SOME SIMPLE MODELS FOR ROOTLESS CONE FORMATION ON MARS. L. Keszthelyi[1], [1]Astrogeology Team, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, USA.

Introduction: Volcanism provides a unique tool to sound for water in Mars' geologic past. The interaction between molten lava and surface and ground water produces a range of morphologic features on Earth. Many of these features are interpreted to exist on Mars. Rootless cones (a.k.a. pseudocraters) have been reported in a number of locations on Mars and interpreted to be the result of explosive interaction between the liquid lava and groundwater/ice [1-7]. The enigmatic ring structures seen in Athabasca Valles may have formed by relatively gentle lava-groundwater interaction [8]. Mesas-like features in several areas of Mars are interpreted as constructional features formed by lava erupted under ice and/or water [2,9-10]. However, rootless cones remain the feature most often and definitively cited as evidence of lava-water interaction on Mars.

Despite the repeated use of these rootless cones to infer the presence of water in the shallow subsurface, only limited quantitative information has been extracted from them. The minimum depth to subsurface water or ice has been calculated [7,11] based on the simple assumption that the lava must conductively heat the substrate, melt ice, and boil water. *Greeley and Fagents* [7] also calculate the amount of gas needed to propel clasts to build a rootless cone on Earth and Mars. They concluded that only small amounts of water are necessary for rootless cones to form on Mars.

Simple Steam Accumulation Model: In rootless cone models for Mars, the ability to accumulate steam beneath a lava flow is a prerequisite to forming a cone. A crude model can be used to estimate the conditions under which this is possible. Steam generation is by heat conduction into the substrate: $Q_{gas} = q/(\rho_{gas} L)$, where Q_{gas} is the steam flux, ρ_{gas} is the steam density, L is the latent heat of vaporization, and q is the heat flux. Under steady state conditions, $q = k\,\Delta T/h$, where k is the thermal conductivity of the dry substrate, ΔT is the temperature difference between the base of the lava and the boiling point of water, and h is the thickness of the dry substrate (Fig. 1). Steam can accumulate only if it is generated faster than the escape rate. Steam escape is assumed to be governed by Darcy's law: $Q_{gas} = h\,K\,\Delta P/(W\,\eta)$, where K is the permeability of the substrate, ΔP is the pore steam pressure in the dry substrate (= lithostatic pressure = $\rho_{lava}\,g\,H$), W is the width of the flow, and η is the viscosity of the steam.

Table 1 shows some reasonable values for the input parameters for this model. This model suggests that the permeability of the substrate is a key parameter controlling the ability of steam to accumulate. On low permeability bedrock, even steam generated tens of meters below the surface could not escape. However, for values appropriate for regolith and aeolian sands, the desiccated layer can be no more than a few tens of centimeters thick. This result is in contrast with previous studies that have suggested that rootless cones could form with ground ice several meters below the surface [6,7,11].

Figure 1. Diagram of the geometry of the simple steam accumulation model.

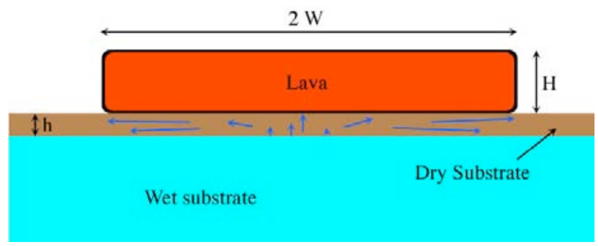

Table 1: Range of reasonable input values for steam accumulation model. h_{crit} is the maximum value for h that will allow steam to accumulate.

Parameter	"Min."	"Mean"	"Max."
ρ_{gas} (10^{-3} kg/m^3)	4.5	4	3.5
L (kJ/kg)	3000	2600	2200
k (Wm/K)	0.1	0.5	1
ΔT (K)	400	500	600
K (m^{-2})	10^{-8}	10^{-10}	10^{-13}
W (m)	100	1000	10000
η (10^{-5} Pa s)	3	3.4	4
ρ_{lava} (kg/m^3)	3000	2000	1500
H (m)	50	20	5
h_{crit} (m)	0.0012	0.23	100

Lessons from Terrestrial Analogs: While placing some constraints on Martian rootless cone formation, field observations on Earth suggest that the simple steam accumulation criterion does not control the formation of rootless cones. Terrestrial cones appear to require sustained and intimate mixing of liquid lava and water (or very wet sediments) [12]. Hawaii field observations suggest that cone construction requires that liquid lava come in direct contact with liquid water [13]. This idea is supported by field observations from ancient rootless cones in Iceland. Rootless cones form in locations where sustained flow of both lava and water are predicted [14,15]. There also are rare clasts of sediments from below the lava flow found incorporated in the rootless cones.

