A pyroclastic origin for cones in Isidis Planitia: 2. Estimation of runout lengths and preliminary thermal calculations

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Introduction

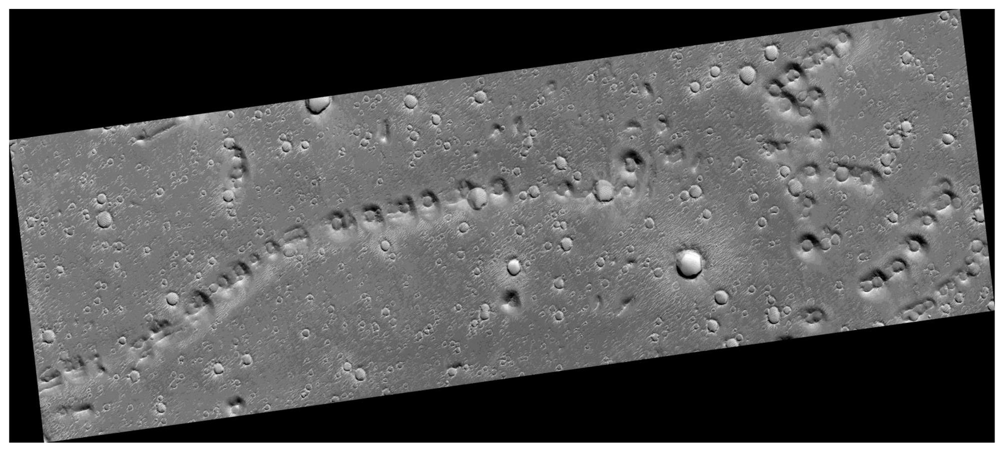
The Isidis Planitia impact basin, in the eastern equatorial region of Mars, contains a peculiar surface geologic unit extending over the majority of its western half. This flat terrain is covered in numerous cone structures on the order of 200-1000 m in diameter, many of which are spatially organized in long, parallel arcuate chains [1]. (A typical example is shown in Fig. 1). The origin of these cones has been a source of much speculation, with hypotheses ranging from glacial morraines to hydrothermal vents [2]. We examine herein an origin for the cones as the result of degassing of a hot blanket of ash from a (or perhaps several) pyroclastic flow(s), using physical modelling to constrain the feasibility of such an event producing a deposit of the observed length scale and retaining enough heat to cause phreatic degassing.

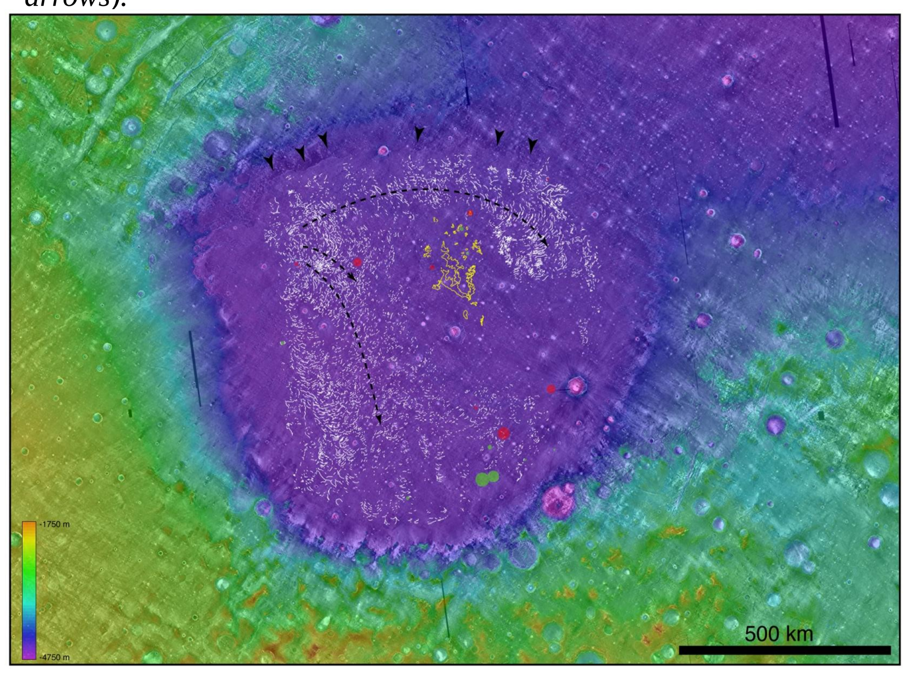
Previous Results

In a previous LPSC abstract [3] we examined a simplified box model of a pyroclastic density current (PDC) to constrain the minimum and maximum expected runout length of such a PDC on Mars, given the previously estimated volume of the deposit [4]. We constrained the input parameters based on either previous estimates of these values for Mars or, in the case of grain size, through derivation from remote-sensing thermal intertia data. However, these results ignored many of the complicated dynamics of a typical PDC, and so here we first reanalyze our results using the more sophisticated model of [5].

