A FROZEN LAKE/GLACIOLACUSTRINE MODEL OF CRATER GREG (MARS).

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Introduction: Hartmann [1], Berman [2] and Hubbard et al. [3] presented compelling evidence for glacial flow of a landform in a crater east of Hellas, Mars (Fig. 1). This feature also exhibits evidence for meltwater channels and possible moulins according interpretation of HiRISE imagery [4]. These viscous flow features occur in a landscape containing many other features characteristically formed by glacial activity, but the depositional environment is not certain. One straight-forward interpretation based on terrestrial analogs is that the landscape in Crater Greg, like those also in Argyre and elsewhere, represents a glacially modified terrain formed under conditions somewhat typical of those prevailing in glacierized realms of Earth [5-8]. However, there remains a conundrum in some experts' minds: Mars currently has a severely cold climate; Earth-like glacial processes, occurring near the triple-point of H_2O, are not readily possible. A huge climatic excursion is needed to allow glaciation on Mars that is comparable to that normally observed on Earth. Here we examine another model that involves glacial flow but under conditions that are not usual for Earth.

In Search of Alternate Models: There are two general solutions: Either there has been a major climatic excursion to warmer, wetter conditions [6], or the Martian landscapes, though resembling glacial landscapes on Earth, were formed quite differently than is common on Earth. Here we continue to scrutinize alternatives to an Earth-like glacial environment. Last year we showed that a blanket of insulating dust could—with just about every input parameter pushed to extreme values-- allow melting under the present climate if the dust was thick (then blown away to reveal the ice), its thermal conductivity was low, and Martian heat flow was high. This 'climate change minimalist' model differs from the dusty snowpack model of melting [9] because ordinary geothermal heat, not warm air and sunlight, drives melting. However, the model of Kargel et al. [4] seems in some respects more extreme and improbable than a model involving a large climatic excursion. This year we look at another cold-climate model, but one involving a thick ice cover of a frozen lake and seasonal surface melting, which drives sediment and water into and through the ice and produces a sub-ice rock glacier-like mass of sediment and ice and emits sediment onto the unfrozen lake bed. The model requires modest climate change, but allows extreme perigacial conditions.

Conceptual Model: In Figure 2 we schematically illustrate a potential alternative model, which can produce rock-glacier-like sediment and diamicton flows and a host of sub-ice and subaqueous sedimentary deposits. The model relies on a thick ice-cover of a partly or mostly frozen lake, in this case residing in Crater Greg. The model also requires conditions whereby seasonal summer meltwater can be generated, pool at the edge or near the edge of the thick ice cover, and eventually drain through the ice or along its bed. This mechanism would have been considered not possible a decade ago according to terrestrial glaciology because the ice cover is extremely cold and allows liquid water only seasonally at the surface. However, it is now well established that supraglacial lakes in very cold realms of Greenland are able to hydrofracture the cold ice and penetrate to the bed, despite having to traverse ice that is far below the melting point. This process is known to be associated with surging of Greenland outlet glaciers.

In our alternative model, sub-ice aqueous flows generate, transport, and redeposit sediment along with ice formed when the subsurface flows tend to freeze. Gradually, ice-rich sediment masses build up along the interface between the thick lake ice cover and the crater wall. The icy sediment mass starts to flow glacially, or rather much like a rock glacier or mud flow. The lake ice deforms as it yields to the gravity-driven mass flow. In this alternative model, these flows are the lobate viscous flow features identified and described by [1-4]. Evidence for water erosion and drainage through the viscous flow features [4] is consistent with continued seasonal meltwater drainage to the bed of the frozen lake ice cover. Liquid water might drain through the viscous flow features of they are composed largely of ice. The density relations needed to explain the observations are that the lake ice cover is least dense, the gravity flows of icy sediment are between the density of the ice cover and the water, the water is denser still, and of course the crater wall is densest of all. Eventually, some of the water and sediment may reach the liquid lake below, if it is not entirely frozen. Subaqueous sediment fans can be constructed on the crater floor. The lakewater is probably rather briny, and so salt deposition (freeze-driven) is also possible.

Partial Earth analogs are the submarine glacial diamicton flows and a host of other sedimentary features described following the collapse of the Antarctic Peninsula ice-shelves [Evans and Pudsey, 10].

