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Insights and Uncertainties Regarding the Existence, Recharge, and Extent of Martian Groundwater Flow Based on the Elevation and Location of Outflow Channel Activity

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Consideration of the thermal and volatile evolution of a water-rich Mars suggests that, if the inventory of H_2O exceeds the pore volume of the cryosphere by more than a few percent, then a planetary-scale subpermafrost groundwater system will necessarily result – a system whose existence may have played a critical role in the long-term climatic and hydrologic evolution of the planet. Under the climatic conditions that have prevailed throughout most of Martian geologic history, any water discharged by outflow channel activity should have frozen, sublimed away, and been transported by the atmosphere to the planet's obliquity-dependent coldtraps. Given an initially ice-saturated cryosphere, the deposition and retention of ice anywhere on the planet will result in the rise of the melting isotherm at the base of the cryosphere, the onset of basal melting, and the downward percolation of meltwater into the underlying global aquifer, thereby recharging the reservoir of groundwater from which the outflow channels formed. Although thick, ice-rich deposits may have accumulated in a variety of locations under different obliquity conditions, the only persuasive geomorphic evidence for the basal melting of such deposits lies in the Dorsa Argentia Formation (DAF), near the South Pole.

The Martian outflow channels appear to have had diverse origins, including: the catastrophic discharge of subpermafrost groundwater following the disruption of the cryosphere, the melting of near-surface ground ice by local magmatic activity, the breaching of surface lakes, and erosion by low-viscosity lavas. Of these possibilities, the abrupt emergence of most outflow channels from regions of collapsed and disrupted terrain, along the dichotomy boundary, suggests that they were formed by a massive discharge of groundwater from a subpermafrost aquifer, whose elevated water table was maintained in hydraulic disequilibrium with the lower-lying northern plains by its confinement beneath kilometers-thick layer of frozen ground. Barring some type of mechanical or thermal disruption, the cryosphere is capable of confining groundwater under a significant hydraulic head as long as the hydrostatic pressure in the aquifer does not exceed the lithostatic pressure exerted by the local thickness of frozen ground.

The failure of global groundwater flow models to predict superlithostatic heads, where outflow channels have previously formed, has been cited as evidence that groundwater flow on Mars is compartmentalized, rather than global. In this scenario, the downward propagation of the cryosphere, in response to the planet's declining geothermal heat flow, may have created isolated reservoirs of groundwater that became pressurized by the increase in volume that occured when the groundwater froze, generating hydraulic heads sufficient to disrupt the local thickness of frozen ground and result in the catastrophic discharge of groundwater (e.g., Carr, 1979).

However, superlithostatic heads are not a necessary condition for the generation of outflow channels – which could have occurred anywhere the local hydraulic head exceeded the elevation of the surrounding terrain. The only requirement to produce such discharges is the disruption of the cryosphere, which could have been breached by a variety of tectonic, impact, or geothermal processes. Although outflow channel activity peaked $\sim$3 Ga, the occurrence of such activity within the last $\sim$10-100 Ma, suggests that subpermafrost groundwater and the potential for outflow channel formation, continues to the present day.