THE ROLE OF MAGMA RECYCLING IN CONTROLLING THE BEHAVIOUR OF HAWAIIAN-STYLE LAVA FOUNTAINS: E.A. Parfitt[1], L. Wilson[1,2], and J.W. Head III[1], [1]Geological Sciences Department, Brown University, Providence RI 02912, U.S.A. [2]Environmental Science Division, Lancaster University, Lancaster LA1 4YQ, U.K.

Introduction: It is common during the explosive eruption of a mafic magma for a lava fountain to form over the vent. The fountain consists of a mixture of liquid clots and magmatic gases, and arises because sufficient volatiles exsolve from the magma during its ascent and decompression to form a population of gas bubbles which occupies more than 75% of the bulk fluid at some finite depth below the surface vent. When this value is exceeded, the magma disrupts and the mixture of gas and pyroclasts emerges from the vent as a jet within which the clasts are suffciently large to behave ballistically. The height, H, of this jet, or lava fountain, is given by:

$$u_a^2 = 2\,g\,H \qquad (1)$$

where u_a is the mean eruption speed in the vent and g is the acceleration due to gravity. In this way, the fountain height can be used to deduce the eruption speed which, as long as the mass eruption rate is known at least approximately, can be used to infer the amount of gas released from the magma [1]. On reaching the ground, the clasts will accummulate and, depending on their temperature and size, will either form hot, mobile, rootless flows and relatively minor vent structures or the lava clasts will have cooled considerably in flight and form a sizeable unwelded cinder cone on landing [2,3]. If any kind of spatter rampart or cinder cone develops, (and one usually does), this provides a topographic constraint on clots and clasts whose trajectories cause them to land close to the vent. In some cases these topographic structures can almost completely surround a localised conduit-type vent, and lead to the development of a distinct lava pond, through which the fountain will punch up (e.g., 4). In a typical fissure eruption the situation is probably less extreme some of the accumulating lava clots sliding back into the fissure along the edge of the fountain. Any recycling of material back into a fountain in this way, either by simple "drainback" or from a lava pond, is likely to have a significant effect on the behaviour of the system because energy must be expended in accelerating the entrained material back up into the fountain, thus causing it to behave as though it were being formed by a magma with a lower exsolved gas content than is actually the case. We have developed a model to investigate the significance of this process in terms of reducing fountain heights and altering eruption style. The details of this model are given in a separate paper [5].

Results: (a) Circular vents: We carried out the modelling for circular vents with magma mass fluxes of 10^4 to 10^8 kg/s, exsolved water mass fractions of 0.03 to 2 wt%, and lava pond depths ranging from zero to 50 m, (values typical for the Earth). Fig. 1 shows the variation of lava fountain height with lava pond depth for a range of erupted mass fluxes at a constant exsolved magma water content of 0.3 wt %. It is readily apparent that a pond only a very few meters in depth can greatly reduce the height of even an energetic lava fountain. For example, a fountain having a mass flux of 10^6 kg/s and an exsolved gas content of 0.3 wt% will have a height of 501 m in the absence of any lava ponding but the height will decrease to 263 m if a pond 5 m deep is present within the vent. For a given gas content the lowest mass flux eruptions are more susceptible to the effects of entrainment than are higher mass flux events. For a constant mass flux and variable gas content we find that the fractional decrease in fountain height as pond depth increases does not vary greatly for different gas contents but higher gas content eruptions are somewhat more susceptible to the effects of entrainment than are low gas content eruptions. (b) Fissure vents: Figure 2 gives the variation of lava fountain height with lava pond depth for a range of erupted mass fluxes per unit length of fissure at a constant exsolved magma water content of 0.3 wt%. Again, ponds only a few meters in depth can greatly reduce lava fountain heights. For example, for a fountain having a mass flux per unit length of 10^5 kg s^{-1} m^{-1} and an exsolved gas content of 0.3 wt% the fountain will have a height of 467 m in the absence of any lava ponding but the height will decrease to 409 m if a pond 2 m deep is present around the fissure. Fig. 2 shows that, as in the central vent case, for a given gas content the lowest mass flux eruptions are more susceptible to the effects of entrainment than are higher mass flux events. For a constant mass flux and variable gas content we find that the fractional decrease in fountain height as pond depth increases is greater for high gas contents than low gas contents, as was the case for the central vent example.

