THE EFFECTS OF THE LOWER MARTIAN GRAVITY ON SHAPING THE GLACIAL LANDSCAPES OF MARS.

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Introduction: For the last billion years, Mars' surface conditions have been too cold, and atmospheric pressure too low to allow for surface water stability. However, in the early stages of Mars' geological history during the Noachian and early Hesperian periods (3.9-3.5 Byr ago), atmospheric pressure was close to 1 Bar [1], and surface temperature was the main control on surface liquid water presence.

3D, state-of-the-art climate models which incorporate the effects of reduced solar insulation from a younger, fainter young Sun and the large Martian topographic contrasts, predict the accumulation of large bodies of ice on the elevated southern hemispheric highlands over a wide range of initial conditions [3], the so-called Late Noachian Icy Highlands (LNIH) climate scenario. Adiabatic cooling drives ice stability on high elevations, the same principle that allows for glaciers to form in high, equatorial areas such as the Kilimanjaro.

Even with the warmer, wetter early Mars strongly suggested by the geological record [4,5], a transitional period from this warm regime to the cold, arid current conditions would result in the advance of large ice sheets on the highlands. Yet common landscapes related to widespread glaciation on Earth, such as mega-scale lineations, large striations (fig. 1), end moraines, paternoster landscapes, drumlin fields, etc. are largely missing on Mars, existing only in very localized areas [6,7].

Fig. 1: Mega-scale glacial lineations formed under the Laurentide ice sheet. Image credit: Landsat/Copernicus. Image centered at 57.00N, 63.65W. Lineations, striations and end-moraines are a common sign of glaciation on Earth.

This issue becomes even more puzzling when considering that, even in close proximity to the existing polar caps, and including the remnants of a larger, locally warm-based southern polar cap in the Dorsa Argentea geological unit, typical warm-based glaciation landscapes are largely missing [8]. Where are the Martian signs of glacial erosion? Have they been erased, did such glaciers never exist, were all glaciers always cold based, or did they simply never form?

We present a preliminary study that shows that glacial sliding may behave fundamentally different on Mars, inhibiting the formation of sliding-related morphologies even under warm-based glaciers.

Methods: We use well-established glacial sliding laws [8,9] to model ice sliding velocity under the effects of the lower Martian gravity (approximately a third of Earth's) in combination with the parameter space appropriate for Mars's Late Noachian Icy Highlands ice sheet reconstruction [10] and under different climate scenarios. In general, ice sliding velocity (u_s) depends on ice rheology through Glen's laws parameters (A and n), subglacial water effective pressure (N) (ice cryostatic pressure minus subglacial water pressure), and bed roughness (a) in the following manner (eq.1) [8]:

$$u_s = \frac{\tau_b a \, A(T) N^{n-1}}{2}$$

Erosion rates (E) are then thought to be a function of ice sliding velocity and erodibility, so that an increase in sliding rates will increase erosion rates with a power of 1-2, as shown in the results figures below.

We then consider the effects of subglacial hydrology allowing for a reorganization of the glacial drainage system from linked cavities to networks of channels (fig. 2), and discuss the landscape consequences of both regimes.

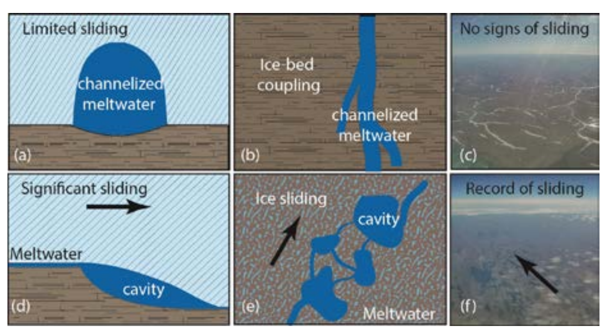

Fig. 2: Representation of the subglacial drainage system and resulting landscape signature. Image credit: author. Image location: central Devon Island (c), northern Ontario (f).

Such reorganization has been observed on Earth to occur and is controlled by meltwater subglacial discharge and cross sectional size of the conduits (larger conduits and higher discharges lead to channel opening) [9]. The switch from cavity dominated drainage to a channel dominated drainage increases effective pressure (see equation 1), which decreases sliding velocity to negligible values. The switch from a channel dominated to a cavity dominated drainage has the opposite effect of accelerating ice sliding by decreasing effective pressure to nearly zero [9].

