DISPERSAL OF TEPHRA IN EXPLOSIVE ERUPTIONS ON MARS (1): STABLE CONVECTING ERUPTION CLOUDS. L. Wilson[1] and J. W. Head[2], [1]Environmental Science Dept., Lancaster Univ., Lancaster LA1 4YQ, UK (l.wilson@lancaster.ac.uk), [2]Dept. of Geological Sciences, Brown Univ., Providence, RI 02912, USA (James_Head@brown.edu).

Overview: We derive results for the dispersal of pyroclasts on Mars from relatively steady, long-lived explosive (plinian and sub-plinian) eruptions taking place at low enough mass-fluxes that their eruption clouds are stable in the current atmosphere. In a closely related study [1] we present an alternative model for pyroclast dispersal in high mass flux explosive eruptions and show that the model applies to many fire-fountain eruptions on Mars. In both cases we discuss the consequences if the atmospheric pressure were higher in the past.

Background: Volcanism has been important throughout Mars' history [2]. Morphologies of early-formed paterae (e.g., Hadriaca, Tyrrhena), together with the presence of fine-grained deposits mantling subjacent cratered terrain [3, 4], suggest that early edifices and deposits were mainly produced by explosive volcanism in contrast to the largely effusive nature of the later shield-building eruptions in Tharsis and Elysium [5-7]. High magma volatile contents and/or incorporation of groundwater may have encouraged the early distinctive explosive eruption style [8-10]. Early models [11-14] suggested that explosive eruption clouds on Mars should rise much higher than on Earth for a given mass eruption rate [11]. However, [13] showed that some assumptions made in these models about entrainment of atmospheric gases are not justified above about 20 km height on Mars, so that clouds from high discharge-rate eruptions, expected to convect to much greater heights, cannot do so. In [1] we present a model showing that the products of such eruptions will resemble the umbrella-shaped plumes on Io; here we consider the dispersal of pyroclasts on Mars from stable convective plumes rising to heights up to ~20 km. We add to previous treatments the consequences of the possible formation of accretionary lapilli within rising eruption clouds.

Methods: The inputs to our plume models are a range of magma volatile contents and eruption rates (mass fluxes). For simplicity we treat point-source conduit-type vents rather than fissures. We assume that H_2O dominates exsolved volatile (others can be converted to equivalent H_2O amounts) with values up to 5 mass %, suggested by estimates up to ~2 mass % H_2O in some SNC meteorites [15] and up to 1.9 mass % H_2O, 5.4 mass % CO_2 (4.1 mass % equivalent H_2O) in some ocean floor alkali basalts/nephelinites on Earth [16]. Mass fluxes span 10^5 to 10^8 kg s^{-1}, covering the entire range observed for all types of mafic eruptions on Earth [17]. The methods given by [17] are used to treat conditions beneath the surface. Under current martian conditions essentially all explosive eruptions are choked at the vent [18, 19] and we decompress the erupted gas/clast mixture adiabatically to atmospheric pressure treating it as a pseudo-gas [18]. The resulting eruption clouds are modeled as in [11], derived from [20]. The much lower atmospheric temperatures on Mars [21] than on Earth suggest that condensation of liquid and then solid H_2O onto pyroclasts will be encouraged, and so we model the formation of accretionary lapilli within rising eruption clouds using [22].

Results: Table 1 shows the choked speed, U_v, of gas and small pyroclasts in the vent (it is the same on both planets) as a function of exsolved H_2O mass %, n; and the gas and small pyroclast speeds after decompression to atmospheric pressure on Earth, U_{aE}, and Mars, U_{aM}. As found earlier [11], the speed is approximately proportional to the square root of the exsolved volatile content, and the lower (current) atmospheric pressure on Mars leads to greater speeds there. Given the prediction [13] that eruption clouds will become unstable at heights in excess of ~20 km, we give in Tables 2 and 3 the variations with exsolved magma water content at a constant mass flux (6×10^5 kg s^{-1}), and mass flux at constant water content (2 mass %), respectively, of the radii r of clouds reaching 20 km height and the maximum sizes f_{Max} of pumiceous pyroclasts that can reach this height. Clearly the cloud radii, and hence distances from the vent at which clasts are released, vary significantly, but maximum clasts sizes could commonly be close to 10-12 mm. However, by considering the distribution of gas bubble sizes at the pressure level where most magma fragmentation takes place, [11] found that the range of pyroclast sizes available to an eruption cloud, i.e. the range of sizes leaving the vent, was likely to be a few tens of microns to a few mm. Thus most explosive eruption clouds on Mars are capable of transporting larger clasts to 20 km height than are actually present in the clouds. The role of accretionary lapilli formation is found (Table 4) to be one of aggregating the smaller pyroclasts into lapilli that may have sizes approaching a maximum of 1 mm. Finally we use standard treatments [20, 11] of terminal velocities of clasts to compute the lateral travel distances (Table 5) of clasts with the range of sizes likely to be present in stable eruption clouds reaching 20 km. Note that the atmosphere model [21] has windspeeds of 40 m s^{-1} at 20 km height, decreasing toward the surface, and travel distances are essentially proportional to the wind speed. To the distances in Table 5 must be added the lateral release distances from the cloud edge (*r* in Tables 2 and 3).

