THARSIS RECHARGE: A SOURCE OF GROUNDWATER FOR MARTIAN OUTFLOW CHANNELS.

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Introduction: The circum-Chryse outflow channels (OCs) [1] are large drainage features carved predominantly during the Hesperian epoch by floodwaters reaching volumes greater than 10^6 km^3 [2]. Emanating mostly from chaos regions east of the Tharsis rise, the OCs extend 100's of km to the east and north, terminating in the low elevation Chryse Planitia. Floodwaters originated from a permeable aquifer, reaching the surface through disruptions in a confining cryosphere [2].

Quantitative descriptions of OC formation remain poorly constrained. Estimated peak flow rates vary from 3×10^6 $m^3.s^{-1}$ [3] to 10^{10} $m^3.s^{-1}$ [2]; durations of discrete flooding episodes vary from a few days [2] to years [3, 4]; and inferred volumetric sediment-water ratios (S/W) vary from 10^{-4} [4] to 0.67 [5]. S/Ws even slightly less than the maximum lead to water volumes exceeding the regional storage capacity of the crust: a source of groundwater recharge is necessary.

Clifford [6] and Clifford and Parker [7] proposed that melting at the base of a South Polar ice cap recharged the aquifer and provided a steady supply of water to the OCs. This model has certain disadvantages, including the requirement of hydraulic connectivity on a lateral scale of several thousands of kilometers, the inability to provide water to high elevation channels [8], and the possible restriction of groundwater flow by a thick polar cryosphere.

We propose that recharge at the high elevation Tharsis rise immediately west of the circum-Chryse OCs overcomes these difficulties and explains previously suggested links between these regions [9, 10]. The dramatic evidence for periodic climate change on Mars, revealed by the recent orbiters Mars Global Surveyor (MGS) and Mars Odyssey, demonstrate that the volatile dynamics of Mars vary with time. Obliquity is the fundamental controller of periodic climate change on Mars, and at high values (approaching 60° in the past [11, 12]) it causes the development of a cold equatorial zone in which surface ice is perennially stable [13-15]. The poles experience warm summers, resulting in rapid sublimation of ice from the polar caps. Polar vapor is transported to the cold lower latitudes where it precipitates [13-16], perhaps preferentially over regions of high topographic elevation [15], such as Tharsis. Evidence of ice-related processes at low-to mid-latitudes is observed in landforms such as rootless cones [17], rampart craters [18] and glacial features flanking volcanic edifices [19]. Tharsis is also a likely location for the efficient infiltration of surface ice into the groundwater aquifer. Extensive volcanic activity spanning most of its history may have thinned the cryosphere [20], perhaps melting it through in places [21]. The immense discharges of the largely Hesperian outflow channels mean that much more water participated in the hydrologic cycle of Mars at this time than in the later Amazonian (which extends to the present).

Model: We support our qualitative arguments with numerical simulations generated by the U.S. Geological Survey's three-dimensional finite-difference code MODFLOW-2000. We model the (initially saturated) Martian aquifer between east longitudes of 180° and 360°, and between latitudes of 90°S and 90°N (Figure 1). The upper and lower model boundary elevations are determined primarily by the Martian topography (taken from MGS MOLA data), from which the younger (Amazonian) volcanic shields have been removed. An impermeable cryosphere offsets the upper model boundary to some depth below the topography determined by the geothermal heat flux and surface temperature. The lower model boundary elevation is also offset from the topography, but to a depth determined by the onset of pore-space compaction due to overlying lithostatic pressure.

We apply South Pole recharge to a model (SPC) with the hydraulic and thermal properties of [7] which favor high geothermal heat flux and aquifer porosity, resulting in a thin cryosphere with high average permeability. We then alternately apply South Pole and Tharsis recharge to models (SP and TH) with improved, more conservative heat flux and porosity. In all cases, recharge is applied at 2×10^{-10} $m.s^{-1}$ [7], but infiltrates into the aquifer at a lower, variable rate determined by permeability and hydraulic head gradient. Excess recharge is assumed to evaporate, sublimate, or become surface runoff. South Pole recharge is applied to model cells within 750 km of the pole [7], while Tharsis recharge is applied to regions whose surface elevation exceeds 6000 m, yielding the same total areal coverage as South Pole recharge.