Results: We present preliminary results for the comparison of ice sliding velocity (eq.1) on Earth and Mars in figure 3. Keeping all parameters the same (ice thickness, temperature, rheological law, ice surface slope), an ice sheet would slide at a velocity of just a few decimeters to centimeters a year on Mars, with erosion rates just a fraction of this number. On Earth, ice velocities are in the range of meters to tens of meters a year for the same ice thickness:

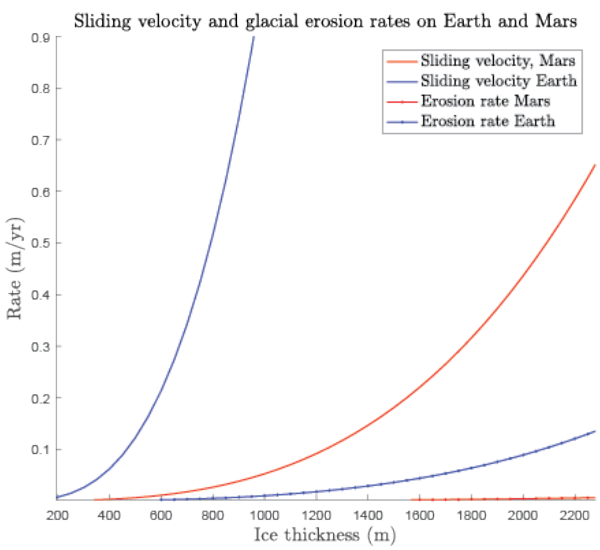

Fig. 3: Sliding velocities for Earth (blue solid line) and Mars (red solid line), and related erosional rates (Earth, blue dashed line, Mars red dashed line).

Switching between a cavity-dominated drainage and a channel dominated drainage (see fig. 2) has dramatic effects on sliding velocity, as shown in figure 4. Sliding velocity for a warm-based, kilometer-thick ice sheet is ~3 km/yr for ice sliding over a perfectly smooth bed (a approaches 0), and drops to ~1 cm/yr if drainage occurs through conduits of 5 m^2 cross sectional area. A further increase in conduit cross-section continuously reduces sliding velocity [9].

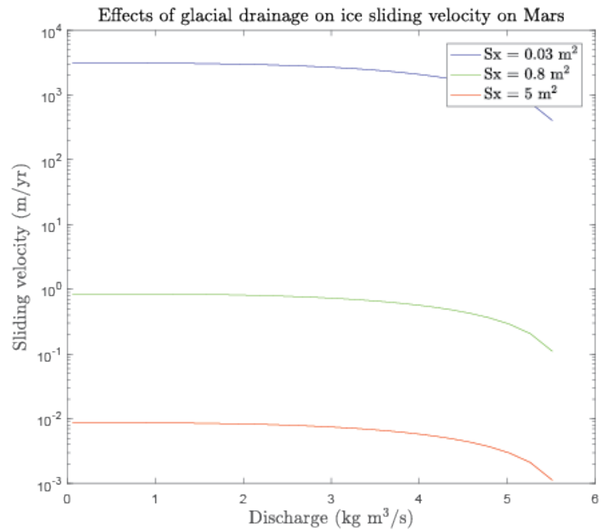

Fig. 4: Sliding velocity of ice for the linked-cavity drainage (blue line) and the channelized drainage (red line) on Mars, as a function of discharge and for different conduit cross section Sx. Transition in drainage style occurs at Sx = 0.8 m^2 for Mars, with ice thickness set to 1 km.

Discussion: The preliminary results presented suggest that glacial landscapes related to warm-based glaciation may be fundamentally different on Mars and Earth. The lower Martian gravity favors the development of subglacial channel networks over linked-cavity drainage systems, favoring the development of channel networks, eskers, and tunnel valleys rather than large mega-scale lineations, striations, end moraines, and other morphologies typically related to ice sliding. The glacial landscapes of large ice sheets on Mars may thus be more closely related to those of the high Canadian Arctic (fig. 2, c) than those typical of northern continental North America and Europe (fig 2, d). Our results also explain the scarce presence of sliding-related features in the Dorsa Argentea formation and around the polar caps [12].

References:

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