MULTISTAGE ICE-DAMMING OF VOLCANIC FLOWS AND FLUVIAL SYSTEMS IN NORTHEAST SYRTIS MAJOR.

Connor Matherne[1], J.R. Skok[1,2], J.F. Mustard[3], S. Karunatillake[1], and P. Doran[1], [1]Louisiana State University Geology and Geophysics (cmath31@lsu.edu), [2]SETI Institute, [3]Department of Geological Sciences, Brown University.

Introduction: The northeast edge of the Syrtis Major complex is located on the western edge of the Isidis Basin (Fig. 1) and contains a basin and channel system (Fig. 2) with many morphological features and geologic units that have been suggested to be related to a global ocean or regional ice sheet 3.4 Ga ago [1]. However, there are many features that remain unexplored and unexplained in this area despite their relevance for the ancient climate. For example: the hydrological source for the channels in the region (Fig. 3), the anomalously thick Syrtis Major flow (Fig. 3, 4), and the basin draining via a higher topographic outlet than what is available (Fig. 2, 4). Such unique features and their explanations aim to address many unknowns surrounding the debate of Early Mars containing a global ocean [2], or instead, being covered by multiple large ice sheets [1].

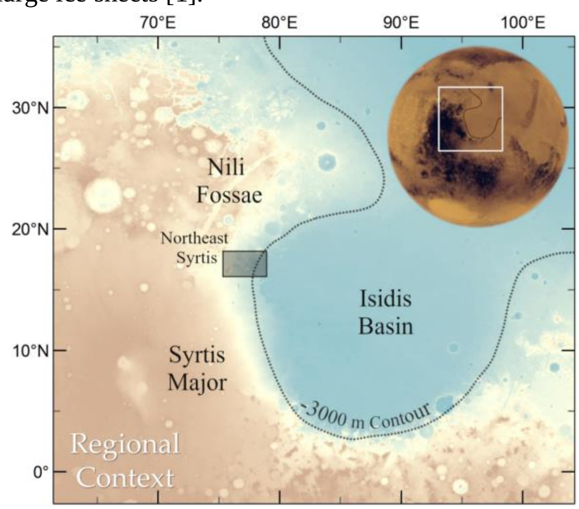

Figure 1. *The regional context of Northeast Syrtis on shaded MOLA map and study area (dark shaded box on map, subsequently figure 2). Viking image of Mars in the upper right portion with a white box to show the location of the underlying image (Mars globe: NASA / USGS / ESA / DLR / FU Berlin (G. Neukum)).*

Methods: Geomorphology was assessed using the Context Camera (CTX), the High Resolution Imaging Science Experiment (HiRISE), the Mars Orbital Laser Altimeter (MOLA), and High Resolution Stereo Camera (HRSC). Local topography determined using HRSC and MOLA blended derived digital elevation models (DEMs) provided by the USGS [3] with a vertical resolution of 10 m. All imaging data are maintained in an ArcMap GIS database.

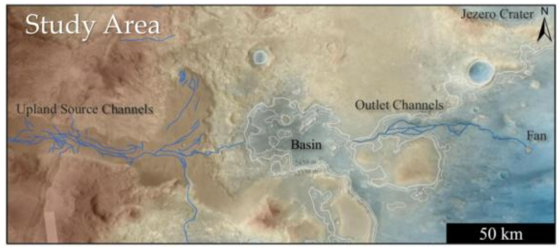

Figure 2: *CTX mosaic, with colored HRSC DEM overlay of the channel system on the edge of Northeast Syrtis with Jezero Crater labeled for orientation.*

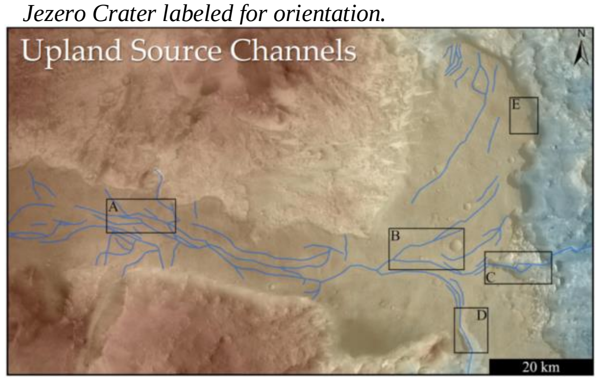

Figure 3. Upland source channel terrain showing braided channels carved in Syrtis Major volcanic flow from the CTX mosaic with shaded relief of the HRSC DEM overlay.

Results and Discussion: The braided channels have a diffuse origin and an average bifurcation angle of 43 ± 21° which suggests precipitation as the source [4]. Additionally, boxwork fracturing of sulfates, required at least 550 km^3 of water to develop the extensive fracturing seen throughout the area [5]. The cliffs of the volcanic mesa are up to 300 m high in some locations, an order of magnitude larger than all other flows throughout Syrtis Major [6], which suggests that the volcanic flows encountered an obstruction that caused them to thicken from the 30 m flow height to the termination height observed today. Additionally, a pooling of the flows forced them to become topographically flat, resembling ice-dammed volcanic flows observed on Earth [7]. Lastly, the basin has a single inlet channel and NE outlet channel (Fig. 2). The outlet channel has two requirements to activate: First, the southeastern outlet had to be inaccessible when the channel formed. Second, a lake with a maximum depth of 200 m and volume of 60 km^3 was needed to for drainage via the more elevated NE channel. That suggests a blockage in the southeastern outlet [5].

