FROM MT. PINATUBO TO MARTIAN POLLYWOGS: INVESTIGATING A RUNOFF SOURCE FOR CRATER-FILLING WATER. A. O. Warren[1], S. Holo[1] and E. S. Kite[1] [1]University of Chicago, Department of Geophysical Sciences (aowarren@uchicago.edu).

Introduction: Wet events on Mars after the main Noachian and Late Hesperian Valley Network (VN) forming fluvial activity are recorded by young alluvial fans[1,2], Fresh Shallow Valleys (FSVs)[1,3], and exit breach craters or "pollywogs"[4]. Pollywogs are craters with one or more valleys leading outwards from the crater rim, but no inlet valleys. These outlet valleys extend away from the lowest point on the crater rim. This suggests the craters were once filled with water, which overtopped the crater rim, forming a breach and channel. By understanding breach erosion processes, we can determine the volume of water and number of outflow events required to produce observed pollywog breach depths and valley widths. Previous authors have proposed a groundwater upwelling source for crater-filling water[4]. Here, we investigate whether pollywogs are consistent with a precipitation/snowmelt water source.

Overflow Model: We use a 0-D model coupling lake drainage to breach erosion that couples flow resistance, eroded sediment transport, and lake-draining[5] written as a simple differential equation:

$$\frac{dH}{dt} = \frac{4(Q_{in} - W_c q_{out})}{\pi D^2} + \frac{W_c q_s}{W_v L} \qquad 1)$$

Where Q_{in} is water in (m^3s^{-1}), q_{out} is water out (m^3s^{-1}), q_s is sediment out (m^3s^{-1}), D is effective lake diameter (m), w_c is channel width (m), w_v is valley width (m), L is channel length. By assuming Manning's law of flow resistance, the Meyer-Peter Mueller relation for capacity bedload sediment transport (transport-limited system), and a typical scaling for Manning's n (ref. 6),

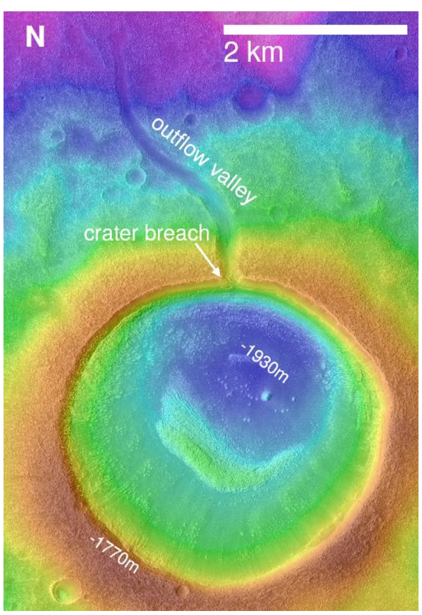

Figure 1: Pollywog DEM centered at 34.797N 17.398E (ESP_053222_2150/ESP_052945_2150) overlain on HiRISE. Elevations relative to the Mars geoid. DTM made by NASA/JPL/University of Arizona/USGS

we can non-dimensionalize Equation 1:

$$\frac{dT}{dt_*} = K_2 - K_1 T^{5/3} + (\max(T, 1) - 1)^{3/2} \qquad 2)$$

Where K_1 and K_2 (proportional to Q_{in}) are dimensionless numbers from quantities that can be measured for pollywogs (e.g. w_v, L, D), and parameters that can be estimated by looking at Earth analogues and existing data, including channel width to valley width ratio ($w_c/w_v \leq 1$, in this work we assume $w_c/w_v=1$ which corresponds to a rectangular trough-like channel), representative grainsize (d <1m as no individual clasts visible in HiRISE images), initial slope S (channel slope $\leq$ S $\leq$ crater rim slope). The value of K_1, and the ratio of K_1/K_2 control the overflow behavior[5].

There are 3 possible regimes: 1) *Runaway erosion* (K_1 small) – q_{out} always exceeds what the channel can accommodate, such that the channel bottom erodes downwards faster than the lake level drops. This corresponds to erosion consuming all available topography. 2) *Self-arrest* (K_1 large) – initially, there is some erosion to compensate for the onset of lake draining, but the channel is able to deepen enough to "catch up" with q_{out}. In this regime, lake level drops faster than the bottom of the channel. 3) *Sustained erosion* (only possible when K_2>0, i.e. there is flow into the crater) – the channel is able to accommodate q_{out}, but Q_{in} exceeds the sediment transport threshold, leading to continuous erosion. For the pollywog in Fig 1, the depth of the breach is much less than the topography available, so we can eliminate the runaway erosion case. By solving Equation 2, we can find the total eroded depth in the outflow channel. Before applying this model to Martian pollywogs, we test it against terrestrial breach events.

