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THE (MISSING) RECORD OF WET-BASED GLACIATION ON ANCIENT MARS. A. Grau Galofre,^{1,2} K. X. Whipple¹, P. R. Christensen¹, S. J. Conway² ¹School of Earth and Space Exploration, Arizona State University, Tempe, AZ, US, ²Laboratoire de Planétologie et Géosciences CNRS UMR 6112, Nantes Université, France (anna.graugalofre@univ-nantes.fr)

Introduction: The lack of evidence for large-scale glacial scouring landscapes on Mars has led to the belief that past martian glaciations were frozen to the ground [1,2]. Indeed, whereas ice 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 [1,2].

Two issues arise with this perspective, however. First, the presence of surface liquid water on early Mars [3,4] and the Noachian-Amazonian climate evolution to the current day global cryosphere poses a problematic transient: It is reasonable to expect that in the time between surface liquid water stability and the current cold-based ice masses, some degree of water-ice interactions occurred [1]. Second, the presence of extensive eskers and meltwater corridors in the Dorsa Argentea Formation [5,6,7], as well as examples dating from the Amazonian period in the mid-latitudes [8] challenges the hypothesis that Martian ice masses were always frozen to the ground. Our work thus explores the possibility that the fingerprints of Martian wet-based glaciation are the remnants of the ice sheet drainage system, that is, channel networks and eskers, instead of the large scoured fields generally associated with terrestrial Quaternary glaciation (Figure 1).

To make progress, we use models of terrestrial glacial hydrology to interrogate how the Martian lower surface gravity modifies the state and evolution of the glacial drainage system, ice sliding velocity, and the rates of glacial erosion. Taking as reference the geometry and characteristics of the ancient southern circumpolar ice sheet that is thought to have deposited the Dorsa Argentea formation [6], we compare the theoretical behavior of identical ice sheets on Mars and Earth and show that, whereas on Earth glacial drainage is largely inefficient and produces glacially scoured landscapes, on Mars the lower gravity favors the formation of efficient subglacial channelized drainage. The apparent lack of large-scale glacial fingerprints on Mars, such as scouring marks, drumlins, lineations, etc., could then be justified. The presence of subglacial water, possibly into the Amazonian period, has important implications for the history of climate, hydrology, and the presence of habitable environments well after the early Mars period.

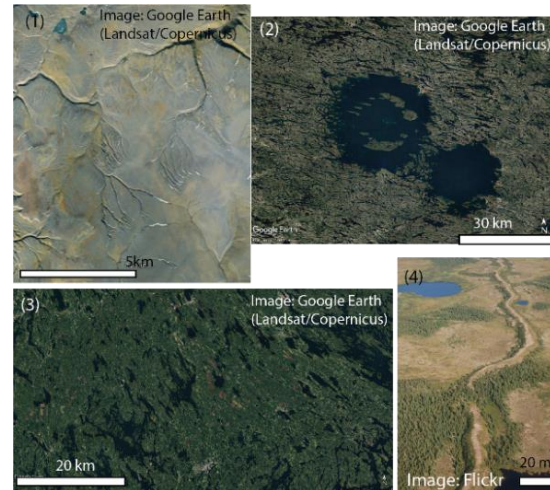


Figure 1. Fingerprints of wet-based glaciation on Earth. (1) Subglacial channels (Nunavut). (2) Mega-scale lineations (Québec). (3) Scouring marks and striae (Finland). (4) Esker (Labrador). Image sources indicated in each panel.

Hypothesis: *The fingerprints of wet-based glaciation on Mars are largely the drainage system.*

The lower surface gravity of Mars modifies the hydrology of wet-based ice masses, favoring the emplacement of efficient drainage conduits in the form of subglacial channels, and limiting ice sliding motion and thus erosion by glacial scouring (figure 1, panels 1 and 4). Terrestrial analogue landscapes in the Canadian Arctic Archipelago (Figure 1, panel 1) further support the role of glacial hydrology in landscape evolution.

Methods: We use the existing glacial hydrology framework [9,10,11] to interrogate the dominant modes of subglacial drainage (figure 2), using an ice sheet parametrized after the late Noachian southern circumpolar cap [6]. Coupling glacial drainage with a model of glacial motion [9,10], we evaluate the rates of glacial sliding and compare them between Mars and Earth, for identical ice sheet geometry and conditions.