Discussion: Our model results have several important implications for observations of explosive basaltic eruptions. Most basaltic eruptions start as a "curtain of fire", in which magma erupts from a fissure which may be hundreds to thousands of metres in length. As the eruption proceeds, the fissure vents tend to localise so that lava issues from only one or two points along the fissure [4, 6-8]. If the eruption continues for long enough, this localisation will continue to the point where accumulation of spatter and cinders around the vent produces a central cone (e.g., 3,4). If the total mass flux does not decline significantly during the process of localisation, then the mass

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flux per unit length of fissure will increase rapidly as vent localisation occurs. This localisation will have a dramatic impact on the heights of the vent fountains for two reasons. Firstly, as the vent geometry becomes more equant the energy losses due to friction within the vent are reduced [9] and the fountain height will increase. In addition, however, our results demonstrate that fissure vents are more susceptible to the effects of entrainment than are central vents. Thus, we expect that, for the same amount of entrainment, as the vent becomes localised the fountain height will increase by an amount greater than that which can be explained by reduced friction losses alone. For example, for an eruption with a total mass flux of 10^6 kg/s, an exsolved gas content of 0.3 wt%, an initial fissure length of 1 km (and therefore a mass flux per unit length of 10^3 kg m^{-1} s^{-1}) and an equivalent pond depth of 1 m. The fissure fountains are predicted to have an initial height of 32 m; this height increases to 225 m as the fissure length decreases to 100 m and reaches a maximum value of 425 m by the time the vent has become circular. These results are consistent with field observations on historic eruptions (e.g., 8, 10-11). The strong susceptibility of fissure eruptions to the effects of reentrainment makes for the possibility of eruptions in which the behaviour can appear to be strombolian rather than hawaiian in nature, simply because the large degree of entrainment almost completely suppresses steady fountaining. Because strombolian activity normally reflects very low eruptive mass fluxes or very low gas contents (or both) [9,12], the observation of apparent strombolian activity could lead to serious misinterpretation of the magma gas content and eruption dynamics. Finally, although many basaltic eruptions are shortlived and never progress beyond the initial fissure eruption stage, some basaltic eruptions become centralized at a single vent where eruption may continue for many months or years [4,6]. The style of such events varies - some eruptions exhibit vigorous fire fountaining and episodic activity [4] but more commonly such eruptions occur from a central lava pond which overflows intermittently and which exhibits only strombolian spattering and no fountaining [6,13]. As we discuss in a separate paper [14] strombolian eruption from lava ponds is often indicative of low rise speed rather than low gas content and there are cases of eruptions in which, once the rise speed increases, fire fountaining activity is initiated at the vent (e.g., 6,13). In this situation, the vent is partially filled with magma which has largely degassed and which has been cooling for some time and thus has a higher viscosity than fresh magma. Thus, by analogy with our simple entrainment situation, we would expect that this cooling body of degassed magma would inhibit the onset of fire fountaining activity as the rise rate at depth increases to a level at which fountaining should be sustained [14]. Initially, energy is required to set up a circulation pattern in the degassed lava consistent with the upward motion of the new magma through it. As soon as new magma reaches the surface, it will inevitably have entrained some of the old lava, the high density of which will maximise the extent to which fountaining is suppressed. The onset of new activity through the cooling remains of earlier-emplaced lava is therefore always likely to have the appearance of the eruption of new magma which is volatile-poor, and true fire fountaining activity will not be possible until the bulk of the degassed magma has been erupted.

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