Summary: Tables 2, 3 and 5 show that pyroclastic fall deposits on Mars produced by stable convecting eruption clouds should spread up to at least ~100 km from the vent even if accretionary lapilli formation drastically coarsens the grain size distribution, but can readily range up to many thousands of km for any fine (tens of micron) component not involved in lapilli formation. Accretionary lapilli scavenge H_2O from an eruption cloud and emplace it as ice in the fall deposit instead of dispersing it into the atmosphere, with implications for subsequent chemical and morphological evolution of the deposit [23]. If the atmospheric pressure on Mars had been higher in the past, e.g. similar to that of Earth today, this would have influenced all aspects of the eruption process (eruption speed, clast size distribution at the vent, maximum stable cloud rise height, clast fall speed, and wind patterns); clast dispersal would have been greater, but only by a factor of order two, not by orders of magnitude. Finally, these results must be considered in the light of our parallel modeling [1] of quasi-ballistic plumes generated in high mass-flux eruptions. For volatile-rich magmas, such plumes will lead to a similar dispersal pattern of fine clasts to that given here, but ballistic plumes can release the coarsest (i.e. a few mm-sized) clasts into the atmosphere at much greater distances, up to ~100 km from the vent, allowing them to reach ranges of ~300 km.

Table 1. Conditions in and above explosive vents as a function of exsolved magma H_2O content, *n*. U_v is choked speed leaving vent; U_{aE} and U_{aM} are speed after decompressing to local atmospheric pressure on Earth and Mars, respectively.

n/mass %	0.1	0.3	0.5	1	2	3.5	5
U_v/(m s^{-1})	35	61	79	112	158	209	250
U_{aE}/(m s^{-1})	46	104	146	227	344	475	577
U_{aM}/(m s^{-1})	95	176	234	340	488	642	756

Table 2. Eruption cloud radii at 20 km height, *r*, and size of largest pumice that can reach this height, f_{Max}, as a function of exsolved magma H_2O content, *n*, at a constant mass flux of 6 × 10^5 kg s^{-1}. Eruption cloud with 0.1 mass % H_2O collapses forming pyroclastic density currents.

n/mass %	0.1	0.3	0.5	1	2	3.5	5
r/km	-	2.50	2.58	2.65	2.70	2.75	2.80
f_{Max}/mm	-	10.0	10.8	11.2	11.7	12.3	12.9

Table 3. Eruption cloud radii at 20 km height, *r*, and size of largest pumice that can reach this height, f_{Max}, as a function of exsolved magma H_2O content, *n*, at a constant exsolved H_2O content of 2 mass %.

M/(kg s^{-1})	10^5	10^6	10^7
r/km	6.2	7.9	14.5
f_{Max}/mm	3.7	10.8	14.2

Table 4. Maximum sizes, *D*, of accretionary lapilli formed in 20 km high eruption clouds as a function of exsolved magma H_2O content, *n*.

n/mass %	0.1	0.3	0.5	1	2	3.5	5
D/mm	0.90	0.75	0.72	0.69	0.69	0.71	0.73

Table 5. Downwind travel distances *R* of clasts with diameters f released from 20 km height.

f/mm	2	1	0.5	0.2	0.1	0.05	0.02
R/km	10	23	94	585	2340	9360	58500

References: [1] Wilson, L. and Head, J.W., this meeting. [2] Tanaka, K.L. et al. (1992) pp. 345-382 in *Mars*, ed. H. H. Kieffer, et al., Univ. Ariz. Press. [3] Grant, J.A. and Schultz, P.H. (1990) *Icarus, 84*, 166-195. [4] Moore, J.M. (1990) *JGR, 95*, 14279-14289. [5] Carr, M.H. (1973) *JGR, 78*, 4049-4062. [6] Greeley, R. and Spudis P.D. (1981) *Rev. Geophys. Space Phys., 19*, 13-41. [7] Greeley, R. et al. (2000) pp. 75-112 in *Environmental Effects on Volcanic Eruptions: From Deep Oceans to Deep Space*, ed. J.R. Zimbelman, T.K.P. Gregg, Kluwer. [8] Greeley, R. and Crown, D.A. (1990) *JGR, 95*, 7133-7149. [9] Crown, D.A. and Greeley, R. (1993) *JGR, 98*, 3431-3451. [10] Robinson, M.S. et al. (1993) *Icarus, 104*, 301-323. [11] Wilson, L. and Head, J.W. (1994) *Rev. Geophys., 32*, 221-264. [12] Hort, M and Weitz, C.M. (2001) *JGR, 106*, 20547-20562. [13] Glaze, L.S. and Baloga, S.M. (2002) *JGR, 107*, doi: 10.1029/2001JE001830. [14] Kieffer, S.W. (1995) *Science, 269(5229)*, 1385-1391. [15] McSween, H.Y. et al. (2001) *Nature, 409*, 487-490. [16] Dixon, J.E. et al. (1997) *J. Petrol., 38*, 911-939. [17] Wilson, L. and Head, J.W. (1981) *JGR, 86*, 2971-3001. [18] Kieffer, S.W. (1982) pp. 143-157 in *Explosive Volcanism: Inception, Evolution and Natural Hazards*, ed. F.R. Boyd, N.A.S. Press. [19] Mitchell, K.L. (2005) *JVGR., 143*, 187-203. [20] Wilson, L. and Walker, G.P.L. (1987) *G. J. R. Astron. Soc, 89*, 657-679. [21] Moudden, Y. and McConnell, J.C. (2005) *JGR, 110*, doi: 10.1029/2004JE002354. [22] Gilbert, J.S. and Lane, S.J. (1994) *Bull. Volcanol., 56*, 398-411. [23] Fassett, C. I. and Head, J. W., Layered mantling deposits in northeast Arabia Terra, Mars: Noachian-Hesperian sedimentation, erosion and terrain inversion, *JGR*, 2006JE002875, in review, 2007.