# HELLAS BASIN, MARS: A MODEL OF RIM AND WALL GLACIATION IN THE LATE NOACHIAN AND PREDICTIONS FOR ENHANCED FLOW, BASAL MELTING, WET-BASED GLACIATION AND EROSION, AND GENERATION AND FATE OF MELTWATER.

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**Introduction:** The Hellas impact basin plays an extremely important role in the geologic and geodynamic evolution of Mars. Its formation marks the stratigraphic base of the Noachian Era **[1]**, and its large diameter, extreme depth and significant asymmetry have made it a focus of attention for key problems in impact processes and history, geological modification processes, hydrological system and cycle evolution, glacial deposition and erosion processes, and atmospheric circulation and evolution. Due to its great depth, 1) its floor is the site of the highest atmospheric pressure and warmest temperatures on Mars **[2-4]**, 2) its presence significantly influences global atmospheric circulation, eolian processes and dust accumulation **[2-4]**, 3) its floor hosts a series of unusual deposits thought to represent the former presence of glaciation **[5]** and both Noachian and Hesperian oceans **[6]**, 4) its rim and inner slopes are significantly asymmetric **[7]** and were modified by Early Hesperian volcanic centers (Hesperian Planum and Malea Planum) **[8]** leading to Hesperian ridged volcanic plains on the walls and floor **[9]**, and 5) valley network systems, and several major Late Hesperian outflow channels debouch onto the basin floor **[9]**. This sequence of events has resulted in an extremely complex stratigraphy of the basin floor and its surroundings **[10-11]**.

One of the key factors linking events in this complex history is the hydrological system/cycle, its nature and state (vertically integrated or horizontally stratified), the implications for dominant conditions (rainfall and erosion; snowfall and glaciation; volcano-ice interactions) and the role of related processes (pluvial/nivial precipitation, overland flow, infiltration, recharge, glacial, fluvial, lacustrine and oceanic). In this study we explore the results of recent atmospheric General Circulation Models (GCMs) that predict snow and ice accumulation and glacial flow in South Polar and southern high altitude/latitude regions **[2-4]** and we call on glacial flow models to assess the role of ice accumulation, nature of flow, presence and significance of basal melting and erosion, and the fate of meltwater in the ablation zone at the bottom of the Hellas basin.

**Approach and Analysis:** We begin with the GCM scenario for a glaciated early Mars **[2-4]** shown in Fig. 1A. Using UMISM (see below) adapted for Mars **[12-17]** we investigate the behavior of ice flowing down the steep slopes from the large accumulation zone grid-south of Hellas, where accumulation rates are predicted to be several cm/yr. UMISM is run in a "supply-limited" mode, where only a finite amount of water is available to build ice sheets. This is done by separating the accumulation and ablation rate specific to each cell into positive and negative components (the net sum of these two may be either accumulation or ablation), and reducing the positive component, while retaining the negative component, as ice volume approaches the supply limit. This generally results in a shrinkage of the accumulation areas as can be seen in **Fig. 1B** for a 1X supply limit. Runs of 1 Ma are generally sufficient for the resulting ice sheet to reach an equilibrium configuration. **Fig. 2** shows profiles crossing Hellas from grid-south to grid-north (E-W) bisecting the basin. For reference, the grid origin is at the South Pole, with positive-y axis along the 0° longitude and positive-x axis along the 90°E longitude. The 4 lines show profiles for 0.5X (thinnest profile), 1X, 2X, and 5X (thickest profile), the last being more than is currently estimated for the early water budget of Mars **[18]**.

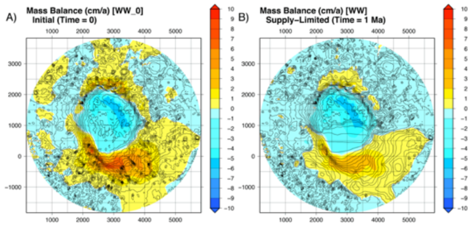

**Figure 1: Mass balance distribution from a GCM [3] (600 mbar $CO_2$ atmosphere and 42° obliquity) showing accumulation zones around the rim of Hellas Basin, with an ablation zone in the deep interior. A) Directly from the GCM. B) After the "supply-limit" of 1X current water inventory is reached. Grid-south is East.**

Of interest is the bed condition. Mean annual surface temperatures from the GCM for the bottom of Hellas are relatively warm, on the order of 240 K, while the rim is

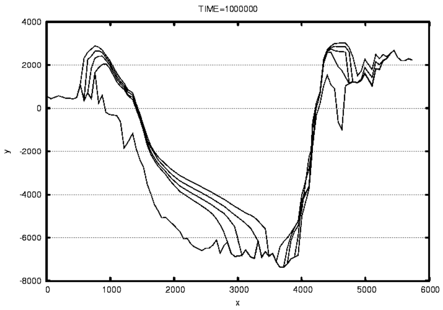

**Figure 2: Profiles from grid-south to grid-north (E, left; W, right) across the center of Hellas Basin. The least thick profile is for 0.5X, the thickest for 5X, with 1X and 2X between.**