Hawaii observations show that there are several distinct types of explosive hydrovolcanic eruptions: (1) tephra jets, (2) lithic blasts, (3) lava bubble bursts, and (4) lava fountains [13]. The lava fountains are the most efficient at producing substantial constructs. In one case, a 7.5 m tall cone was built in only 20 minutes [13]. These lava fountains are believed to form when a continuous stream of both water and lava are mixed in a confined area, such as a lava tube [13]. The cones are built of agglutinated (welded) spatter and are relatively resistant to erosion. This is the style of activity that forms most rootless cones on Earth and presumably also on Mars.

Tephra jets are also efficient at building cones. An 8-m tall example was built in less than 24 hours [13]. However, in this case, the cone was dominated by unconsolidated tephra and is very easily eroded. Tephra jets form where lava flows into the sea, resulting in unconfined explosions. We consider this type of activity unlikely to explain most of the rootless cones seen on Mars. Lithic blasts and bubble bursts are not efficient at building cones. Lithic blasts occur when there is wholesale mixing of incandescent rock and water, such as when a large volume of hot but solid lava gravitationally collapses into the sea. Bubble bursts are extremely energetic explosions that form when water manages to enter a lava tube system. While bubble bursts generally do not build cones (only low rings), on one occasion a bubble burst vent did build an 8-m tall cone [13].

Existing models can be used to provide some simple constraints on the conditions of lava fountains that would have formed the Martian rootless cones. Ignoring the effect of gas drag, pyroclasts must leave the vent at ~50 m/s (at 70° [7]) to form a typical 50 m radius rootless cone. Wilson and Head [16] provide the following expression to estimate the velocity of the material in a lava fountain: $0.5u^2 = 0.5u_d^2+K(nRT/m)\ln(P_d/P_a)$, where u is the vent velocity, u_d is magma rise rate, K is a factor of about unity, n is wt.% of gas, R is the ideal gas constant, T is the temperature, m is the molecular weight of the gas, P_d is the pressure at which disruption occurs, and P_a is the atmospheric pressure. For a rootless cone, $u_d = 0$, m = 18. P_d is assumed to be the pressure at which the gas volume reaches 75% which results in disruption of the lava and P_a = 600 Pa. Only about 0.03% water is required to enter the lava to produce appropriate fountains on Mars. This same calculation suggests that ~0.2% water is needed to form a similar sized rootless cone on earth. This factor of ~7 reduction in the required volume of water is in accord with the more complete calculation by Greeley and Fagents [7] who conclude that the factor should be between 4 and 16.

The flow velocity in the Martian flood lavas is estimated to be 0.1-3 m/s. Assuming a feeder ~1 m wide, this translates to a lava flux of 100-4x10^5 kg/s into the rootless cone's vent. This in turn requires a steam flux of ~0.04-100 kg/s to feed a lava fountain. To produce steam at this rate requires a heat flux of 1x10^5-4x10^8 W. If the steam is generated in an area equivalent to the footprint of the vent (~1 m^2), and the heat is provided by conduction, then the liquid lava must be no further than 0.4 microns – 1 cm from liquid water. If all the material went into the cone, it could be built in tens of seconds to a few hours. These same calculations suggest that a Hawaiian cone could build in about an hour and the lava and water would have to be separated by no more than 0.3 mm. This matches the field observations.

Conclusions: Based on these simple model calculations, it appears that rootless cones on Mars require water essentially at the surface. Under realistic conditions, steam will accumulate only when the desiccated layer is no more than a few tens of centimeters thick. Furthermore, if the terrestrial observation that lava fountains are needed to form rootless cones also applies to Mars, then the lava and water must have a maximum separation of ~1 cm. Such intimate mixtures of lava and water make it likely that the rootless cones observed in the Elysium region formed when lava and water were simultaneously flowing over the surface.

References:

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