Valley Networks And The Fingerprints Of Wet Based Glaciation On Mars. A. Grau Galofre.[1], K. X. Whipple[1], P. R. Christensen[1] [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, US (agraugal@asu.edu)

Introduction: Thousands of valley networks incise the southern hemispheric highlands of Mars, standing as evidence that liquid water sculpted the Martian surface billions of years ago [1, 2, 3]. This scenario contrasts starkly with the much colder and drier planet that Mars is nowadays, with a hydrological cycle that consists of sublimation and precipitation of water ice into the polar caps [4], and thousands of ice deposits (viscous flow features) in the mid-latitudes [5]. These ice bodies are entirely frozen to the substrate (cold-based) and deform at negligible rates due to the cold temperatures and large dust volume fractions.

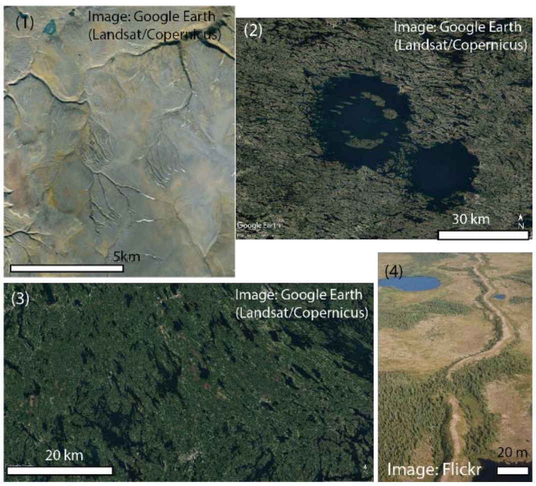

Fig 1. Fingerprints of wet-based glaciation on Earth. (1) Subglacial channels (Nunavut). (2) Mega-scale lineations (Quebec). (2) Scouring marks and striae (Finland). (4) Esker (Labrador).

A problematic transient lies in between: It is reasonable to expect that the climatic transition between surface liquid water stability and the current cold-based ice masses produced large-scale water-ice interactions [6]. And whereas glacial masses with basal meltwater accumulation (wet-based) produce some of the most arresting and large-scale erosional landscapes on Earth (Figure 1, panels 2 and 3), these same morphologies are notoriously rare on Mars. This problematic lack of wet-based glacial erosion signs has historically led to the interpretation that Martian glaciation was cold-based [6, 7]. However, the discovery of extensive eskers and esker fields around the southern polar cap [8], as well as examples dating from the Amazonian period [9] in the mid-latitudes, challenge the hypothesis that Martian ice masses were always frozen to the ground.

Hypotheses: (1) The lower Martian surface gravity affects the dynamics of wet-based glaciers, favoring the emplacement of efficient subglacial drainage conduits, reducing water availability at the base, and limiting ice sliding velocity [10]; (2) the morphology of certain valley networks is consistent with observations of subglacial channels in the Canadian Arctic Archipelago [11, 12], which are the erosional fingerprints of the subglacial drainage system. As a consequence, the fingerprints of wet-based glaciation on Mars may be largely limited to channels and eskers (figure 1, panels 1 and 4).

Framework: Water accumulated beneath ice masses is confined under large pressures and strong gradients, which drive it away from thick ice towards the ice margin. When no efficient drainage exists, basal water accumulates in pockets and cavities, where water pressure builds up and partially opposes ice pressure, lubricating the ice mass. This process results in the acceleration of the glacier, which slides as a block under its own weight (Figure 2). The process of glacial sliding is the most common response on Earth to water accumulation at the base, and leads to landscapes sculpted by directional abrasion (Figure 1, panels 2 and 3).

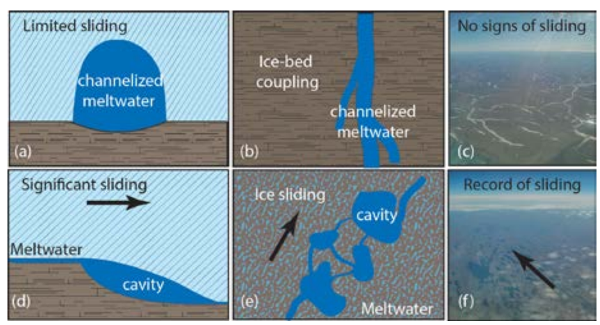

Fig. 2. The drainage of wet-based ice sheets. Upper row shows the formation of subglacial channels and efficient drainage, and effect on the landscape. Bottom row shows inefficient drainage (poorly connected cavities) and its effects on the landscape.

The opposite occurs when basal meltwater drains efficiently through subglacial channel networks. The resulting low water pressure cannot produce ice lubrication, which slows or halts ice sliding. The fingerprints of channelized drainage consist on subglacial channels etched on the ground, intertwined with depositional landforms such as eskers. These features may or may not be associated with signs of sliding, scouring, moraines, etc. [11].

The feedback that controls sliding velocity as a function of effective pressure (ice overburden minus basal water pressure) and subglacial drainage scenario (cavities/ channels) is controlled by a competition between sliding velocity [12] and drainage system evolution [10].