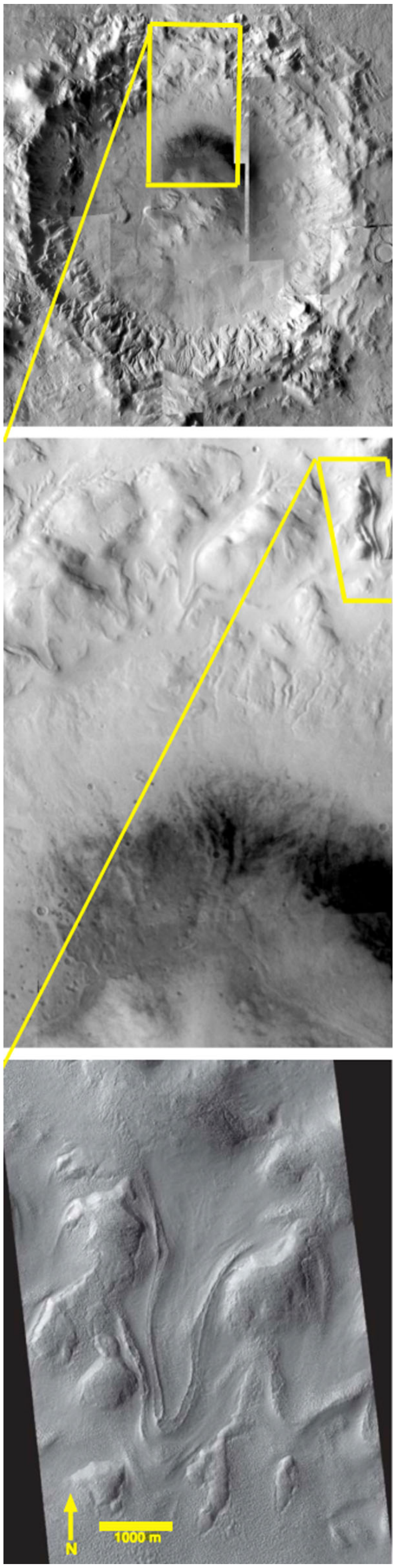

Figure 1. Crater Greg (A) About 60 km across, Greg exhibits classic complex crater geomorphology, including a central peak and terraced walls. The crater has sediment fans (here considered subaqueous) and viscous flow features [1-4].

In our presentation we will show a set of thermal models explaining some of the geologically observed phenomenology involving such mass flows of icy sediment or debris-rich glacier-like features. This non-traditional glacier-like mechanism and our suggested frozen-lake depositional environment may have applicability in other crater-hosted glacial landscapes, such as Argyre [11] and potentially can explain some peculiar features of those landscapes. On the other hand, this model does not escape from a requirement for some climate change, as our thermal models will indicate.

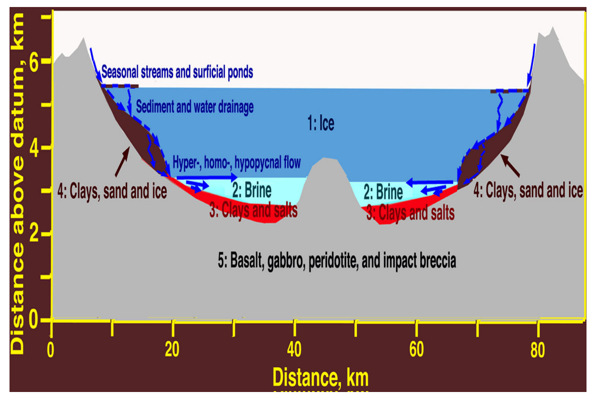

Figure 2. Schematic of Crater Greg's hydrogeologic regime at the time of formation of the viscous flow features. The lake has thick ice cover, but summer melting produces liquid water, which eventually reaches the bottom of the icecover on the crater walls. Over many years—maybe hundreds of thousands of years—a sediment-laden icy mass builds up at the bottom of the ice cover, and the deposit starts to flow glacially toward the lake. Lake-floor sediment fans, fallout of suspension load, and possibly salt deposits spread out across the crater floor. The viscous flow features are eroded by sub-ice water. Eventually, the ice sublimates, the lake disappears, and the sedimentary/glacial landscapes remains.

References: [1] Hartmann et al., 2011, EPSC Abstracts v. 6, EPSC-DPS2011-1394. [2] Berman, D.C. et al., 2009, *Icarus* 200, 77-95. [3] Hubbard, B. et al., 2011, Icarus, 211 (1), 330-346. [4] Kargel, J.S., 2011, Lunar and Planetary Science Conference, Abstract #2266. [5] Kargel, J.S., and Strom, R.G., Ancient glaciation on Mars, Geology, 20, 3-7, 1992. [6] Kargel, J.S., Mars: A Warmer, Wetter Planet, Praxis-Springer, 557 pages (2004). [7] Banks, M.E., et al., 2008, J. Geophys. Res., 113, E12015, doi:10.1029/2007JE002994. [8] Banks et al. 2009, J. Geophys. Res. 114, E09003, doi:10.1029/2008JE003244. [9] Clow, G.D., 1987, *Icarus* 72, 95-127. [10] Evans, J. and C.J. Pudsey, 2002, J. Geol. Soc., 159 (3), 233-237. [11] Dohm, J.M., et al., 2011, LPSC 42, #2255.