HYDROLOGICAL MODELING OF THE JEZERO CRATER OUTLET-FORMING FLOOD. C. I. Fassett[1,*] and T. A. Goudge[2,*], [1]NASA Marshall Space Flight Center, Huntsville, AL 35805 (caleb.i.fassett@nasa.gov), [2]Jackson School of Geosciences, University of Texas at Austin, Austin, TX78712 (tgoudge@jsg.utexas.edu).

Introduction: Abundant evidence exists for lakes on Mars both from orbital observations [e.g., 1-3] and in situ exploration [e.g., 4-5]. These lakes can be divided into two classes: those that were hydrologically closed, so their source valley(s) terminated at the basin [3], and those that were hydrologically open, where there was sufficient flow from inlet valley(s) to cause the lake to breach and form an outlet valley [2]. It is easier to be confident from orbital data alone that a standing body of water must have existed in open basins, because there is no other way for their perched outlet valleys to form. The majority of basins fed by valley networks, rather than by isolated inlet valleys, are open [6], with some important exceptions (e.g., Gale Crater).

Jezero crater (Fig. 1) is one of the most well-studied open basin paleolakes on Mars, with a breach that remains well above the lowest part of the crater floor, and two sedimentary fans at its northwestern margin that are likely deltaic in origin [7-9]. CRISM observations of these sediments indicate they host a variety of alteration minerals [9-11], including smectite and carbonate, and both the mineralogy of the sediments and their settings suggest they have a strong potential for preserving organic materials [10]. As a result, Jezero is a strong candidate landing site for the Mars 2020 rover.

Approximate formative discharges have been estimated for its well-preserved western fan (Q~500m^3/s) [7], but to our knowledge, no estimates for the discharges associated with formation and incision of its outlet valley have been presented. Indeed, only a few studies [e.g., 12-14] have attempted to reconstruct the formation of outlet breaches broadly similar to Jezero anywhere on Mars, despite the apparent commonality of basins with large outlets [e.g., 2].

The outlet valley formed as a dam breach when the lake overflowed. In such an event, the growth and incision of the breach is directly coupled to flood discharge. In the case of Jezero, the discharge through the breach eventually lacked the energy needed to erode through the dam further, preventing complete drainage of the lake. After the initial flood, further incision can take place if additional water flows into, and thus out of, the hydrologically open lake, though the rate of this erosion occurs under more typical fluvial conditions.

Despite this qualitative understanding of the process, it is useful to explore numerically what range of model parameters are potentially consistent with observations of the outlet. We ultimately seek to address questions that include: (1) What was the flood hydrograph?, (2) What sediment transport processes were involved and what can we infer about the erosion process? (3) Can most or all of the Jezero outlet's morphology be explained as a consequence of catastrophic formation, or is additional longer-term erosion required?

Methodology: We have used two modeling approaches to explore the Jezero outlet flood. First, we constructed a 1D numerical model using equations commonly applied to reconstruct terrestrial dam breaches [15]. We specify the initial hydraulic head, calculate discharge as flow over a weir, and compute erosion, sediment transport, and further dam incision by calculating the shear stress on the channel bed [e.g., 16]. Channel and breach width are fixed parameters in the 1D model, and we solve for the evolving topography of the breach and outlet (i.e., valley depth).

Second, we use the numerical model BASEMENT (http://www.basement.ethz.ch/) to explore the outlet-forming flood in 2D. The physics and geometric assumptions are similar to the 1D model, but the breach and valley morphometry are free parameters.

