MODELING STEAM PRESSURE UNDER MARTIAN LAVA FLOWS: IMPLICATIONS FOR ROOTLESS ERUPTIONS. C. M. Dundas[1] and L. P. Keszthelyi[1], [1]Astrogeology Science Center, U. S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ, 86001 (cdundas@usgs.gov).

Introduction: Rootless cones are volcanic features formed when lava flows over wet or icy ground, triggering steam explosions and building cones on the flow [1]. Such features were first suggested on Mars based on Viking imagery [e.g., 2-3]. Recent observations with higher-resolution data have strongly supported the occurrence of rootless cones on Mars [e.g., 4-8], although different origins have been proposed for the original candidates [9, 10].

Some aspects of rootless cone formation remain incompletely understood. In particular, it is unclear whether heat conduction through dry soil can initiate eruptions, or if mixing water and lava in a molten fuel-coolant interaction (MFCI) is required [7, 11]. Ground ice emplaced from atmospheric water vapor on Mars is expected to occur under a dry lag typically centimeters to decimeters thick [e.g., 12], depending on latitude and orbital (climate) conditions. Some rootless cones on Mars occur above buried crater rims (Fig. 1) where water melted by lava is likely to drain away if pore space is available, making MFCIs difficult to explain unless ice was (unexpectedly) present at the surface. A better understanding of rootless cone formation could thus help us understand the history of water and ice in locations like Athabasca Valles, where there is evidence for both large floods and recent volcanism.

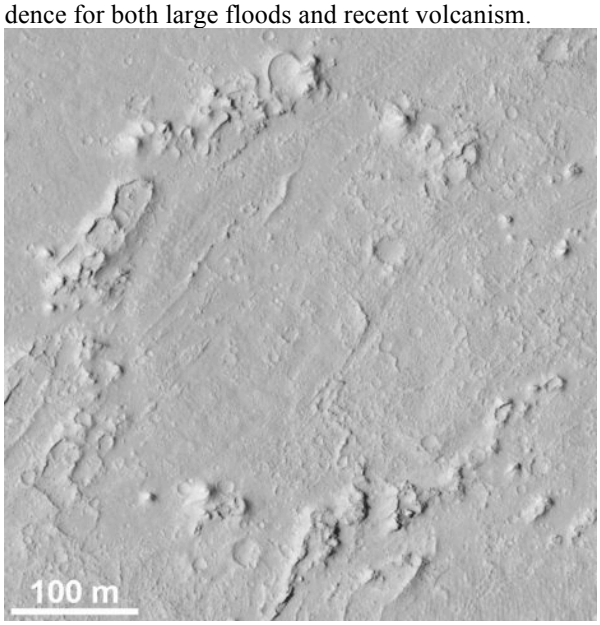

Figure 1: Rootless cones over a lava-covered crater rim (HiRISE image PSP_002648_1880).

Modeling: We investigate the buildup of steam pressure in a dry lag by passive heat conduction using two coupled models. Melting and boiling rates are found with a one-dimensional vertical thermal model, and gas transport and pressure are found with a one-dimensional horizontal model using Darcy's Law.

The thermal model consists of three material layers, each with many model layers at a spacing of 2 mm. These layers are the lava flow, dry lag, and ice-cemented ground, each with variable thermophysical properties. Cooling and crystallization of the lava is modeled following [13]. When phase changes occur in the water/ice substrate, the interface is held at the relevant temperature while the layer undergoes the phase change. The boiling point of water is varied as a function of the steam pressure at the center of the flow (the peak pressure). It is assumed that the flow is instantaneously emplaced without eroding the substrate.

In modeling the pressure we assume that steam is generated uniformly beneath the lava flow at each timestep, with the edge of the flow given an atmospheric-pressure boundary condition. We assume that the flow is symmetric and the substrate is spatially uniform. Lag thickness is increased to account for pore space added due to melting, assuming that water moves downward to fill pore space. Water transport and possible capillary flow are not modeled. The pressure rise is tracked to 1 MPa, a reasonable value to overcome the strength and weight of the lava flow [5].

Scenarios: We consider a 1-km-wide, 10-m-thick lava flow with properties of the Hawaiian basalt modeled by [13]. The regolith is assumed to have a permeability of 10^{-11} or 10^{-13} m^2, consistent with Mars soil analogs [14], and the ice depth is varied from 0.1-1.2 m. Such values are plausible for recent Martian conditions, although ice may be closer to the surface near the poles [12].

Results: For all but the deepest ice table and most permeable lag, the pressure rises to 1 MPa, our estimated pressure to drive explosions. The time for the pressure to rise varies strongly with the ice table depth, ranging from a few days to many months. The pressure rise is shown in Fig. 2. Significant pressure gradients arise near the flow edge, but the interaction between the flow edge and center varies with both permeability and the pressure rise time.