Fig. 2 (below): Figure 11 from [4], showing mapped cone chains (white) in Isidis Planitia, as well as dense cone fields (yellow), boundaries of the cone-bearing unit (black triangles), and potential pyroclastic flow lobe directions (black arrows).

Fig. 3 (right): HiRISE image PSP_009177_1985 showing a typical cone chain. The closely-spaced nature of the cones may reflect degassing from a hot pyroclastic flow. Resolution is ~28.7 cm/pixel.





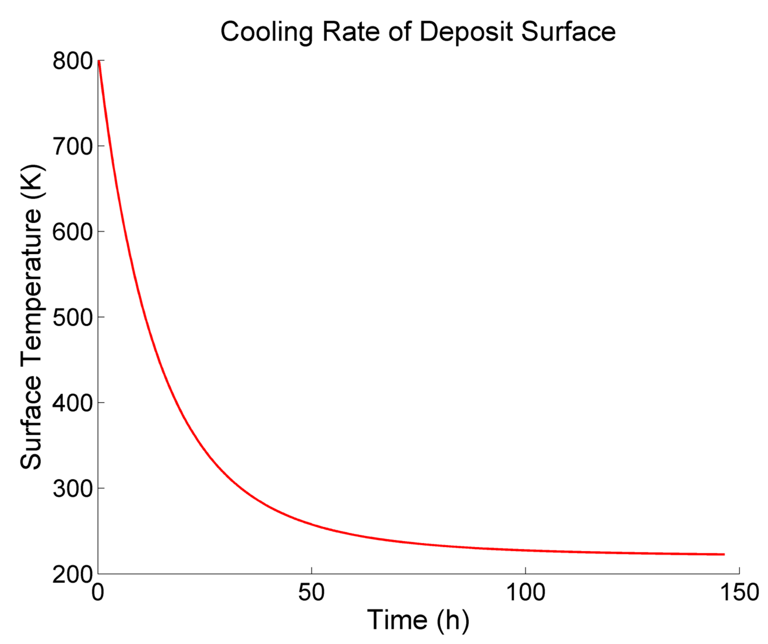


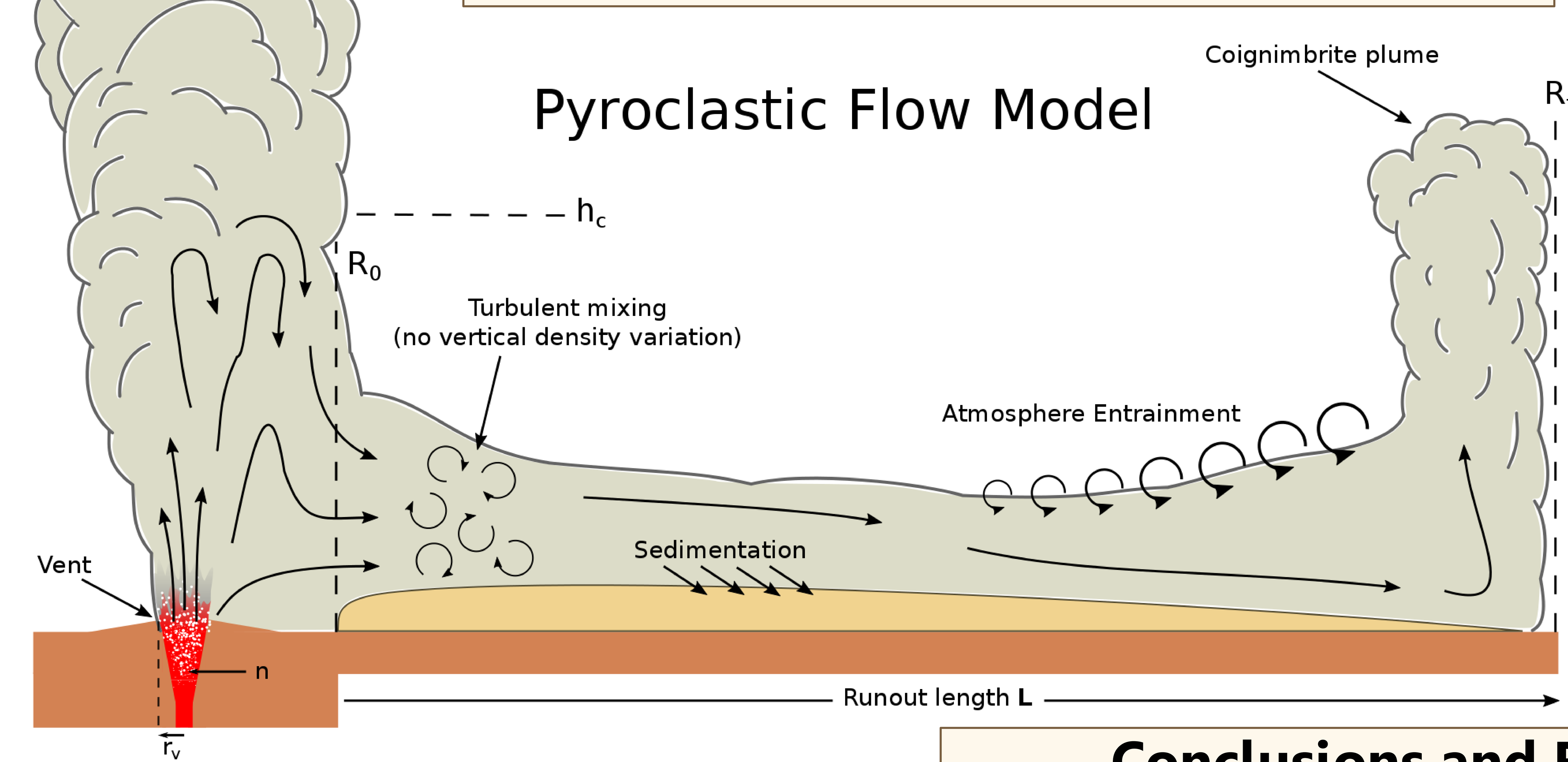
Fig. 3 (above): Surface temperature as a function of time for the cooling deposit.. The curve ends where cooling reached less than 0.01 K per time step, at about 150 h.

Fig. 4 (below): Thermal profiles of a cooling ash layer for a span of 37 Earth years. The layer loses heat via convection at the top and conduction at the bottom.

Fig. 5 (below right): Prediction of a range of clast distances due to an explosion beneath the cooling layer, for a range of temperature and initial gas masses.

Estimating Runout

We used the equations of [5] for a n isothermal, axisymmetric pyroclastic flow that maintains a vertically homogenous density via turbulent mixing throughout its depth. Particles sedimented out the bottom of the flow and atmosphere was entrained until the density of the flow equalled the background atmospheric density, defined as the point of lift-off and formation of a coignimbrite plume. The range of mass fluxes in the flow was derived from consideration of appropriate dissolved mass fractions of gas n and vent radii r_v, as well as maximum attainable heights h_c after [6]. The runout estimates based on these parameters are shown in Fig. 6. On Mars, we expect pyroclastic flows to reach extents at least 4 times those on Earth, due to the lower atmospheric pressure and consequently higher buoyancy gradient available to drive the flow, as well as finer fragmentation of particles leading to lower terminal velocities. We can see that to reach the lengths of the proposed flows in Isidis Planitia, the mass flux would need to be approximately a few times 10^{11} kg/s, attainable in the largest pyroclastic eruptions seen on Earth [7].



