I. Introduction and Summary

Jezero crater is a site of prime scientific interest because it was a lake early in Mars history [1]. Preserved clay- and carbonate-bearing sedimentary fans [2] on Jezero’s western and northwestern margin (Fig. 2) are accessible to future exploration. Geologic context [1] and stratigraphic analysis of the western fan [3] strongly support the interpretation that these fans were deposited as deltas into the lake. This has helped establish Jezero as one of the final candidate landing sites for Mars 2020. The high level of certainty that Jezero was a lake results from the existence of its outlet valley, which required filling of the crater to form [e.g., 4]. Here, we specifically focus on how this outlet valley was carved by the dam breach flood that eroded the eastern crater rim. We have completed preliminary modeling in both 1D and 2D of the outlet’s formation.

The growth and incision of the breach in this type of dam break is directly coupled to flood discharge [e.g., 5]. For Jezero, the discharge through the breach eventually lacked sufficient energy to erode through the whole crater rim dam, preventing complete drainage of the lake. After the flood, additional incision in the outlet valley was limited to what is possible under more normal fluvial conditions.

Given the observed number of hydrologically open-basin lakes on Mars, basin-breaching floods were a common occurrence [4]. Thus, in addition to being of interest for Jezero, better understanding the character of these floods has broad potential implications for understanding Noachian/Hesperian martian surface hydrology.

We estimate that the peak discharge of the outlet valley-forming flood was ~1.5x10^10 m^3/s, consistent in both the 1D and 2D models. In the parameter space explored to date, it has been hard to reproduce the outlet valley’s morphology from the flood alone, despite this being the most likely geological scenario.

2. 1D Hydrological Modeling

We constructed a 1D model using equations commonly applied to reconstruct floods from terrestrial dam breach events [5, 6]. Because the growth of the breach and fluid discharge from the lake are coupled by the rate that the breach can erode, we iteratively solve for the evolving topography of the breach and outlet valley depth.

To do so, we specify the initial hydraulic head (lake level and breach depth), grain size (D_{50}, D_{90}), fluid and sediment density (\rho and \rho_s), and critical shear stress for erosion \tau_c (see Table 1). Discharge is calculated as flow over a weir, and we compute erosion, sediment transport, and breach growth by calculating the shear stress on the channel bed [e.g., 6].

The breach width is a fixed parameter in the 1D model. The strength of the crust is controlled by the grain size of transported sediment, while the breach geometry establishes the initial energy available for erosion.

Fig. 3 and Table 1 show examples of our 1D modeling results. In Fig. 3, the outlet breach is eroded ~140 m during the initial flood over the course of days to weeks. Beyond that depth the flood lacked sufficient competency to deepen the breach further and the lake did not fully drain. Incising the total depth of the outlet valley required additional geomorphic work under more normal fluvial conditions.

Table 1. Assumed (italic) and Output (bold) Values for 1D Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Breach (hydraulic head)</td>
<td>30-40 m</td>
</tr>
<tr>
<td>D_{50} (m)</td>
<td>0.1-0.5 m</td>
</tr>
<tr>
<td>D_{90} (m)</td>
<td>0.5-1 m</td>
</tr>
<tr>
<td>\rho (kg/m^3)</td>
<td>1000 kg/m^3</td>
</tr>
<tr>
<td>\rho_s (kg/m^3)</td>
<td>1700 kg/m^3</td>
</tr>
<tr>
<td>\tau_c (Pa)</td>
<td>2000 Pa</td>
</tr>
<tr>
<td>Peak Q (m^3/s)</td>
<td>3.9x10^7 m^3/s</td>
</tr>
<tr>
<td>Time to erode initial dam</td>
<td>4.6-7.9 days</td>
</tr>
<tr>
<td>Time to erode outlet valley</td>
<td>1.9-2.1x10^5 yrs</td>
</tr>
</tbody>
</table>

The outlet breach is ~6 km wide and ~200 m deep; the outlet canyon 20 km downstream is ~1 km wide and 300 m deep. Matching this width and depth of the outlet valley downstream of the breach is particularly challenging for the 2D model runs to date, which tend to produce wider and less entrenched valleys (see Fig. 5). Possible solutions include making the exterior of the crater more erodible than the rim, or improving our parameterization of sediment entrainment and transport.

3. 2D Hydrological Modeling

We used the 2D numerical model BASEMENT [10] to explore the outlet-forming flood. BASEMENT has been used to model dam breach floods in the past [e.g., 11] and has sufficient flexibility to allow its straightforward adoption for Mars' problems (changing \rho_s, grain size distributions). The physics and geometric assumptions are similar to the 1D model, although the initial geometry has additional free parameters and the sediment transport assumptions are slightly different. Example results of this work are illustrated in Figures 5 and 6 below. One key finding is that most sediment moves as washload.

4. Discussion

The questions we ultimately wish to address about Jezero’s outlet-forming flood are: (1) What was the flood’s hydrograph? (2) What sediment transport and erosion processes were involved? (3) Can Jezero outlet’s morphology be explained by catastrophic formation alone, or is longer-term erosion required?

We have made progress towards these questions, but more of the relevant parameter space needs to be explored to be fully satisfied. Peak discharges of ~1.5x10^10 m^3/s are most consistent with the geometry of the Jezero breach. It is evident that large grains (up to coarse gravel) could be moved as washload, at least in the initial flood stages. However, no existing model matches the outlet valley downstream of the breach is generally less entrenched and wider than actually observed. The outlet valley also shows strong evidence of channel migration in the model runs, which is not obvious in observations.

Ideas for reconciling modeling with observations include: (1) improving sediment transport parameterization; (2) allowing for different erodibilities between the crater rim and exterior; or (3) accepting that the outlet valley continued to be eroded well after the breach-forming flood.

4. References