Discussion: Passive heat conduction is capable of building explosive pressures beneath lava flows on Mars with ice at depths of decimeters. This is consistent with initiating rootless cones without MFCIs occurring, although it does not rule them out. After an

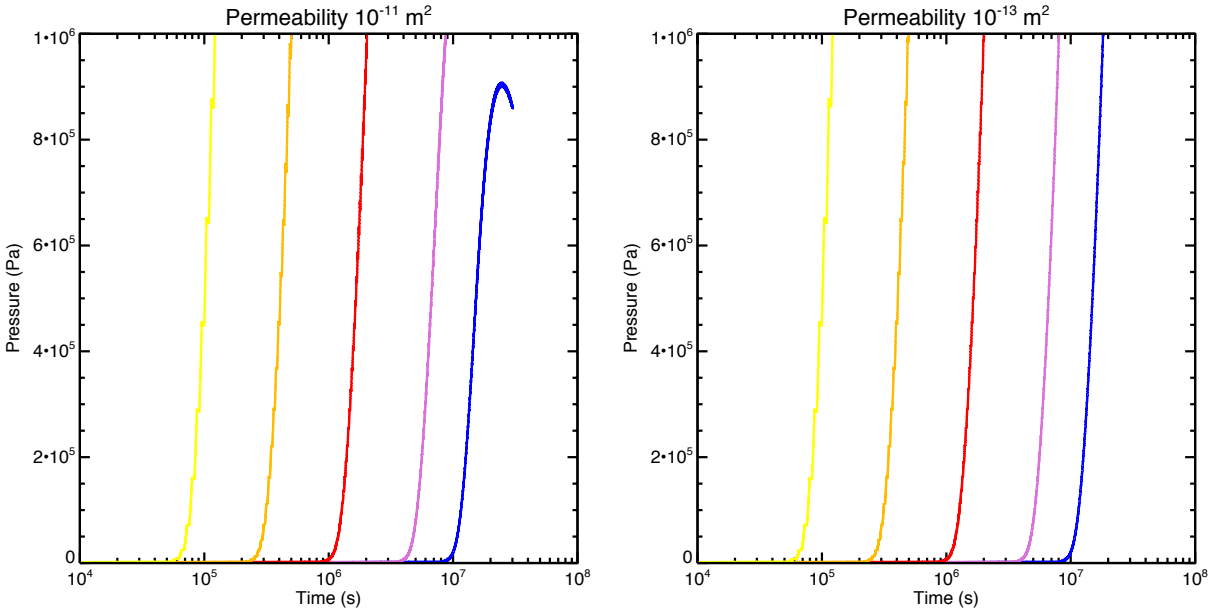

Figure 2: Pressure rise beneath the flow center, for ice depths (left to right) of 0.1, 0.2, 0.4, 0.8 and 1.2 m.

initial explosion, steep pressure gradients would drive inward flow of water, steam and lava, potentially leading to subsequent, ongoing MFCIs contributing to the construction of the rootless cone. This dynamic situation is beyond the scope of our model.

However, there is an important limitation to the passive heat conduction mechanism. The total capacity of gas in a thin lag (treated simply as an adiabatically expanding piston) to do work is inadequate to completely excavate many lava flows. Consequently, we expect this mechanism to operate most effectively where lava flows are thin, such as over buried topographic highs. We note, however, that this is consistent with observations of many Martian rootless cones [Fig. 1; 8, 10]. Lags may also be thickened there if meltwater locally drains away. Also consistent with this mechanism is the occurrence of small rootless cones on a thin portion of a flow [10], where a lower overburden would require a lower explosive pressure.

Two assumptions warrant discussion. First, we did not consider lateral water flow. This is reasonable for the final pressure gradients in the low-permeability cases, but may affect more permeable lags. Second, we do not include the effects of fracturing in the lava on gas flow. This could increase gas escape, but since the fractured thickness is expected to be less than or equal to the lag thickness we do not expect this to change the general nature of our results.

These results indicate that many Martian rootless cones such as those in Athabasca Valles could have been caused by atmospherically emplaced ground ice. Recent stability modeling [15] suggests that such ice has not occurred in Athabasca Valles in the recent past (within the timeframe of the youngest estimated age of the Athabasca Valles surface [16]). However, stability could have been enhanced beyond the model predictions by surface snow (plausible in the Athabasca region [17]) or by higher atmospheric water contents in the past. Alternatively, ice could have been present at the surface due to a recent flood, but uncertainties in past climate are large enough that this is not required. Significant erosion by the lava to reach deep ice is not favored, since rootless cones are observed near channel margins where there has been little erosion.

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