Notably, the basin's fill volume is well below the amount of liquid in the area based on volume loss fracturing in the sulfates [5].

Conclusions and Implications: The diffuse source morphology and narrow branching angle suggests precipitation origin, possibly snow, to feed the system rather than a spatially concentrated groundwater system which would be more consistent with a global ocean. A large ice sheet, likely covering the Isidis Basin [1] would halt the flows of the lava in order to preserve the basin. That ice sheet would also force the volcanic flow to thicken downslope and become topographically flat. The outlet channel that is inconsistent with current topography would require significant erosion [5], or a temporary paleo ice dam. Following the channel formation, the ice dam sublimates away, removing any trace of it and results in the current landscape (Fig. 4).

Collectively, our observations suggest late-stage, glaciofluvial processes in the Northeast Syrtis region with a basin preserving ice sheet and an episodic ice dam (Fig. 4). Regional glaciation has been suggested in this location before [1], however, such observations place specific spatial constraints on the western portion of the ice sheet based on morphological observations (Fig. 4). Future mast-camera imaging by the Mars 2020 Rover of small-scale jointing along the volcanic mesa [7] would further test the interpreted glaciofluvial history of this region as emphasized in our peer-reviewed work [8]

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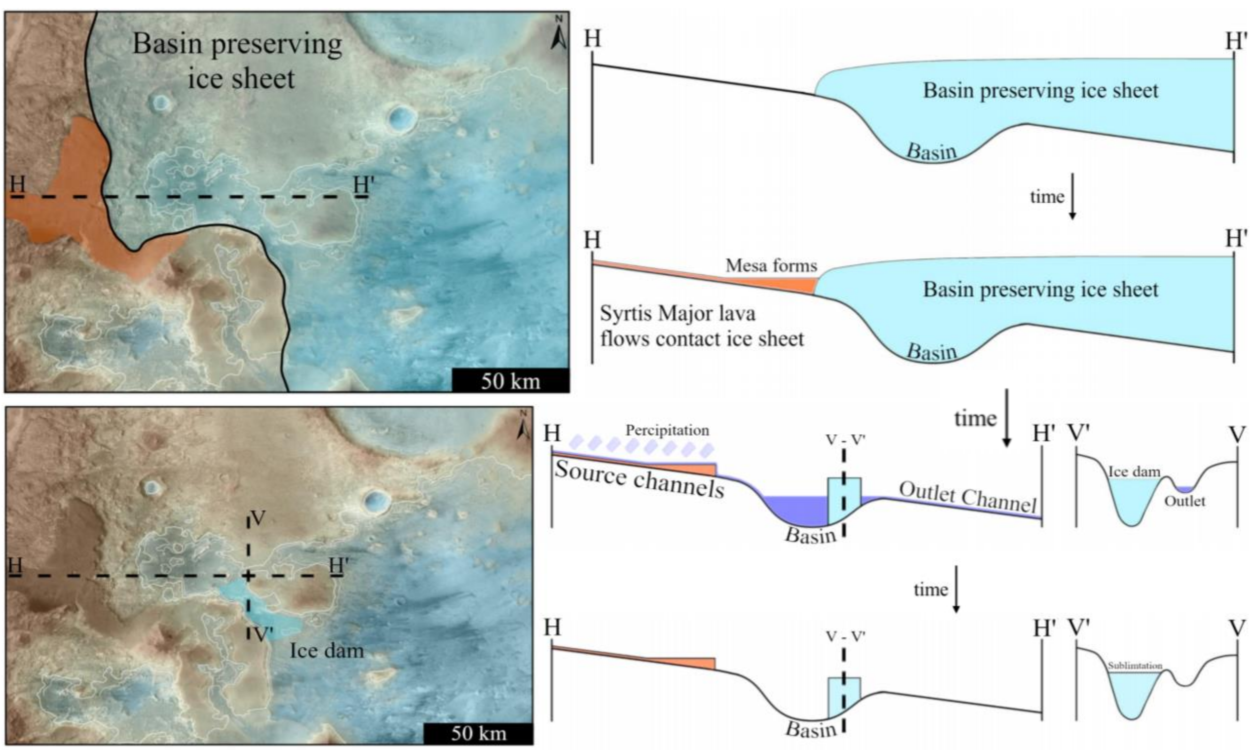

Figure 4: *Timeline for the geologic history for the area. Initially (~3.4 Ga), the Isidis Basin ice sheet covers the small basin within the study area before Syrtis Major lava flows down slope and is dammed by ice to form a mesa. Subsequently, the southeastern outlet of the basin is blocked by ice while the fluvial channels are active causing them to exit the northern outlet of the basin. Lastly, the loss of water and ice leaves behind the current landscape.*