Preliminary results: We interrogate the effects of the lower Martian gravity on the glacial sliding velocity of Martian ice masses (keeping all other parameters equal between Earth and Mars) and present the preliminary results in figure 3 (left). Comparing Earth (blue) and Mars (red), we notice that sliding rates are a factor ten slower on Mars than Earth before taking into account glacial hydrology. When we include it in the model (figure 3, right) the difference scales up to a factor 20 to 90.

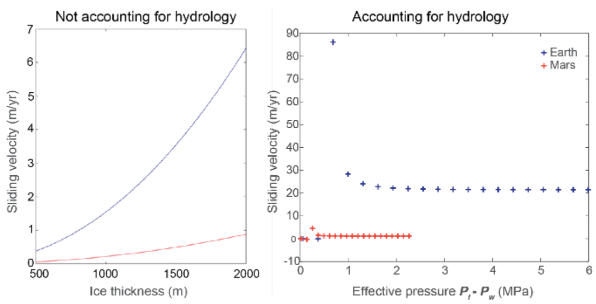

Fig. 3: Preliminary results showing glacial sliding velocity on Earth (blue) and Mars (red) without including the effect of the lower gravity on drainage efficiency (left) and after considering these effects (right). Water pressure is a factor 0.7x ice pressure in the left panel.

Discussion: If ice sliding velocities are indeed 1-2 orders of magnitude slower on Mars than Earth for the same ice sheets characteristics, erosion rates by sliding should be barely noticeable (erosion scales with ice sliding velocity to a power 1-2 [13], yielding a factor 10^2-10^4 difference between Earth and Mars), concentrating sediment removal, transport, and deposition in the subglacial channelized drainage instead. The fingerprints of wet-based glaciation on Mars may thus be fundamentally different.

Additionally, there is a remarkable morphological similarity between subglacial channels and rivers (figure 4) [11], with morphological differences in subglacial channels including: the presence of undulating sections (uphill downflow segments) in subglacial systems; a near-constant downstream width; the absence of inner channels; the absence of interfluve dissection between networks; depositional regimes including inverted ridges (eskers) and ice terminal fans; trapezoidal cross-sections, etc. It is interesting to consider that these characteristics may explain puzzling morphologies observed in the Martian valley networks that are hardly consistent with riverine erosion [1, 3], as well as pose a valid analogue to their planform morphology (figure 4). Based on the similar characteristics between terrestrial subglacial channels and Martian valleys, it is possible that some valley networks formed subglacially.

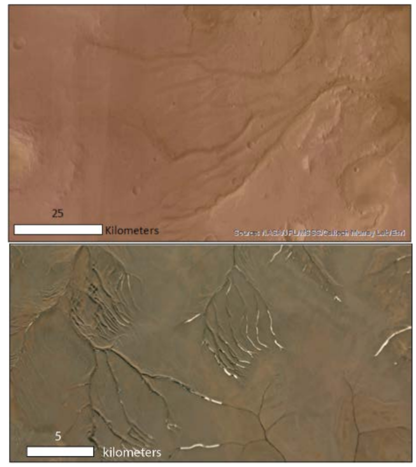

Figure 4: Planform similarity between a small valley network (above, image center is 18°49'2.80"N, 55°13'12.46"W) and subglacial channel networks (below) in Devon Island (image center is 75°17'12.27"N, 89° 8'44.64"W).

Conclusions: To understand the lack of large scale wet-based glacial erosional features on Mars, we use the theoretical framework developed for glacial hydrology on Earth. We show that glacial sliding is heavily inhibited on Mars (20-90 times slower), owing to its lower gravity, and instead a stable system of subglacial channel networks is emplaced. Comparing the morphology of subglacial channels on Earth (analogues from Devon Island) with Martian examples, we find similarities in planform, longitudinal profile characteristics (undulations), and cross-sectional shape and evolution. We conclude that the search for similar glacial landforms to those formed on Earth under large wet-based ice sheets may be unjustified for Mars, and that some small valley networks may have formed beneath a wet-based, ancient ice sheet.

References: [1] Carr M. (1995) *JGR: Planets, 100*(E4) 7479-7507. [2] Hynek B. et al. (2010) *JGR: Planets, 115*(E9). [3] Gulick V. (2001) *Geomorphology, 37*(3-4), pp.241-268. [4] Byrne S. (2009) *Ann. Rev. EPS*. 37, pp.535-560. [5] Levy J.S., et al. (2014) *JGR: Planets 119*(10), 2188-2196. [6] Wordsworth R. (2016*) Ann. Rev. EPS 44*, 381-408. [7] Fastook, J. L., and Head, J. W. (2015). *PSS*, *106*, 82-98. [8] Kress, A.M. and Head J.W. (2015) *PSS 109*, 1-20. [9] Butcher, F.E.G. et al. (2017) *JGR planets 122*(12), 2445-2468. [10] Schoof, C. (2010) *Nature*, *468*(7325), 803. [11] Grau Galofre, A. et al. (2018), *TC, 12*(4), 1461. [12] Cuffey, K. M., and Paterson, W. S. B. (2010). *The physics of glaciers*. Academic Press.