THEORETICAL ANALYSIS OF THE EXPLOSIVE EMPLACEMENT OF BASALTIC MAGMA IN LAVA FOUNTAIN ERUPTIONS: IMPLICATIONS FOR PYROCLAST DISPERSAL ON EARTH, VENUS AND MARS; S.A. Fagents and L. Wilson, Environmental Science Division, Lancaster University, Lancaster LA1 4YQ, England, UK.

Summary. A model has been formulated and implemented as a set of FORTRAN computer routines to simulate basaltic lava fountain eruptions. The model is used to make some predictions of the types of near-vent structure that should be formed for any given set of eruption initial conditions. It is found that the magma mass flux, exsolved volatile fraction and planetary environment most strongly control the dynamics of lava fountain activity. The fountain structure, in turn, determines the nature and morphology of the resulting volcanic feature, which may involve pyroclast coalescence into a lava flow, or the formation of spatter or cinder deposits. The model analyses are tested against terrestrial field and remote sensing data and some predictions for deposits on Venus and Mars are offered.

Introduction. It is well established that basaltic volcanism is a fundamentally important process operating on the terrestrial planets, both as a mechanism for heat transfer and as a resurfacing process. On Venus and Mars, the apparent absence of plate tectonics and surficial oceans implies that volcanic activity has even greater significance as a modifying process. Terrestrial explosive basaltic eruptions often manifest themselves as hawaiian style lava fountains, driven by the escape and expansion of magmatic volatiles, which tear the magma apart and eject the pyroclasts from the vent in a gas stream. On any given planet two factors, the exsolved volatile fraction and the magma mass flux, most strongly control the fountain dynamic structure and the pyroclast size distribution. These factors determine the amount of pyroclast cooling and the rate of accumulation at the ground surface [1], which together determine the extent, nature and morphology of the resulting deposit. Common deposits include: lava flows or ponds, spatter ramparts or cinder cones. In addition, planetary environmental factors (most importantly the atmospheric pressure and acceleration due to gravity) also significantly affect the style of eruption [2].

Fountain Model. A model has been formulated to simulate the ascent, fragmentation, eruption, flight and deposition of basaltic magma in order to explore the variations in the types of near-vent structure produced for any given set if magma initial conditions and planetary environment [3]. This draws on existing treatments of magma ascent and eruption [4,5] and computations of pyroclast trajectories [6], but also incorporates an approximation to the motions of volcanic and atmospheric gas induced by the erupting stream of gas and pyroclasts. There exist theoretical [7] and experimental [8,9] information on the way in which a jet of fluid interacts with a second fluid surrounding it. In this case the volcanic jet entrains the atmospheric gas, which causes a decrease in the upward motion of the jet and induces an inward and upward motion in the atmosphere. This information has been used to construct a model of the gas flow-field, and once the velocity and size distributions of the emerging pyroclasts have been specified, the paths of the pyroclasts through the gas flow-field can be computed, taking into account the details of the aerodynamic drag forces acting on the clasts. By keeping track of the landing sites of individual pyroclasts, a much more accurate prediction of the dispersal of pyroclasts from such eruptions than have been inferred by previous workers, who have ignored the presence of such a dynamic gas flow-field and computed pyroclast ranges as if in a vacuum [5,10,11]. Simulations have been performed for a wide range of values of magma mass flux and exsolved gas fraction, and for planetary environments representing the Earth, Venus and Mars.

Results and Discussion. The table below gives some results of the modeling for the Earth, Venus and Mars when the magma mass eruption rate is taken as 10^6 kg s^{-1}, the conduit geometry is cylindrical and the driving volatile is H_2O. The figures given for column height represent the height at which the upward gas velocity becomes equal to zero (left-hand figure) and 5 m s^{-1} (right-hand figure). For Venus the eruption velocity and column height are given for a total volatile content of 1.5 wt%, which is the minimum amount of magmatic gas required for magma fragmentation (and hence lava fountain activity) to occur. For the Earth and Mars values are given for volatile contents of 1.0 (in the upper end of the range of gas contents occurring in terrestrial basalts) and 1.5 (for comparison with Venus).

BASALTIC ERUPTIONS ON EARTH, VENUS AND MARS: **Fagents, S.A. and Wilson, L.**

Planet	Volatile content (wt%)	Eruption Velocity (m s^{-1})	Column Height (m)
Venus	1.5	57	>10000 / 2020
Earth	1.0 1.5	131 167	1900 / 1850 2380 / 2300
Mars	1.0 1.5	226 283	4900 / 4750 6970 / 6530

The values for the eruption velocity clearly show the effect of the planetary atmospheric pressure on the exsolution and expansion of magmatic volatiles during mama ascent: on Venus the high pressure suppresses gas expansion leading to low eruption velocities, whereas on Mars the low pressure leads to much greater exit velocities. Earth represents and intermediate case: a gas content of 1 wt% leads to an eruption velocity of ~130 m s^{-1} and a column height of ~2 km. The computed deposit extends up to ~150 m from the vent, with by far the greatest proportion of material falling within a radius of ~50 m. Within this annulus, the accumulation rate is likely to be sufficiently high for clast welding and/or coalescence to occur, which suggests that spatter deposits and lava flows will be formed. These predictions are in agreement with typical terrestrial deposits where the near-vent lava or spatter deposit is often surrounded by a halo of unwelded material.

On Venus the high atmospheric pressure will suppress gas expansion and retard clast flight outside of the fountain column. Within the column the smallest clasts will remain locked to the gas motion up to great heights since the upward velocity does not reach zero for a great distance (>10 km in the example given in the table). This is a result of the greater atmospheric density on Venus encouraging convection [10]. However, the courser clasts making up the bulk of the fountain will fall out close to the vent (within a few vent radii) as a result of the low gas exit velocity (57 m s^{-1}) which will lead to far denser fountains and more localised deposits. The degree of clast cooling will therefore be minimal which, along with the greater accumulation rate of clasts in a more limited depositional area, implies a greater likelihood of clast coalescence and flow on landing.

On Mars, the low atmospheric pressure encourages gas exsolution and expansion in the conduit, hence greater eruption velocities. This, coupled with the low gravitational acceleration implies greater clast flights and would suggest that clasts undergo a greater degree of cooling. Thus one would expect commonly to observe widely dispersed pyroclastic deposits on Mars. However, the presence of very extensive lava flows suggests that this is not always the case which, in turn, suggests that the likely finer grainsize of martian pyroclasts may be critical in maintaining column density and inhibiting cooling of the pyroclasts. An analysis of the dynamics of magma fragmentation may provide further insight into the importance of pyroclast size distributions on martian lava fountain dynamics.

We are currently working on the details of venusian and martian lava fountain models and will present a comparison of the results of analyses of lava fountain eruptions on the Earth, Venus and Mars with the aim of gaining a better understanding of the modes of formation of observed basaltic features.

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