A PYROCLASTIC ORIGIN FOR CONES IN ISIDIS PLANITIA: 2. ESTIMATION OF RUNOUT LENGTHS AND PRELIMINARY THERMAL CALCULATIONS.

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Introduction: Isidis Planitia is a 1100 km-wide infilled impact basin in the eastern equatorial region of Mars that is host to an enigmatic feature known as "thumbprint terrain". High-resolution images from Mars Odyssey THEMIS and Mars Express CTX and HiRISE instruments have shown this terrain to be composed of many 200-1000 m diameter, evenly distributed cones, sometimes showing highly organized chain-like spatial patterns [1]. Based on previous results by Ghent et al. [2], we suspect a possible origin for these cones via emplacement and degassing of one or more large basin-filling pyroclastic flows. The primary evidence is that the timing of cone emplacement appears to be contemporaneous with emplacement of the Amazonian-aged AIi unit defined by Tanaka et al. [3] which comprises the basin floor, and that no fluid-origin features (lava, mud, or water) appear around any of the cones in high-resolution images. Therefore, we attempt to constrain the physics of emplacement of such a large deposit through a multi-stage modeling process.

Previous work: In a previous LPSC abstract, we showed results of a box model of a pyroclastic flow with a single grain size, and varied the input parameters to produce estimates of the possible runout lengths of the flow [4]. We have now developed a more nuanced model of the flow based on the constant-flux model of Bursik and Woods (1996) [5]. [2] proposed that devolatilization of a hot ash layer (or of volatiles underlying the deposition site) was readily capable of producing the observed cone sizes and numbers, given a total water volatilization mass of 1000 kg per explosion, using the calculations of [6].

The Pyroclastic Flow Model: We utilized the model of Bursik and Woods (1996) for a radially-symmetrical, turbulent, well-mixed, dilute, isothermal pyroclastic flow neglecting entrainment of air. In this subcritical (i.e. no entrainment) model, we can estimate the runout length of the flow based on its initial mass-flux and assuming the flow stops when its buoyancy equals that of the background atmosphere. We assume that, on commencement of the flow, the erupted gas-particle mixture has reached hydrostatic equilibrium with the atmosphere, so that its density may be approximated by

$$\beta = \frac{p}{nRT}$$

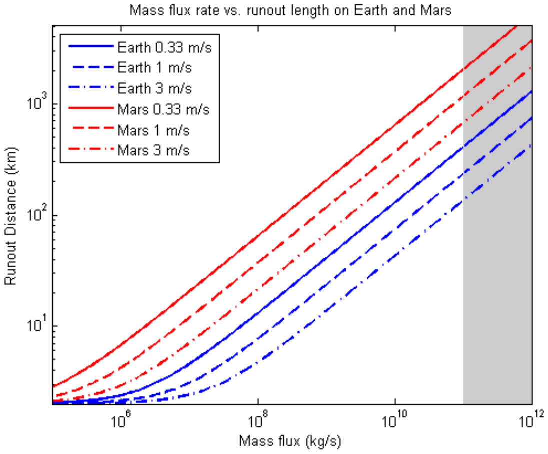

Figure 1: Comparison of PDC runout runout lengths for different eruption mass fluxes on Earth and Mars. For the proposed pyroclastic eruption, it would take between 3 days and a month for the mass of the cone-covered material to be deposited, assuming a mass flux rate between 10^{11} and 10^{12} kg/s (shaded region).

where p is the ambient atmospheric pressure (~600 Pa), n is the mass fraction of gas in the flow, T is the mixture temperature (taken to be 1000 K) and R is the average gas constant for the flow, defined in [7] as:

$$R = \frac{n_m R_m + n_a R_a}{n_m + n_a}$$

where n_m is the mass fraction of volatiles in the initial erupting magma, R_m is the gas constant for these volatiles (taken to be water, R = 461.40), n_a is the amount of entrained background atmosphere, and R_a is the gas constant of this atmosphere (R = 287.05 for Martian atmospheric composition). Thus the runout length occurs when $n = T_a/T$, where T_a is the ambient atmospheric temperature. We can then estimate the runout length via the conservation of particles equation:

$$\frac{d\beta(1-n)}{dr} = -\frac{1}{V}\bar{v}_s\beta(1-n)r$$

where r is the radial distance from the source vent, $\bar{v}_s$ is a constant mean settling velocity for particles of a single size, and V is the volume flux at the source vent, which can be derived from the mass flux M by:

$$V = \beta_0 M$$

where β_0 is the initial mixture density. Integrating this equation between the initial and final radii, we can find the runout length by:

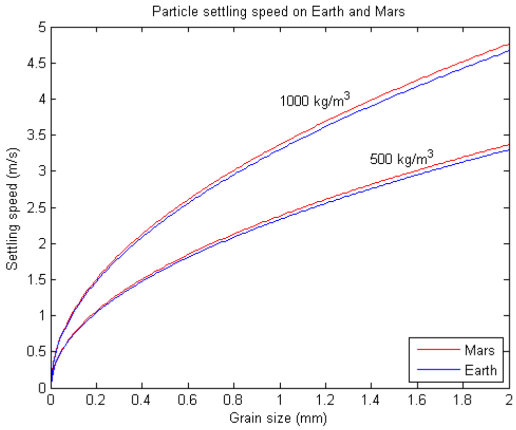

Figure 2: Settling velocities of small particles on Earth and Mars. With a density of 1000 kg/m3, this velocity is ~3 m/s on both Earth and Mars.

$$r_f = \sqrt{r_0^2 + \frac{2V}{\bar{v}_s} \ln\left(\frac{(1-n_0)T_a}{n_0(T-T_a}\right)}$$

We therefore present our results of these runout lengths for a range of settling velocities under Martian pararmeters in Figure 1, compared to the Earth-based results of [5]. The total volume of material in the cone-covered regions is between 3.3×10^4 to 2.6×10^5 km^3, which, assuming a particle density of 1000 kg/m^3, translates to a mass of material between 10^{16} to 10^{17} kg. Divided by a mass flux rate between 10^{11} and 10^{12} kg/s, this means the eruption would have lasted (in stages or in total) 3 to 30 days, consistent with approximations of eruption time from other simulations of supervolcanic explosive eruptions [8]. In this range, the approximate runout length is 800-2000 km for a settling velocity of 3 m/s (consistent with 1 mm average particle size; see next section). This is more than enough to reach the extent of the observed deposit diameter.

Calculation of Sedimentation Rate and Heat Content of Deposit: We will also calculate the heat content of the deposit in order to determine the feasibility of volatilizing enough material in the deposit to produce cone-forming explosions. This can be determined via the sedimentation rate, S, of particles into the deposit underlying flow coupled with a thermal model of conduction and radiation into the surrounding Martian crust and atmosphere. The sedimentation rate can be determined by

$$S = \bar{v}_s \frac{(1-n_0)P}{n_0 RT} \exp\left(-\frac{\bar{v}_s (r^2 - r_0^2)}{2V}\right)$$

where $\bar{v}_s$ is the mean particle settling velocity, calculated via the Newton impact law [9]:

$$v_s = \sqrt{\frac{4sg'}{3C_d}}$$

where s is the particle diameter (in m), C_d is the drag coefficient (taken to be 1 as in [9] and [5]), and g' is the reduced gravity, given by:

$$g' = \frac{(\rho_p - \rho_0)}{\rho_0} g$$

where g is the Martian gravitational acceleration (~3.7 m s^{-1}) and ρ_p and ρ_0 are the particle and background atmospheric densities, respectively. For comparison, the particle settling velocities of Earth and Mars are shown in Figure 2; while the gravitational acceleration on Mars is less, its atmosphere is less dense, so the velocities are nearly the same. We can then use this settling velocity to constrain the material and energetic input into the deposit and find its total heat content after the flow has completely settled. From this heat content, we will determine whether there is sufficient heat to produce the observed number (and distribution) of cones.

Conclusion: We calculate that a massive, long-lasting explosive volcanic eruption should be able to produce a pyroclastic flow with runout length large enough to fill the Isidis Basin to the extent of the presently-observed AIi unit. This presents a second phase of modeling this runout length using a more refined model, with results consistent with those of our previous effort. We are also attempting to model the thermal evolution of the deposit from this flow, in order to establish whether its retained heat could be enough to create small degassing explosions that could represent a possible origin for the enigmatic thumbprint terrain in Isidis Planitia.

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