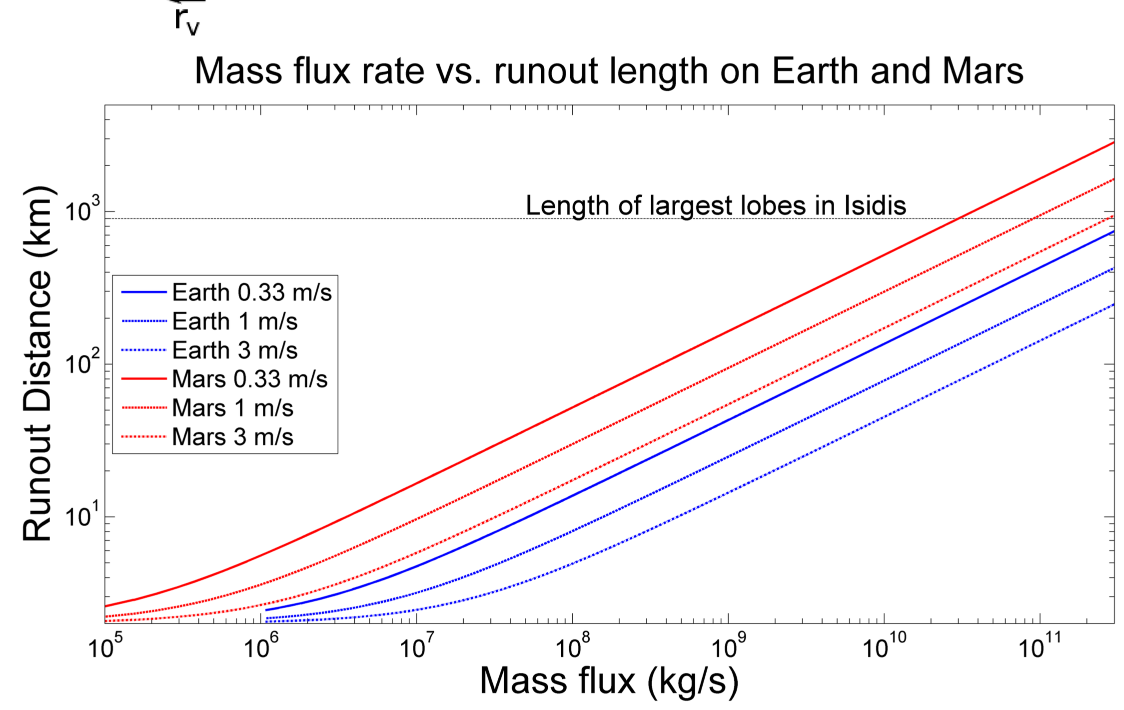


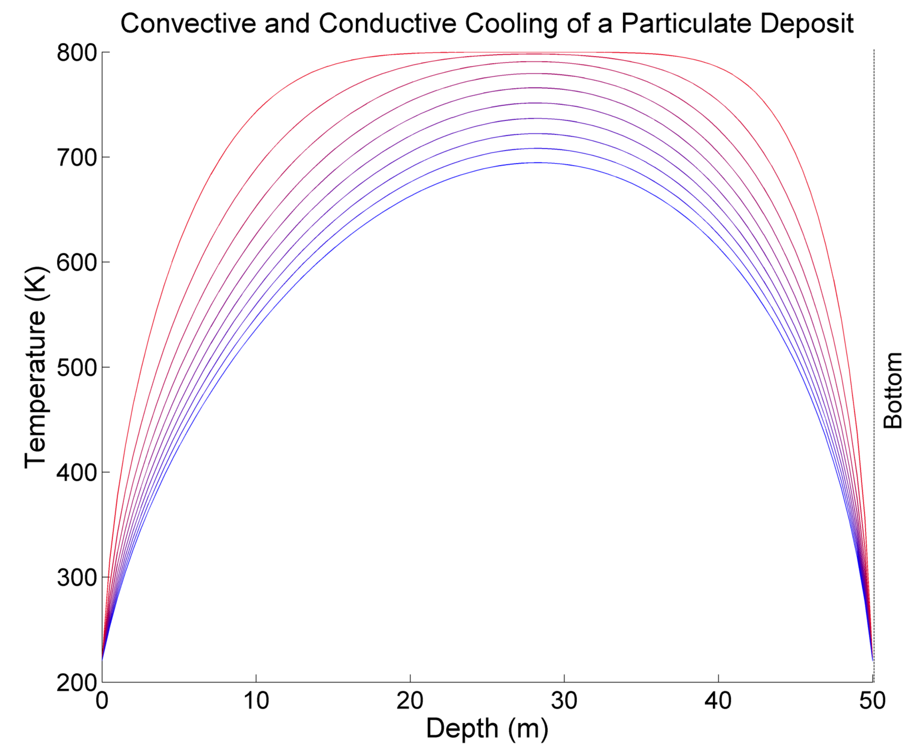
Fig. 6: Results of subcritical pyroclastic flow runout simulations, showing a range of settling velocities (predicted to be approximately equal for Earth and Mars). In this range, mass fluxes would need to be on the order of 2×10^{10} – 2×10^{11} kg/s to reach the 900 km flow-length.