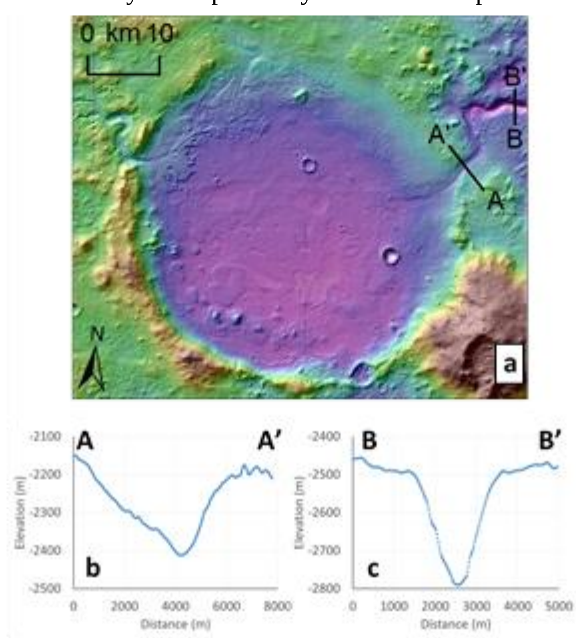

Fig. 1. (a) Mosaic of CTX stereo DTMs of Jezero created at 20 m/px post using the Ames Stereo Pipeline [17,18], superposed on hillshade of the DTM. (b) Profile A-A' across the breach. (c) Profile B-B' across the outlet valley, 20 km from the breach. The depth of the breach is ~200m; 20 km downstream, the outlet valley is incised ~300m.

BASEMENT has been applied to dam breach floods before [e.g., 19], and has considerable flexibility allowing its straightforward adoption for Mars problems (changing g, ρ_{sed}, grain size distributions).

Preliminary Results: Exploring the relevant parameter space, we have made some progress towards reconstructing the flood. In particular, the depth and profile of the immediate breach can be matched well. Another characteristic of the Jezero outlet observed both in the data (Fig. 1a) and the modeling experiments is erosion that occurred inside the breach (up to ~80 m depth). The fact that an appreciable amount of sediment was stripped from the lake bed and transported through the outlet is symptomatic of the energetic nature of the flood.

Hydrograph: The 1D and 2D models both lead to estimates for the peak discharge of approximately 1 to 5×10^5 m^3/s. In all cases, the flood peaks and then declines rapidly; most of the flood-related geomorphic work is done within ~2 weeks. The detailed form of the flood hydrograph is dependent on two unknowns: the conditions under which sediment was eroded and entrained, and the available hydraulic head when the dam breach occurs. These two unknowns trade off against one another when seeking to match the final breach morphometry, as larger initial head is needed if more energy is required to erode the observed outlet, and vice versa. The uncertainty about erosion mechanics comes from lack of knowledge about the grain-size distribution of materials transported and whether the eroding crust was strong (e.g., bedrock) or weak (e.g., unconsolidated or weakly cemented sediment). Our imperfect knowledge of the initial hydraulic head comes from uncertainty in the topography of the outlet prior to its formation, and the initial failure behavior of the dam.

Erosion and Sediment transport: One qualitative finding arising from our numerical experiments is that much of the sediment transport must have been as suspended sediment (or wash load, for sand-sized particles and smaller). This result – which is unsurprising in hindsight – became quickly apparent when comparing model runs that allowed only bedload and to those with suspension enabled. This is also consistent with Komar's classic paper [20] that emphasized the importance of wash load on Mars, where larger grains can remain in suspension than on Earth. Jezero's outlet valley is even steeper slope (~3%) than the outflow channels considered by Komar [20], meaning that the Rouse parmeter for the Jezero outlet flood supports coarse gravels remaining in suspension once entrained, at least in the early stage of the flood.

Comparing Observations and Model Results – was the canyon carved in a single flood?: To date, none of our 2D model experiments completely match the outlet valley's morphometric characteristics. In particular, the outlet valley downstream of the breach is generally less entrenched and wider than the ~300-m deep, 1-km wide canyon that is actually observed (e.g., Fig. 1c; profile B-B'). The outlet valley also shows strong evidence of channel migration in the model runs, which is not obvious from observations (though not precluded). We continue to explore scenarios that might better reconcile modeling with observations. Ideas for accomplishing this include: (1) improving parameterization of the erosion mechanics by using different sediment characteristics and/or sediment transport formulae, (2) allowing differences between bed characteristics of the crater rim and exterior (a currently unexplored part of the parameter space), or (3) accepting that the outlet valley was entrenched well after the breach-forming flood.

Like the 2D model, in the currently explored parameter space, our 1D model can only match the depth of the outlet in the third scenario, where, after the flood, fluvial erosion occurred slowly, integrated over tens of thousands of years. The possibility that a significant amount of geomorphic work occurred after the main breach-forming flood is reasonable, but somewhat ad hoc given the scale of the outlet-forming event. For this reason, we disfavor this hypothesis unless no reasonable scenario is found where the flood did most of the observed geomorphic work.

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