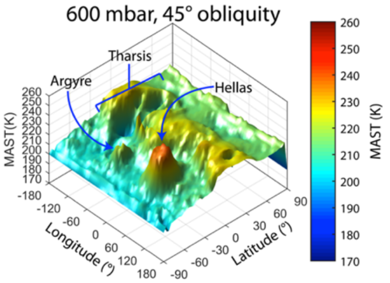

**Figure 3: GCM results [25] for mean annual surface temperature (MAST) of Mars from [18] for a 600 mbar $CO_2$ atmosphere and 45° obliquity.**

close to 210 K (**Fig. 3**). We adopt a surface heat flux of 45 mW/m$^2$ for the floor of Hellas following **[19]** on the basis of heat flux models of **[20, 21]**, and adopt a typical Late Noachian average heat flux of 50 mW/m$^2$ for the walls and 55 mW/m$^2$ for the rim and plateau from **[20, 22-24]**. With shear heating contributing on the steep slope, much of the bed reaches the melting point, water is produced, and enhanced flow due to sliding can occur. **Fig. 4** shows A) the computed basal melting rate and B) the resulting ice flow velocities for the 2X supply limit. Of note are the channelized flow features that follow valleys down the basin wall. With the warmer surface temperatures in the bottom of the basin, much of it is at the melting point as well. Results for the 0.5X, 1X, and 5X case are similar. The thick ice at the base of the basin wall is melted at the bed, and there are regions of fast flow following topographic depressions down the basin walls. The contribution due to shear heating is significant due to the steep surface slopes producing a high driving stress. The possibility exists that some of the features apparent on the surface today may have been initiated earlier in part by the flowing ice.

**Discussion and Conclusions:** On the basis of our analysis of the accumulation and flow of ice on the rim of the Hellas basin predicted by Late Noachian GCMs **[2-4]**, we conclude that significant ice accumulation should occur on the eastern basin rim and that the steep slopes of the basin walls induce significant glacial flow down into the basin. Indeed, we find that basin wall slopes are sufficiently steep that shear heating causes much of the glacier bed to reach the melting point, and wet-based glacial conditions ensue, further enhancing flow velocities into the basin. Such wet-based conditions along the walls would have caused significant substrate erosion; if the cold and icy climate predicted by the GCMs was the ambient climate for any significant part of the ~400 Ma-long Noachian, such substrate erosion may be partly responsible for the missing mass and unusual shape of the Hellas basin rim and wall in this direction and deposition of significant volumes of material removed from the basin wall, onto the basin floor. In addition, wet-based glaciers would have proceeded to flow out onto the basin floor and glaciation may have influenced a significant part of the floor, depending on supply limitations. Basal meltwater is predicted to have readily drained onto the basin floor and may have formed a large lake/sea, with the total volume of meltwater being supply- and temperature-limited. Despite the relatively higher atmospheric surface temperatures on the deep floor of Hellas **[2, 4]**, a Hellas floor lake/sea surface would have been ice-covered (above the melting temperature for only ~2% of the year). Under these conditions, the hydrological system is predicted to be horizontally stratified (shear heating itself on the walls does not melt the cryosphere), except possibly on the eastern basin floor, the locations of thickest ice/basal melting, where ice might be thick enough to remove the underlying cryosphere if it remained for a sufficient duration **[25]**. The emplacement of Hesperian ridged plains may have been on top of ice deposits, producing significant contact and deferred melting **[26]**.

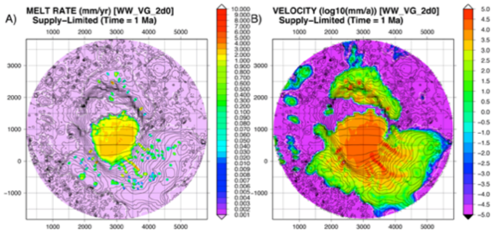

**Figure 4: A) Computed basal melt rate with 55 mW/m$^2$ on the basin rim and plateau, 50 on the basin walls, and 45 on the basin floor, and B) $Log_{10}$ of ice flow velocities in mm/yr.**

This sequence of events and associated geomorphic processes provide a series of predictions that can be tested with detailed analysis of observational data for geomorphic features and stratigraphy of the Hellas basin. For example, buried glacial and frozen lake ice may be the layer seen deforming to produce diapiric-like structures on the basin floor **[10, 11, 19]**; this "honeycomb terrain" is believed to have formed prior to the emplacement of the Hesperian-ridged plains, between ~3.7 Ga and 4 Ga **[10]**, and may offer a constraint on the timing of circum-Hellas glaciation.

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