FORMATION OF THE REULL VALLIS OUTFLOW CHANNEL BY LARGE-SCALE LAVA-ICE INTERACTIONS AND TOP-DOWN MELTING. J. P. Cassanelli[1], J. W. Head[1], [1]Brown University Department of Earth, Environmental, and Planetary Sciences, Providence, RI 02912 USA (James_Cassanelli@Brown.edu).

Introduction: Much work has been dedicated to understanding the mechanisms responsible for the formation of the martian outflow channels, enormous channels thought to have been carved by episodic outburst floods [1,2]. Candidate formation mechanisms include: discharge from pressurized confined aquifers [3], melting of cryospheric ground-ice by volcanic activity [4], melting of buried ice deposits [5,6], release of surficial water reservoirs [7], and dewatering of sedimentary materials [8]. However, difficulties related to limited recharge sources, insufficient water reservoirs, and lack of plausible melting mechanisms remain [9].

In light of recent climate model results predicting the accumulation of regional ice sheets across the martian highlands [10-12], and the widespread distribution of contemporaneous volcanism on Mars [13], recent work has proposed large-scale lava-ice interactions as a potential alternative mechanism for outflow channel formation [6]. Here we assess in detail the potential formation of outflow channels by large-scale lava-ice interactions through an applied case study of the Reull Vallis outflow channel system. We first review the geomorphology of Reull Vallis to outline criteria that must be met by the proposed formation mechanism. We then assess local and regional lava heating and loading conditions to generate model predictions for the formation of Reull Vallis to test against the outlined geomorphic criteria.

Reull Vallis: The Reull Vallis outflow channel consists of 5 individual segments grouped into the upper (northern trough, Waikato Vallis, Morpheos basin, and Segment 2) and lower (Segment 3 and Teviot Vallis) systems [14-16]. Distinct morphologic differences between the upper and lower systems have been interpreted [16] to suggest that the upper portion of Reull Vallis served as a tributary to the lower system and that formation of the lower portion of the system occurred by other mechanisms, with different sources of water, and predated that of the upper system. Therefore, we focus specifically on the upper Reull Vallis system due to the close spatial and temporal association with the Hesperian Ridged plains unit [16], rather than the lower Reull Vallis system which has a more ambiguous origin.

Upper Reull Vallis: The geomorphology of the upper Reull Vallis system suggests a complex fluvial history [15, 16], with multiple episodes of flooding activity. The upper Reull Vallis system emanates from the northern trough, a ~140 km long, tens of kilometers wide, ~100-200 m deep linear depression in southern Hesperia Planum. South of the northern trough, the upper Reull Vallis system emerges abruptly as a large steep-sided canyon within Waikato Vallis (Fig. 1). The Waikato Vallis segment of the upper Reull Vallis system shows an abundance of evidence (Fig. 1) consistent with an origin by fluvial activity and erosion involving undercutting by subsurface flow [16]. The abrupt emergence, lack of tributaries, depressed channel head, and collapsed features at the channel head (Fig. 1) have been interpreted to suggest that the water which carved the upper Reull Vallis system originated from the subsurface of Hesperia Planum, within the northern trough [15,16]. Therefore, the total volume of sediment eroded in the formation of the upper Reull Vallis system is equal to the volume of the downstream channel segments (Waikato Vallis and Segment 2), ~2,200 km^3 [16]. This translates to a minimum required water volume of ~5,500 km^3 assuming an upper-limit sediment to water ratio of 0.4 (the maximum volumetric sediment load which can be carried before the flood transitions to a debris flow; [17]).

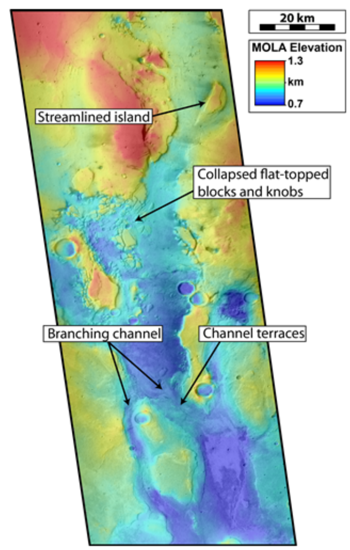

Figure 1. CTX mosaic of a section along Waikato Vallis with overlain gridded MOLA elevation data. Fluvial (Stream-lined island, branching channels, terraces) and collapse/subsidence-related (flat-topped blocks and knobs) features are indicated.

