

## The Present Near-Surface Inventory of Water on Mars: How Well Does it Constrain the Past Inventory and the Existence of a Former Ocean?

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### Abstract

Over the past 40 years, estimates of the total outgassed inventory of water on Mars have ranged from a global equivalent layer (GEL) ~7-1000 m deep [1, 2]. However, Carr and Head [3] have recently argued that it is not the total inventory of outgassed water that is important, but the amount that exists in climatically exchangeable surface and near-surface reservoirs – suggesting that any exchange with water in the deep subsurface is precluded by the existence of a thick cryosphere, at least during the Amazonian and Hesperian. Based on this assumption, and their estimate of the present day near-surface inventory of H<sub>2</sub>O (~34 m GEL, stored as ice in the polar layered deposits (PLD), lobate debris aprons, ice-rich latitude dependent mantles, and as shallow ground ice), they then extrapolate the evolution of this inventory backward in time, taking into account the introduction of new water by volcanism and outflow channel activity and the loss of water by exospheric escape. They conclude that, at the end of the Noachian, Mars had a near-surface water inventory of ~24 m and ~62 m by the end of the Hesperian – inventories that Carr and Head [3] argue were incompatible with the existence of a former ocean.

Yet, estimates of the amount of water lost or gained, over Martian geologic history, have large uncertainties. Further, the freezing and subsequent burial of a Noachian or Hesperian ocean (by volcanic ash, lavas, and eolian and fluvial sediments) provides a plausible and effective means of sequestering many hundreds of meters of H<sub>2</sub>O (GEL) well below the ~60-80 m depths sampled by the MARSIS surface permittivity investigations [4]. The potential survival of a buried remnant of a former ocean, outflow channel discharge, and past climatically emplaced ice-rich latitude dependent mantles, is consistent with theoretical expectations of the hydrologic and climatic evolution of Mars, the abundant geologic evidence for km-thick accumulations of volcanic and sedimentary deposits, and the observed distribution and morphologic characteristics of fluidized ejecta craters, as well as other geomorphic indicators of

subsurface volatiles, throughout the northern plains [5-7]. This suggests that the present near-surface inventory of H<sub>2</sub>O places no constraint on either the past near-surface inventory, or the former existence of a northern ocean.

### Near-Surface Inventory of H<sub>2</sub>O and Resurfacing History of the Northern Plains

Current research suggests that Mars accreted from a population of planetesimals that were more volatile rich than those that formed the Earth [8, 9], yielding an initial Martian planetary inventory of (bound) water ~600-4000 m deep (GEL). A potentially large, but unknown, fraction of this inventory was released from the interior by the formation of an early magma ocean, as well as by subsequent impact and volcanic degassing. It is not known how much of the initial outgassed inventory survived the early period of atmospheric escape – nor how much more was added by volcanic outgassing during the Noachian. However, there is persuasive evidence that Mars experienced intense volcanic activity throughout its first billion years of geologic evolution. This evidence is apparent at the eastern end of Valles Marineris, where ~4-5 km of layered stratigraphy is exposed in the canyon walls, capped by a plateau unit that dates from the Late Noachian [10, 11]. Additional evidence is provided by the regional flow directions of Late Noachian/Early Hesperian valley networks, which indicate that the vast bulk of Tharsis volcanic province was in place prior to the last episode of valley network formation [12].

This inability to quantify the inventory of water on Mars during the Noachian motivated Carr and Head [3] to try a different approach, based on three key assumptions: (1) that the inventory of water present in climatically exchangeable near-surface reservoirs can be considered in isolation from the planet's total outgassed inventory of water, (2) that the present near-surface inventory of water is reasonably well-known, and (3) that we can accurately estimate the amount of water added and removed from the near-surface inventory during the Amazonian and Hesperian. In this way, Carr and Head [3] attempt to

deduce the Late Noachian near-surface inventory of water by extrapolating the present inventory backward in time. While the validity of all three assumptions can be debated, it is the first that represents the most serious weakness of the Carr and Head [3] approach, as extensive resurfacing has heavily modified the nature of the near-surface environment over time.

For example, early Mars global climate models [13, 14] suggest that, if the Noachian inventory of water was large enough to form a northern ocean, it would have rapidly frozen – creating a northern ice sheet. While sublimation may have redistributed some of this ice to high elevations (forming snowpacks and glaciers) [15], Noachian Mars was the most geologically active period in the planet's history [11]. Higher atmospheric pressures would have resulted in enhanced eolian erosion, with global dust storms redistributing dust across the planet. Fluvial discharges, associated with the formation of the valley networks and earliest outflow channels, would have caused extensive erosion and carried substantial volumes of water and sediment to low elevations – especially in the northern plains. Finally, the intense volcanic activity that characterized this era could have readily blanketed any frozen remnant of an early ocean, outflow channel discharge, or ice-rich latitude dependent mantles, with volcanic ash and lavas – 10's to 100's of meters deep.

This episodic resurfacing would have had a profound effect on the stability and preservation of ice at depth [7, 16]. For example, at mid-latitudes, a mantle of regolith <10 cm deep is sufficient to thermally isolate near-surface ice from daily temperature extremes, greatly reducing its sublimative loss. Mantles >1-2 m, provide enough insulation to protect ice from annual temperature extremes, allowing buried ice to survive for billions of years. Present-day Martian examples of this effect include the defrosted regions of the south polar layered deposits and the ice-rich latitude dependent mantles. Numerous examples of the preservation of glacial ice, by its burial beneath mantles of sediment, volcanic ash and lava, can also be found on Earth (Fig. 1a).

## Conclusions

If early Mars possessed an inventory of outgassed water sufficient to form an early ocean, then a frozen relic of that body may survive at depth to the present day. While sublimation undoubtedly depleted some fraction of the initial inventory of ice, later episodes of outflow channel activity and obliquity-driven polar ice redistribution, combined with the concurrent accumulation of ~0.5 - 1.5 km of sediments and volcanics, since the Noachian [17],

would have led to the development of a complex volatile stratigraphy throughout the northern plains [7] – at depths well below those associated with the present near-surface inventory of ice (Fig 1b). Thus, even if we could assess the present near-surface inventory of ice with high precision, it would place no constraint on either the past near-surface inventory of H<sub>2</sub>O or the former presence of a northern ocean. Finally, because the burial of ice significantly inhibits its diffusive communication with the atmosphere [16], any estimate of the original outgassed inventory or water, inferred from the present atmospheric D/H ratio [18], must be considered a minimum.

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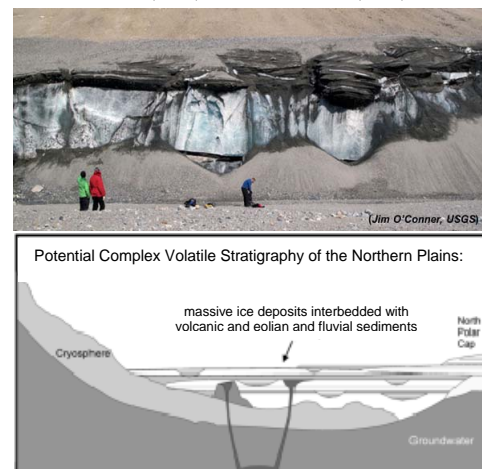


Fig. 1. (a) Several meter-thick sedimentary layer preserving remnant ice from the last glacial maximum in Garwood Valley, Antarctica. (b) Potential complex volatile stratigraphy of the Martian northern plains.