

VULCANIAN EXPLOSIVE ERUPTIONS: A MECHANISM FOR LOCALISED PYROCLAST DISPERSAL ON VENUS. S.A. Fagents and L. Wilson. Environmental Science Division, Lancaster University, Lancaster LA1 4YQ, U.K.

A model of the mechanisms involved in transient (vulcanian-type) explosive eruptions has enabled us to place constraints on the velocities of blocks ejected during such events on Earth as well as on the excess pressure and concentration of gas in the vent prior to the onset of the explosion. This model, suitably modified, can predict the results of similar eruptions occurring under the differing Venusian environmental conditions. It is found that the much higher atmospheric pressure (~100 bars at the mean planetary radius) dominates the form of the resulting deposit in two main ways: (i) by inhibiting the expansion out of the vent of overpressured gas, hence reducing ejecta velocity; and (ii) by retarding the flight of ejected blocks via drag effects. Thus, it is expected that such deposits will typically extend to ~200 m on Venus as compared to several km for documented terrestrial deposits.

The high atmospheric pressure on Venus, especially in areas of low elevation, acts to reduce or suppress volatile exsolution from magmas erupted at the surface or intruded at shallow depths [1-3]. Steady explosive eruptions, i.e. those that involve the continuous release of gas from magma as it rises towards the surface and fragments at or below the vent to produce a steady stream of pyroclasts, may not be possible on Venus unless magma volatile contents are high relative to those commonly encountered on Earth [1]. However, when magma intrudes close to the surface but fails to erupt (most often because the rise rate is slow enough that excessive cooling intervenes), in general it becomes possible for exsolving volatiles to accumulate at the top of the magma column, initially possibly as a foam layer but later, if the foam collapses [4], as a gas pocket. Magmatic gases may be trapped efficiently beneath a rigid "lid" if magma partly invades and seals some of the near-surface fractures produced by the presence of the dike containing the magma. Alternatively, if potentially volatile compounds are present in the near-surface country rocks, these may be evaporated and trapped as high-pressure gases in any fractures not connected efficiently to the surface. It is not clear if such country rock volatiles might be present on Venus [5], but there is every reason to believe that some magmatic volatiles will commonly be released as mafic magmas approach the surface [6].

The failure of part of the lid overlying an accumulation of high-pressure gases leads to expansion of the locally released gases and acceleration of the overlying rocks. Furthermore, local decompression leads to the propagation of an expansion wave into the surroundings, and this can trigger failure of more of the lid, leading quickly to catastrophic disruption of all of the pressurised region in a vulcanian style explosion [7]. Although such activity is most commonly associated with intermediate-composition magmas on Earth, the mechanism can operate in any magma given suitable conditions controlling the approach of the melt to the surface, and may be the source of localised dark halo deposits on the Moon [8].

We have recently re-examined the details of this explosion mechanism in order to estimate the mass concentration factors and excess pressures for gases driving vulcanian explosions on Earth [9]. We computed the initial velocities and subsequent ranges in air of clasts of various sizes expelled in such explosions, using a wide range of possible initial conditions of gas pressure, gas concentration (relative to the inherent volatile content of the magma) and geometry of the exploding region. By comparing the computed ranges of clasts with the observed ranges of blocks in several eruptions for which field data are available, we have found that quite modest excess gas pressures (1 to 10 MPa, i.e., 10 to 100 bars) and gas concentrations (0.01 to 0.1 mass fraction of the explosion products, i.e. a factor of ~3 concentration over magmatic values) are needed to explain the observed dispersion of ejecta. These results differ from those of an earlier analysis [10] which overestimated the pressures and gas contents needed. This was due to the neglect, in the earlier work, of the fact that the atmosphere surrounding an explosion source must initially move outwards with about the same speed as the early explosion products, thus leading to an overestimation of the initial drag forces acting on the clasts and an underestimation of their ranges.

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A similar analysis is readily carried out for Venus with due allowance for the differing environmental conditions. Clast dispersal is computed using a model of the vertical variation of the Venus atmosphere properties. The likely ranges of gas contents in the disrupted region are estimated using calculations of gas exsolution in rising mafic magmas on Venus [6, 11]. These suggest that, since gas exsolution is likely to occur over a smaller range of vertical depths on Venus (the high surface pressure must be added to the lithostatic pressure to obtain the minimum total pressure acting on a magma at a given depth), available amounts of gas are likely to be somewhat less than on Earth. However, if the magma body degasses while remaining close to the surface for a length of time, then the ratio of the gas mass to the caprock mass may significantly exceed magmatic gas contents. Maximum gas pressures in the disrupted region are assumed to be limited (as on Earth) by the tensile or shear strengths of the overlying rocks; the high Venus surface temperature may mean that these strengths are also somewhat less than on Earth. Sizes of regions in which magmatic gas may accumulate are dictated by the typical dimensions of near-surface dikes. There are two possibilities here: if mafic dikes propagate from shallow magma reservoirs then they are likely to have similar widths to such dikes on Earth, since both the planetary gravity [12, 13] and the total range of depths at which neutral-buoyancy zone reservoirs reside [6] are similar. However, there are reasons to suspect that, in low elevation areas on Venus, shallow reservoirs will be absent and magma will rise directly from mantle partial melt zones at depths of ~10 to 20 km [6], leading to wider near-surface dikes than are common on Earth. Elasticity theory [14] suggests that the width factor will increase only as the square root of the depth factor, as a first approximation, however, implying dikes 2 to 3 times wider. On the basis of these considerations we have used gas contents in the explosion products of 0.01 to 0.1 mass fraction, excess pressures up to 100 MPa, and source region sizes up to 50 m.

The results of numerous simulated explosions with initial conditions chosen from the above ranges show that coarse clast ranges are expected to be no greater than ~350 m under the most extreme circumstances. The table below presents values of ejection velocity in m/s and range in m for blocks 2 m in diameter ejected from explosions with initial excess pressure 100 bars and gas region radii 50 m. For each of the volatile species CO₂ and H₂O, results for two values of gas/rock mass ratio are shown. The greater molecular weight of CO₂ ensures that the velocities attained are lower than for H₂O. Variation of the altitude of the vent location illustrates the effect of lower ambient atmospheric pressure on clast ejection velocity and travel distance: for similar initial conditions, blocks will achieve greater velocities and travel further at higher altitudes.

Altitude / (km)	CO ₂				H ₂ O			
	0.05		0.10		0.05		0.10	
	vel.	range	vel.	range	vel.	range	vel.	range
0	3	49	40	140	49	153	160	200
3	15	83	52	169	64	160	112	234
10	43	181	85	266	99	285	157	341

The resolution of Magellan radar data (~100 m/pixel) may not be sufficiently high for such localised deposits to be visible, other than via their effect on sub-pixel surface roughness. It is anticipated that future work on deconvolving roughness from electrical properties of the surface may provide a tool for the detection of such deposits.

References.

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