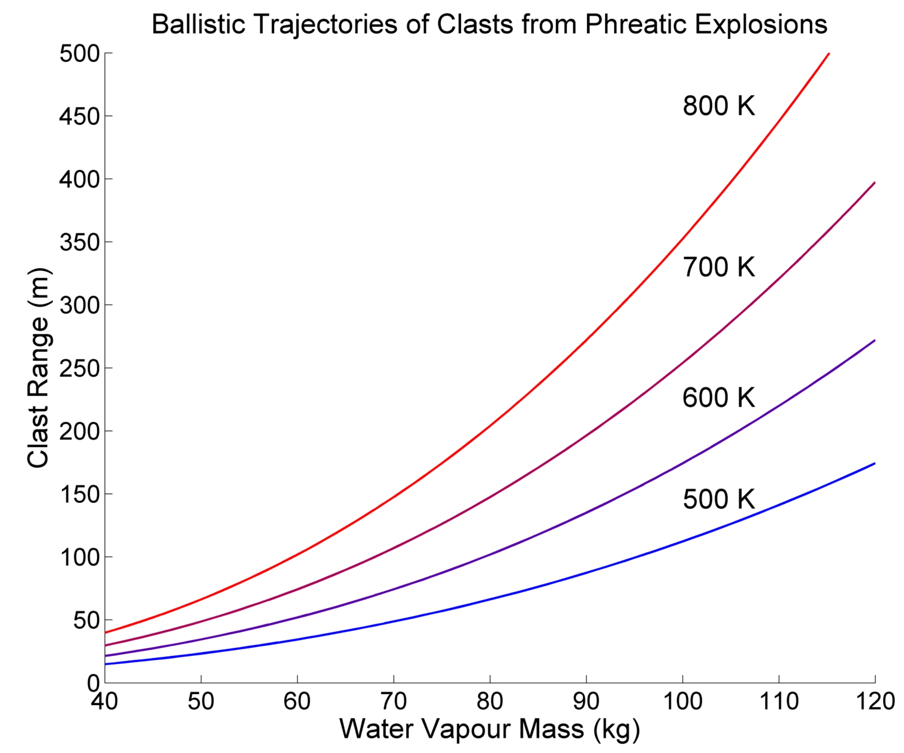
Thermal Model of a Cooling Pyroclastic Deposit

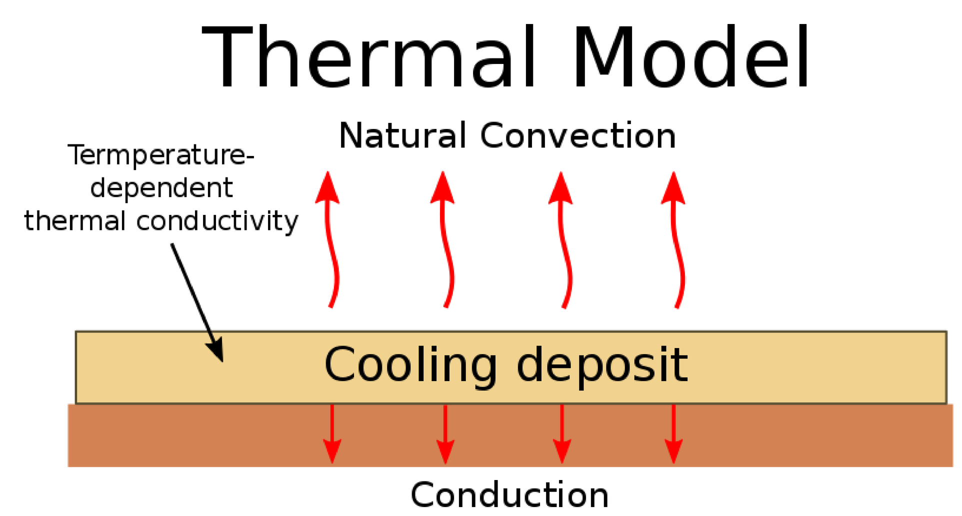
In order to assess the time scale for which cones could form from a single eruption, we carried out a 1D heat diffusion simulation, taking into account the variation of all relevant properties with temperature. We used a central finite differencing scheme and a timestep of 10^{-4} Martian years. The heat was removed from the top of the deposit by natural convection and removed from the bottom via conduction into a fixed-temperature sink at 220 K, near the coldest expected Martian surface temperature at this latitude. We used data from [8] to constrain the viscosity of an assumed pure-CO_2 convecting atmosphere, and heat capacity dataderived from [9] to constrain the regolith intragrain heat capacity. We used the analytic results of [10] to calculate variation of thermal conductivity with temperature and pressure. We assumed the deposit was a single, initially isothermal slab at 800 K with a gradation in mean particle size from 500 microns at the surface up to 0.5 cm at the bottom, and let the simulation evolve for approximately 37 Earth years (20 Martian years in the model). The deposit cooled on a similar timescale to other convective modelling results (Fig. 3) and plots of the temperature distribution show slight concentration of heat in the lower portion of the deposit (Fig. 4).