Mt. Pinatubo Caldera Breach: We use the 2002 breach of the Mt. Pinatubo caldera lake via the Maraunot Notch (MN) as a terrestrial analogue for pollywogs. After the 1991 eruption of Mt. Pinatubo, a

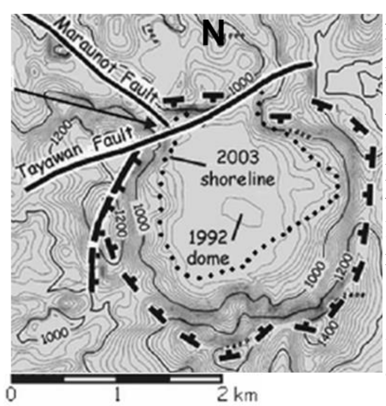

Figure 2: Topographic map of the Mt. Pinatubo Caldera after the 2002 breaching event. The MN is located at the intersection of the Maraunot Fault and the caldera rim (shown by dip symbols). Contour spacing 100 m. Modified from Lagmay et al. (ref. 7).

caldera lake formed. The lake overflowed in 2002 an intense monsoon season, releasing $6.5\times10^7 m^3$ of water in ~1 day, causing a 23m drop in lake level[7]. There are topographic maps of the caldera and MN both before[8] and after[7] the Pinatubo Caldera breaching event (e.g. Fig 2), making it ideal for testing the breach erosion model.

We use initial flow depths <1.54m (ref. 7) to estimate total erosion. We use w_v=w_c=60 m, S=0.35[8], L=2000 m, and calculate an effective lake diameter for the Pinatubo Caldera of D≈950 m. Q_{in} before and during the MN breach event is unknown. We assume Q_{in}=0. For any flow depth >0.5 m it is possible to reproduce ~20 m of erosion with a wide range of grain sizes (Fig 3). Maximum erosion occurs at intermediate grain sizes. Smaller grainsize solutions at higher initial flow depth may be more relevant to the Pinatubo Caldera breach because the MN breccia is matrix supported[6].

There is agreement between the Mt. Pinatubo Caldera breach event and our model to within a factor of 2-3. This is reassuring given the simplicity of the model.

Mars Pollywogs: Pollywogs typically form in mid-latitude craters with a wide range of diameters 0.5<D<13km[4]. We apply the breach erosion model to a 3600m diameter crater with L=3000 m, w_v=235 m, and a valley depth of 20 m at the crater breach (Fig. 1). We run the model for S=0.07 (minimum channel slope at present-day breach point) and S=0.14 (maximum crater rim slope). Channel grainsize is unknown, so we use maximum eroded depth as a function of initial flow depth (Fig 4) to find the minimum number of wet events to form the valley. For S=0.14, the observed breach depth can be produced in a single, self-arrest breach event (Fig 4).

The crater must be filled before it can overspill. We assume a modern cold, dry Martian climate[1] to calculate the rate at which water must be supplied to a cylindrical

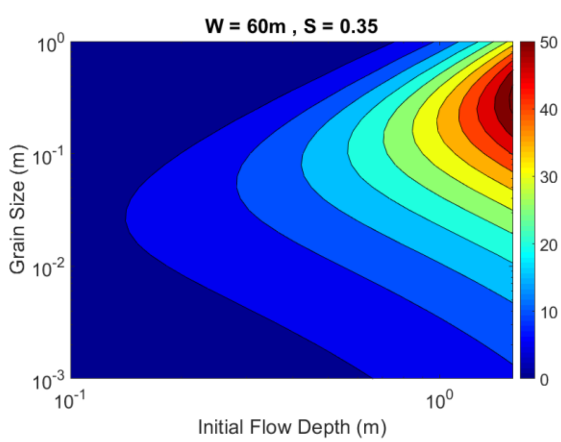

Figure 3: Model results for the Mt. Pinatubo 2002 MN breach event. Colors show total eroded depth over the duration of the flow event. Pinatubo Caldera breach depth 23m.

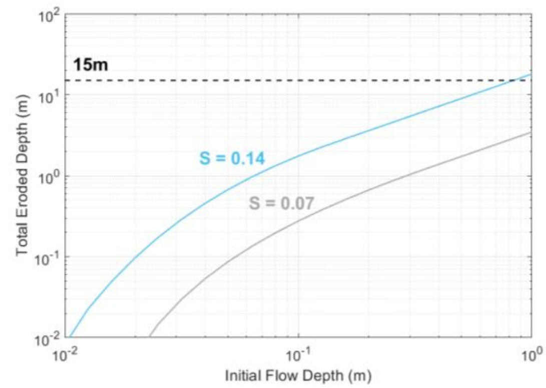

Figure 4: Maximum breach erosion as a function of initial flow depth at the maximum and minimum initial channel slopes for the crater in Fig 1.

crater in order to prevent freezing down into the underlying regolith, or complete evaporation. For the present annual average T=210K, 25 m m^{-2} of water must be delivered in the first year of crater filling. This exceeds the 3-4 m yr^{-1} of energy-limited snowmelt from solar models at 3 Ga[9]. Precipitation (there is evidence for climate-driven runoff as late as 1 Ga[9]) or groundwater[4] are plausible, more intense water sources. Pollywogs could also fill with ice over a number of years, with only the final melt season (i.e. one breach event, Fig 3) forming an annulus of water of volume 1.4×10^8 m^3 that caused the overflow. The timescale for crater filling depends on the supply rate water source.

Future work: We will look for relationships between D and valley depth using DEMs. The model predicts runaway breach erosion for water-filled craters with D>5000 m with pollywog-like outlet valleys (i.e. w_v<500 m). If there is no size-dependence to the occurrence of runaway erosion in pollywog breaches, then caters were predominantly ice-filled at the time of breaching.

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