We consider individual and combined approaches to outflow discharge: in individual-discharge models, each of the nine modeled OC sources begins discharging at the start of the simulation, and is shut off once its individual quota is met. In combined-discharge models, sources are not shut off and each pair of time and cumulative discharge values is interpreted as a complete period of outflow activity and the corresponding discharge quota met by the combined output of all outflow sources in that period. In this way, a range of discharge quotas (and therefore of S/Ws) is obtained in a single simulation (Figure 2).

Results: Our results strongly favor Tharsis over the South Pole as the more efficient recharge location. In individual-discharge simulations, individual outflow activity duration times are almost ten times shorter in the TH model than in the SP model, with the former completing its discharge requirements in 400 Myr (Figure 1). TH and SPC durations are comparable, but discharge requirements in the latter are met by initial storage in its deep, highly porous and permeable aquifer [7], rather than through the influence of recharge. In combined-discharge simulations, the SP model takes almost three times the maximum likely circum-Chryse OC formation time of 900 Myr to meet discharge quotas with sufficiently small sediment concentrations (S/W < 0.67, Figure 2b). To reduce outflow activity duration to this maximum, the average permeability of the model must be increased to three times the modeled value of 2.5×10^{-15} m^2. The TH model scaled to the maximum likely permeability of 2×10^{-13} m^2 [22] produces enough discharge in 900 Myr to dilute the sediment load to a S/W of only 2.4×10^{-3}.

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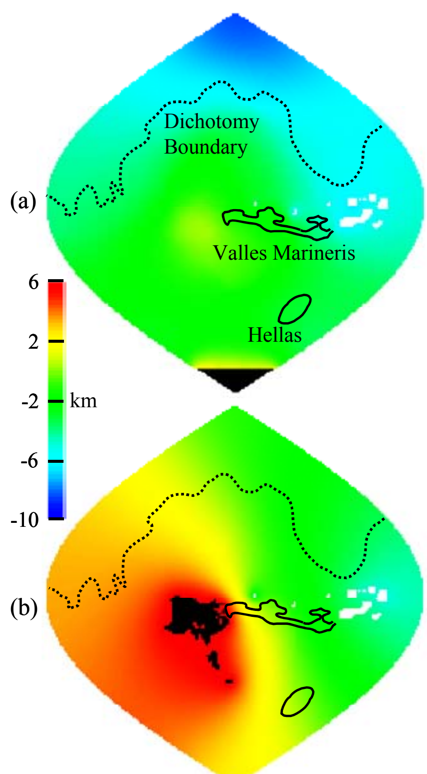
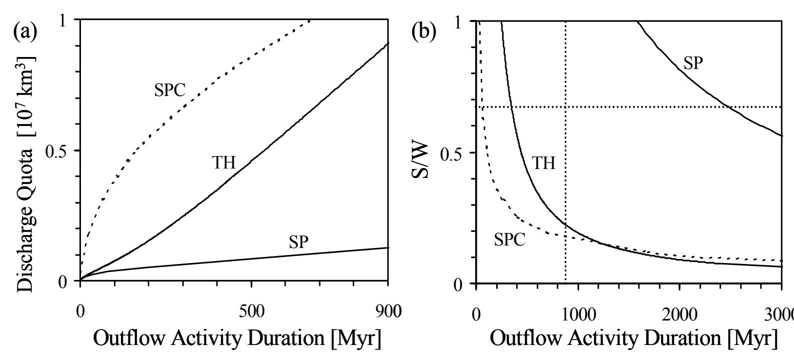


Figure 1 Hydraulic head at 400 Myr in individual-discharge (a) SP and (b) TH models. Black regions represent recharge, white regions represent outflow channel sources.



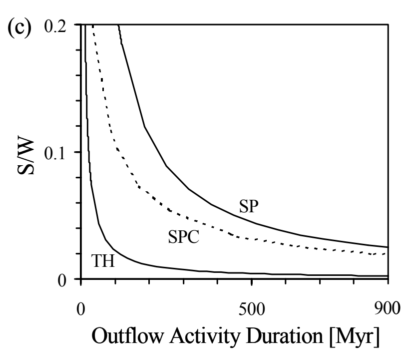


Figure 2 (a) Total discharge quota and (b) S/W for combined-discharge models. Dashed and solid line styles indicate different sets of hydrologic and thermal properties. Dotted lines represent upper bounds. (c) S/W scaled to the maximum permeability.