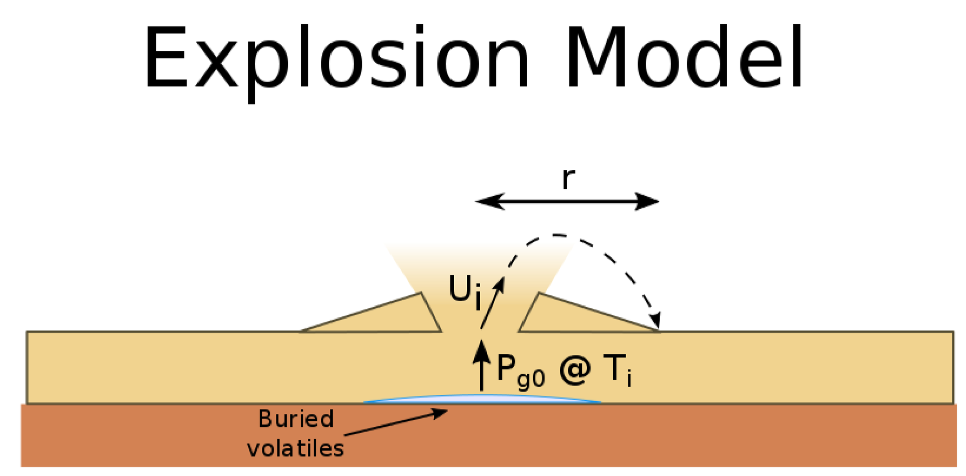
Phreatic Explosions

Fumarolic venting, i.e. venting of volatiles from a post-depositional layer to form degassing pipes or conical constructs, is known to occur post-emplacement for several large pyroclastic flows, e.g. the deposits of Mount St. Helens [11] and the Bishop Tuff [12]. We use the model of [13] to examine the interaction of a gas buried gas-phase component with the hot, possibly welded tuff material, in order to determine the mass of water needed to eject deposit fragments to a distance the size of the observed cones. The critical pressure P_{g0} needed to eject a plug of material is dependent primarily on the thickness and tensile strength of the deposit. Fig. 5 shows the ballistic trajectory results for several initial temperatures and water masses.









Conclusions and Future Work

In order to reach the distance of the largest lobes of the pyroclastic flow seen in Fig. 1, we calculated that the mass flux at the vent of the column-feeding eruption would need to be 2×10^{10} – 2×10^{11} kg/s. Although this is large compared to a typical Martian Plinian eruption on the order of 10^5 – 10^7 kg/s [14], recent evidence suggests that massive volcanic constructs similar to supervolcanoes on Earth exist on Mars and could feed such flows. Additionally, results of our thermal models show that the degassing of an ash layer could provide a steady, ongoing source of cone production, and could explain the paradoxical differences in degradational state of cones in close proximity to one another. Finally, we show that even through a weak ash layer, pressures can build up enough to eject blocks out to the range associated with observed cone diameters.

We intend to proceed with this investigation further; our next steps will be: 1) incorporating the more sophisticated model of Freudnt (1999) in order to assess a range of properties associated with large Martian pyroclastic flows, especially in the supercritical regime, 2) constructing a 2D mass-coupled heat loss model which will examine effects of different initial subsurface temperature distributions and volatile concentrations on the thermal evolution of the deposit and associated cone spacing, and 3) completing the phreatic cone-formation model to properly account for atmospheric drag effects. We may also pursue 2D numerical simulations to better capture dynamics such as variations in vertical density of the flow [15].

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