These geomorphologic characteristics place several constraints on the formation of Reull Vallis: 1) Formation post-dating Hesperian ridged plains emplacement (as evidenced by the deformation and erosion of the plains near the channel head, and the stratigraphic superposition of the channel downstream; Fig. 1). 2) Episodic release of water, consistent with observations suggesting multiple periods of flooding activity (indicated by the presence of terraces within the channel; Fig. 1). 3) Release of water from the subsurface (as indicated by the collapse features in Waikato Vallis thought to have formed by undercutting from subsurface flow; Fig. 1). 4) Subsidence of ~100-200 m within the northern trough, with retention of the Hesperian ridged plains surface morphology (evidenced by the morphology of the northern trough). (5) Production and release of a minimum of ~5,500 km^3 of water (the minimum amount of water needed to erode the upper Reull Vallis channels).

Formation by Ice Sheet Lava Heating & Loading: We find that an ice sheet lava heating and loading scenario involving the accumulation of thick lava flows (~100 m or greater in thickness) atop regional ice sheets generally satisfies the morphologic formation criterion derived from the upper Reull Vallis outflow channel. In the most consistent scenario, accumulation of ~500 m of lava (the minimum total thickness of lava within Hesperia Planum [6]) atop ~0.3-1 km thick regional ice sheets (the approximate range of average ice sheet thicknesses predicted to accumulate in the martian highlands [18]) induces rapid top-down melting following the emplacement of each successive lava flow, efficiently melting significant thicknesses of ice (Fig. 2) [6].

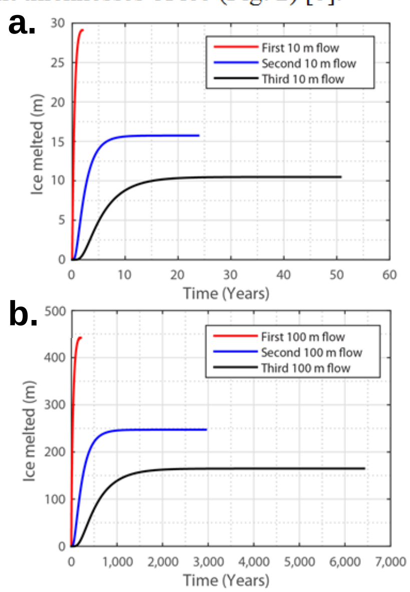

Figure 2. Ice melted versus time due to the emplacement of a series of lava flows (**a.**) 10 m thick, and (**b.**) 100 m thick (adapted from [6]).

Meltwater production by this mechanism is predicted to occur after lava emplacement over timescales of ~1 kyr (Fig. 2) [6]. Successive events of lava emplacement would result in successive episodes of heating and melting and could account for the interpreted episodic nature of the upper Reull Vallis fluvial system, consistent with the second criterion. Water generated by top-down heating and melting due to supraglacial emplacement of lava flows would be expelled from below the superposed lava flows [6], thereby satisfying the third criterion. Ice sheet lava heating and loading is also predicted to result in subsidence of the superposed lava flows due to melting of the subjacent ice and removal of structural support [6]. This satisfies the fourth morphologic criterion requiring subsidence within the northern trough source area (accumulation of ~500 m of lava flows causes a maximum of ~1 km of melting and subsidence depending upon the thickness of ice present, more than the required ~100-200 m of subsidence observed).

The final outlined morphologic criterion requires supply of a minimum of ~5,500 km^3 of water. The cumulative volume of water which can be produced by the ice sheet lava and loading mechanism is dependent upon the area over which melting occurs and the thickness of ice available to melt. The volume of the northern trough depression (the interpreted source of the upper Reull Vallis system) is estimated at ~426 km^3 [16], substantially below the minimum volume of water required to form the upper Reull Vallis system. In order for melting confined within the bounds of the northern trough (approximately 6,100 km^2) to produce the upper Reull Vallis system, an average of ~980 m of ice would need to be melted and removed throughout the depression (which would likely cause significantly more subsidence than the observed ~100-200 m). Conversely, if an average of 150 m (the approximate average depth of the trough) to 300 m (the approximate average predicted Late Noachian regional ice sheet thickness; [18]) of ice was removed from the subsurface, melting would have had to occur over an area of ~40,000 km^2 and ~20,000 km^2, respectively (~1-2% of the total area of Hesperia Planum). Melting of subsurface ice over this larger area would produce uniform subsidence throughout the area, however the northern trough is clearly topographically depressed relative to the surrounding terrain. This could have resulted from concentration of subsurface flow within the northern trough as melt was channeled to the surface, scouring out additional subsurface material, resulting in the additional ~100-200 m of subsidence observed relative to the surrounding ridged plains.

The areas over which melting must occur by ice sheet lava heating and loading to produce the water required to form the upper Reull Vallis system are less than those required by magmatic melting of ground-ice (since the ice volume is not constrained by the subsurface pore space) as previously proposed [4] to explain the formation of outflow channels in Hesperia Planum. We conclude that ice sheet lava heating and loading is an advantageous plausible alternative formation mechanism which generally satisfies the morphologic criterion derived from the upper Reull Vallis system. We are now examining this top-down lava-ice melting model in other outflow channel environments.

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