacement of the last lobe cooling would have stopped motion, and thus a final length for the lobe and the flow as a whole are calculated. Two versions of the program have been used, which assess the limitations on lava flow differently. In one program it is assumed that the channel lava ceases flow when it cools to the point where its yield strength is equal to that of the channel levées. In the other version of the program cooling continues until the channel lava viscosity is equal to that of the levées. We calculated pairs of viscosity and yield strength values for the levées of 10 cooling-limited flows from the Pu'u 'O'o eruption and found that the levée temperatures corresponding to these pairs of values are not the

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same. The levée yield strength value consistently corresponds to a temperature 30-100 °C higher than the corresponding viscosity value. The reason for this behaviour is currently unclear and is under further investigation, but it means that the yield strength limited model always produces shorter flows, as the amount of cooling that must occur before flow stops is less than in the viscosity limited case. The Pu'u 'O'o flows have levée viscosities of 1.3×10^4 to 7.6×10^5 Pa s, corresponding to a temperature range of 1030 to 1080 °C, while the yield strength range is 980 to 7800 Pa corresponding to temperatures of 1119 to 1128 °C. The solidus of basalt is ~1000 °C, so that the highest viscosity levées correspond to lava that has almost solidified.

Results: The model was run for effusion rates of 10 to 1000 m^3/s; ground slopes of 1-60°; lava temperatures of 1150 to 1250 °C; levée yield strengths of 500 to 10000 Pa; levée viscosities of 10^3 to 10^6 Pa s and ambient temperatures of 10 to 1000 °C. While the resulting flows vary widely in length (from 3.5 to 125 km), a consistent pattern of behaviour emerges. In almost all cases the model flows never result in more than 3 lobes forming (i.e., two frontal breakouts). Exceptions to this are the very hottest flows, which may produce a fourth lobe, and the lowest viscosity flows, in which only two lobes form. As mentioned above, the current model overestimates the amount of cooling experienced by a flow because it assumes the same cooling rate from the top and bottom of the flow. To assess how much this would affect our findings we ran the model for a range of different ambient temperatures. The results show that only when the ambient temperature exceeds ~500 °C does this have a significant effect on the number of flow breakouts which occur. Thus, while further modelling needs to be done, we suspect that the current model results will not differ significantly from those in which the cooling rate is treated more correctly. It should be noted however that, at ambient temperatures above 500 °C, the exact temperature of the surroundings has a profound effect on the number of breakouts experienced by a flow and, while the situation is more complex in detail, this does reinforce the idea that a tube-fed flow which is insulated from its surrounds may achieve much greater lengths than an open channel flow.

Discussion: While the results of this study are considered only preliminary due to the need for a better treatment of the levée rheology and of the flow cooling, the consistency of our current results over a wide range of conditions suggest that a more detailed model is unlikely to alter our conclusions significantly. The main implication of this model is that, while individual flow lobes vary greatly in length, a cooling-limited flow can only in very rare cases grow to more than 3 times the length of the initial cooling-limited lobe length, the number of lobes therefore being independent of the actual lobe length. Thus, observation of the emplacement of an initial cooling-limited lobe in the field can be used to make a relatively precise prediction of the maximum length that subsequent breakouts from this flow lobe can travel from the vent. Alternatively, knowing the effusion rate of an eruption and the ground slope, a maximum length can be predicted by assuming reasonable levée rheological properties. Thus, for a given volcano, expected maximum flow length ranges can be calculated.

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