BASALTIC PLINIAN ERUPTIONS ON MARS: UPDATED MODELS OF CO-ERUPTED TEPHRA, H_2O, SO_2, S_2, H_2S AND PRECIPITATION OF H_2SO_4. Lionel Wilson[1,2] & James W. Head[2] [1]Lancaster Environment Centre, Lancaster Univ., Lancaster LA1 4YQ, U.K. (l.wilson@lancaster.ac.uk). [2]Dept. Earth, Environmental & Planetary Sciences, Brown Univ., Providence, RI 02912, U.S.A. (James_Head@brown.edu).

Introduction: The current low atmospheric pressure on Mars and the fact that the acceleration due to gravity is ~38% that of Earth have readily predictable physical volcanic consequences [1, 2]. Specifically, since volatile solubility in magmas is mainly pressure-dependent, by the time magma reaches the surface of Mars it will have exsolved a greater mass fraction of all available volatiles than the same magma erupted on Earth. Those volatiles will expand more than they would on Earth, making more energy available to power explosive activity feeding basaltic plinian eruption plumes. The degree of fragmentation of magma erupted as pyroclasts will be greater, and the resulting smaller pyroclasts will be ejected at greater speeds. Further, the fact that the largest martian volcanoes extend vertically over close to 2 scale heights of the martian atmosphere means that the amounts of volatiles released in explosive activity will have been different for lowland and shield volcano summit eruptions.

Early studies of martian volcanism assumed that the commonest magmatic volatiles on Mars would be the same as on Earth, water and CO_2 [1, 2]. There is now a growing body of information on the likely species and amounts of volatiles released by martian magmas as a function of pressure, and this prompts a new appraisal of the implications. Specifically, Gaillard et al. [3] show that the proportions of SO_2, S_2 and H_2S, relative to CO_2 and CO, released from martian magmas increases dramatically as the final pressure experienced by the magma on eruption decreases through the range 10 bars to 10 millibars (Fig. 1). The

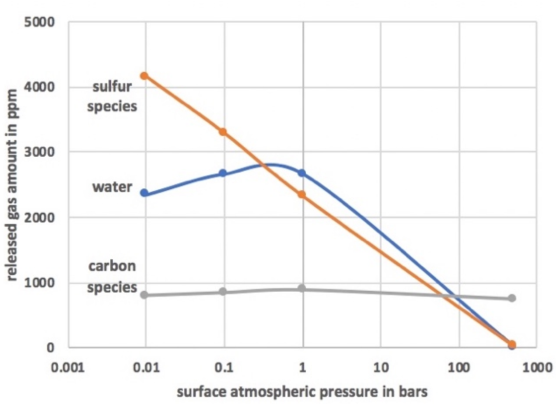

Figure 1. Absolute amounts of sulfur species (SO_2, S_2 and H_2S), water, and carbon species (CO_2 and CO) released as a function of pressure by relatively volatile-rich martian magma [3].

amount of H_2O released also increases dramatically over this pressure range. The current martian atmospheric pressure ranges from ~6 mbars in lowland areas to less than 1 mbar at shield volcano summits, and is postulated to have been at least a few bars early in the planet's history [4]. Clearly atmospheric pressure loss must have had a profound effect on both the amounts and species of gases released by volcanic activity on Mars and of chemical interactions between volcanic gases and surface rocks. We discuss in companion abstracts [5] the formation of sulfuric acid and sulfates, and focus here on the volcanic issues.

Dynamic issues: Migration of melt formed by pressure reduction in rising parts of mantle convection systems is slow (meters/year, [6]) encouraging thermodynamic equilibrium. Melt segregation into dikes when brittle cracks nucleate is also a slow process. Mafic magma flow speed at depth in dikes connected to the surface is orders of magnitude faster (~0.1 meter/second) and gas exsolution and expansion increase it (~1 m/s, [7]). If the combination of released gas volume fraction and shear rate in the magma become large enough, magma fragmentation to feed an explosive eruption occurs and speeds reach 10s of m/s [7]. Gas release and expansion is pressure-dependent, and the pressure in a magma cannot be very greatly different from the ambient lithostatic pressure [8]. Lithostatic pressure is proportional to depth and to the acceleration due to gravity, only 38% that of Earth on Mars. Thus, all the processes involving subsurface volatile release and expansion take place over vertical distances 2.6 times greater on Mars than Earth but at similar speeds until the magma approaches close to the surface, thus ensuring that the time scale for geochemical interactions is also as least twice as long on Mars. After gas and clasts leave the vent, travel time is proportional to (launch speed)^2 and inversely proportional to the acceleration due to gravity, and so is also greater than on Earth. Thermodynamic equilibrium is therefore likely to be closely approached.

