PYROCLAST SIZES IN TERRESTRIAL AND MARTIAN IGNIMBRITES. Sally E. Heslop & Lionel Wilson, Institute of Environmental and Biological Sciences, University of Lancaster, Lancaster LA1 4YQ, U.K.

Abstract: Using the concept [1] that a collapsed, fountain-like structure over a vent acts as the source of ignimbrites (large-scale pyroclastic flows) produced when a gas/pyroclast mixture is erupted explosively into an atmosphere, it is possible to devise [2] a physical model of the resulting fluid flow-field which allows the pressure and velocity of the "dusty-gas" mixture emerging from the vent to be deduced. Consideration of the drag forces exerted by the dusty gas on relatively large clasts allows us to deduce the sizes of the largest clasts which can just be transported through the vent to contribute to a proximal lag-breccia deposit. We find that putative martian ignimbrite lag-breccia deposits may contain near-vent clasts up to twice as large as those in terrestrial deposits produced in eruptions with the same volatile contents.

Background: Sparks et al. [1] modelled ignimbrites as being generated from "collapsed" eruption columns, too dense to produce a convection cloud in the planetary atmosphere; however, they did not investigate the pressure distribution in the dusty gas in the vicinity of the vent. Consideration of the dynamics of the fountain which forms over the vent [2] shows that expansion of the gas phase in the central, rising part is largely compensated by recompression during descent in the outer part of the fountain. A stagnation pressure, generally much greater than the local atmospheric pressure, is generated around the vent by the elimination of the vertical momentum of the fluid [3]. The pressure distribution (which acts to divert the flow from vertically downward to radially outward from the vent vicinity) must be continuous across the vent itself and so implies an identical pressure in the gas emerging through the vent.

Model: The variables involved are U_v and P_v (the velocity and pressure of the dusty gas in the vent), R_v and M (the density and viscosity of the gas in the vent), n and x (the mass fraction and molecular weight of the gas exsolved at the level in the feeder dike where magma fragmentation occurs), Q (the universal gas constant), T (the magma temperature), g (the acceleration due to gravity), D (the diameter of the largest clast of density c just transported through the vent), E (the diameter of the largest pyroclast of density d just able to stay locked to the motion of the dusty gas flowing around and supporting the clast of diameter E), m (the mass fraction of all the pyroclasts with diameters not greater than D), R_{ef} (the effective bulk density of the dusty gas supporting the clast of diameter D), C_d (the drag coefficient for turbulent flow of the dusty gas around the largest clast supported), and s (the density of the magmatic liquid).

For high mass flux gas/pyroclast eruptions we can write [4]:

$$U_v^2 = 2\,K\,n\,T\,(Q/x)\,\ln[(n\,Q\,T\,s)/(3\,x\,(1-n)\,P_v)]$$

where K is a constant approximately equal to 0.9 which accounts for the neglect of frictional and potential energy losses in the above equation. The requirement that the vent pressure be equal to the stagnation pressure of the recompressing fluid in the outer part of the fountain leads to:

$$P_v = L\,R_v\,U_v^2$$

where L is a constant close to unity. A further relationship between P_v and R_v can be obtained from the definition of the bulk density:

$$(1/R_v) = [(n\,Q\,T)/(x\,P_v)] + [(1-n)/s]$$

The balance between weight and dusty-gas support for the largest erupted clast gives:

$$D = (3\,R_{ef}\,C_d\,U_v^2)/(4\,g\,c)$$

R_{ef} can be found in terms of the mass fraction, m, of pyroclasts which are capable of behaving as "dust", i.e., of staying locked to the gas motion:

$$R_{ef} = [(m+n)\, R_v\, d]/[m\, R_v + n\, d]$$

where m is the mass fraction of pyroclasts smaller than the critical diameter E for which [5]:

$$(D/U_v) >> (E^2\, d)/(18\ M)$$

The relation between m and E for terrestrial ignimbrites is taken from [6].

Results: This system of equations can be solved recursively from any initial (preferably small) estimate of the value of E to yield P_v, U_v and D as a function of n. In Table 1, values of D are given for Mars (D_m) and the Earth (D_e) for several values of n for x = 18 (i.e., water as the magmatic volatile). Since n is the mass fraction of exsolved gas, the solubility laws for water in magmas can be used to find the equivalent total water content which is implied. The values for both basaltic (n-bas) and rhyolitic (n-rhy) magmas are shown in Table 1. Clearly, the chemistry of the magma makes little difference to the implied relationships: maximum erupted clast size increases rather faster than linearly with total magma gas content, being ~4 times larger on Mars than Earth. It should be noted that the largest sizes yet identified in terrestrial deposits have diameters generally less than 10 m [6], several times smaller than the theoretical maximum, but this probably just reflects the unavailability of coarser clasts.

Discussion: It is known that ignimbrite-forming eruptions (as distinct from those that produce convecting plinian eruption clouds) can only occur for a given mass discharge rate when the exsolved magma volatile content is less than some critical value [1]. These critical values have been calculated for both Earth [1] and Mars [7] and imply that only the first few lines of the Table are likely to be relevant to actual eruption conditions. Computation of the vent sizes (V) for the critical mass discharge rates for each of the gas contents in the Table shows that, on Earth, the vent is always wide enough to accomodate the largest lithic clast which is capable of being transported out by the dusty gas, whereas on Mars this is never the case. As a result, the practical limit on the size of the largest clasts erupted into lag breccias in martian ignimbrites is the vent diameter (actually a size somewhat smaller than this, reflecting the more complex flow field around an object nearly blocking the vent). Thus, martian lag-breccia clasts are likely to be just over twice as large as their terrestrial counterparts for n = 1%, the ratio decreasing somewhat with increasing n. Lithic clasts with sizes between 20 and at least 50 m (for n in the range 1 to 3%) should be readily visible (if they are present) on high-resolution imaging frames obtained by future Mars missions.

Table 1. Parameters of ignimbrite eruptions on Mars and Earth.

n%	n-bas%	n-rhy%	$P_v/(10^5$ Pa)	U_v/(m/s)	D_m/m	D_e/m	V_m/m	V_e/m
1.0	1.171	1.571	19.3	89.4	43	10	22	34
2.0	2.280	2.813	39.1	126.4	109	28	34	81
3.0	3.375	4.001	59.3	154.8	187	51	57	132
4.0	4.462	5.162	79.9	178.7	279	79	98	179
5.0	5.543	6.305	100.8	199.8	378	110	174	215

Key: n% = exsolved water wt.%; n-bas%, n-rhy% = implied total wt.% of water in basalt or rhyolite melt; P_v = gas pressure in vent; U_v = upward speed of dusty gas in vent; D_m, D_e = diameters of largest supported clasts with density 2500 kg/m^3 in vent on Mars and Earth; V_m, V_e = minimum vent diameter to allow an ignimbrite eruption to occur for the given magma gas content.

References: [1] Sparks, R.S.J, Wilson, L. & Hulme, G. (1978). J. geophys. Res. **83**, 1727-1739. [2] Heslop, S. *Aspects of volcanic fluid dynamics*. Ph.D. Thesis, Univ. of Lancaster, U.K. [3] Wilson, L. and Mouginis-Mark, P.J. (1985). NASA TM 88383, 328-330. [4] Wilson, L. (1980). J. Volcanol. geotherm. Res. **8**, 297-313. [5] Saffman, G. (1962). J. fluid Mech. **13,** 120-128. [6] Walker, G.P.L. (1985). J. Volcanol. geotherm. Res. **24**, 157-170. [7] Wilson, L., Head, J.W. & Mouginis-Mark, P.J. (1982). ESA SP 185, 107-113.