Ice sheet basal meltwater is confined under large pressure gradients, which drive it from thicker ice towards the ice margin [11]. When no efficient drainage exists, basal water accumulates in cavities where water pressure builds up, decreasing basal friction and accelerating ice (Figure 2) [9]. Glacial sliding thus leads to highly directional scoured landscapes (Figure 1).

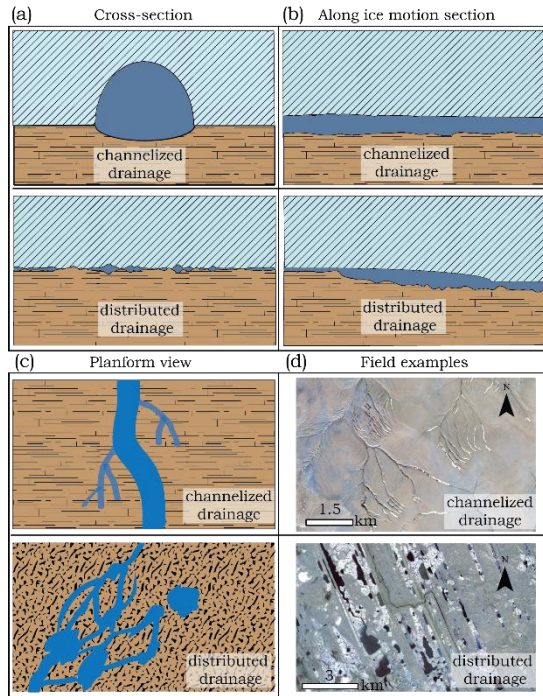


Fig. 2. The drainage of wet-based ice sheets. Upper a,b,c panels show subglacial channels and efficient basal drainage, and their landscape expression (d). Bottom a,b,c panels show inefficient, distributed drainage by cavities, and their landscape expression (d).

The opposite occurs when basal meltwater drains efficiently through subglacial channel networks [10]. Water pressure drops, basal friction increases, and ice sliding slows down. The fingerprints of channelized drainage consist on subglacial channels etched on the ground, intertwined with depositional landforms such as eskers [12].

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 and drainage system evolution [9,10,11].

Results: We present our results for sliding rates on Earth and Mars in figure 3 [13]. Comparing Earth (blue) and Mars (red), we notice that sliding rates are a factor ~20-90 slower on Mars than Earth when the effects of glacial hydrology and drainage are considered, for the same ice geometry and basal meltwater discharge. We also find that whereas Earth's gravity favors less efficient drainage, subglacial drainage on Mars is dominated by channels to much larger subglacial conduit cross-section (compare arrows).

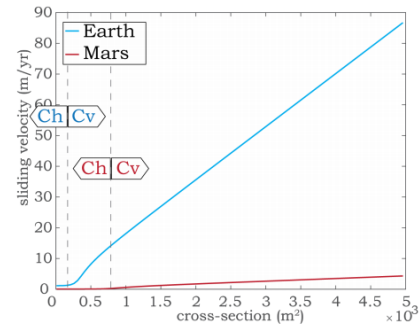


Figure 3: Results showing glacial sliding rates on Earth (blue line) and Mars (red line) vs. subglacial drainage cross-section. Cv arrows indicate the point where cavities open, Ch where channels open.

Discussion: Glacial erosion scales with ice sliding velocity to a power 1-2, so that erosion rates on Mars could be up to $\sim 10^2$ - 10^4 smaller than Earth according to our results. Erosion and deposition under wet-based glacial landscapes would thus occur in subglacial channels on Mars, leading to Martian glacial landscapes similar to those of the high Arctic (Figure 1) [12,13,14].

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 should be emplaced. Hence, we infer that the fingerprints of wet-based glaciation are fundamentally different between Mars and Earth, with the former being characterized by subglacial channels and eskers and the later by areal scouring by glacial sliding. This work supports the possibility that some valley networks may have formed beneath ice sheets [14], explaining the lack of wet-based glacial erosion in the Martian highlands [15] and in the Dorsa Argentea formation [5,6,7].

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