Pyroclast grain sizes: The size distribution of pyroclasts from explosive eruptions depends on the depth and pressure at which volatile release begins, the depth at which close packing of bubbles causes the onset of fragmentation, and the atmospheric pressure which dictates when all bubble expansion stops. Using treatments by [1] and [9] we estimate that, for the gas species distribution and pressure-dependent release pattern proposed for martian magmas under current atmospheric conditions by [3], basaltic pyroclast sizes will dominantly be between 10 μm and 5 mm on Mars, to be compared with corresponding ranges of 10 μm to 200 mm for the Earth and 10 μm to 2 mm for the Moon. Assuming Gaussian particle size distributions, the smaller range of clast sizes on Mars leads to an approximately three-fold greater pyroclast surface area available for volatile condensation on Mars than Earth.

Pyroclast dispersal in plumes: Maximum heights of eruption plumes are proportional to (erupted mass flux)$^{1/4}$ [10] as long as the atmospheric and volcanic gases obey the normal gas laws. Above at most 20 km height in the current Mars atmosphere gas densities are so low that atmosphere entrainment become very inefficient), so convecting eruption plumes are not likely to exceed this height on Mars [11]. The mass flux required to reach this height is only 10^5 kg s^{-1} (30 m^3 s^{-1} dense rock equivalent). This is 10 to 100 times smaller than basaltic eruptions rates common on Earth, and [1] showed that the lower gravity on Mars should lead to magma eruption rates being systematically larger than on Earth by a factor of 5, so a very large proportion of all explosive eruptions on Mars in current atmospheric conditions should produce plumes reaching ~20 km height. If very volatile-rich and high discharge rate explosive eruptions occurred on Mars, especially at shield volcano summits, they could effectively punch through the atmosphere and form an "umbrella"-type plume like those on Io [12]. Pyroclasts would then reach heights >> 20 km, but quickly fall back over a 40-60 km radius area to re-encounter the atmosphere at the ∼20 km level and fall to the ground with similar travel times to clasts transported to the 20 km level by eruptions with much smaller mass eruption rates. The effect of this on their total travel distance and deposition area then depends on the mean wind speed and their sizes. In a typical martian wind profile [13], where the speed increases steadily to values of ∼40 m s^{-1}1 at ∼20 km, large (∼5 mm) clasts will fall quickly (at ∼80 m s^{-1}) and travel only a further 10 km from their re-entry point, so the "umbrella" effect will significantly influence their dispersal. In contrast, the smallest (20 μm) clasts will fall extremely slowly (at ∼0.01 m s^{-1}) and could travel 60,000 km, about 3 times around the planet. Clearly for these small clasts the details of how they reach the 20 km high re-entry point are irrelevant. For the intermediate case of 200 μm clasts the fall speed from 20 km averages ∼1 m s^{-1} and the distance travelled is ∼600 km, so in this case too the details of what happens in the vicinity of the vent are of minimal importance. In earlier, higher-pressure and therefore denser martian atmospheres, rise heights of plumes would have been greater, fall times of pyroclasts longer and dispersal area greater. Pyroclast grainsize distributions would have extended to coarser grain sizes, mainly having the effect of reducing the pyroclast surface area available for chemical reactions.

Chemical consequences of atmosphere evolution: The most important result of atmospheric pressure reduction with time on Mars is the increase in the proportion of sulfur compounds in volcanic gases and the potential for the formation of acid-rich pyroclast layers, especially by eruptions at the summits of shield volcanoes. The volumes of magma discharged in typical eruptions on Mars are most easily estimated from lava flow volumes. These range from ~0.1 km^3 on the southern flanks of Olympus Mons [14] to a few tens of km^3 on the flanks of Elysium Mons [15] to ~300 km^3 for a flow originating between Pavonis and Ascraeus Montes in Tharsis [16], but many of the smaller flows are parts of multi-flow eruptions. A better guide to the largest total volumes erupted in single eruptive episodes is the volumes of caldera collapse events. The individual calderas on the summit of Olympus Mons imply that dense-rock equivalent volumes of 412, 425, 518, 462, 750 and 3675 km^3 of magma left the sub-surface reservoir in discrete events [17]. In some cases this magma was intruded to form giant lateral dikes, but in other cases may have been erupted explosively at the surface. At Arsia Mons the caldera volume implies that as much as 5000 km^3 of magma may have been erupted in one event. With water and SO_2 contents of 2350 and 2667 ppm, respectively [3], a conservative erupted magma volume of 1000 km^3 implies that as much as 1.5 x 10^{13} kg of sulphuric acid could be generated during a single eruption. Assuming that this accumulated on pyroclasts deposited over a 600 km radius area it would form the equivalent of a film of concentrated liquid sulfuric acid about 7 mm deep. We discuss the consequences in companion abstracts [5].

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