THE SECULAR LOSS OF GROUNDWATER ON MARS. R.E. Grimm[1] and S.L. Painter[2], [1]Department of Space Studies, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302 (grimm@boulder.swri.edu), [2]Geosciences and Engineering Division, Southwest Research Institute, 6220 Culebra Rd., San Antonio, TX 78228 (spainter@cnwra.swri.edu).

Introduction. A new global-scale model for subsurface transport of volatiles on Mars predicts massive loss of subsurface H_2O. This occurs because excursions to low obliquity strongly drive ice sublimation and subsequent groundwater evaporation at low latitude, which in turn allows high-latitude H_2O to migrate toward the equator and also escape. After a few billion years, only a few monolayers of adsorbed water remain: the interior of Mars is not habitable under these conditions. Saturated zones persist only where vertical flow is capped by deep, stable ice (i.e., at mid-to-high latitudes) and where lateral flow is blocked by lithological boundaries. Joint criteria for minimum depth to such compartmented groundwater and landing accessibility are optimized in the northern plains at 30-45°N.

Model. We used the computer code MarsFlo [1,2], a three-phase simulator for water migration in partially frozen porous media. Conservation of H_2O (as ice, liquid and vapor) and CO_2 (in the gas phase and dissolved in liquid water) are coupled to a heat transport equation. Multiphase flows are described by generalizations of Darcy's Law and the van Genuchten relative permeability and capillary pressure relationships. Classical binary diffusion and Knudsen flow describe the gas-phase diffusive transport of H_2O and CO_2 [3]. Diffusion coefficients are calculated from temperature, pressure, and tortuosity based on the local gas content and porosity [4]. The equation of state and thermophysical properties are efficiently provided by lookup tables. The nonlinear equation solver uses a finite-volume spatial discretization scheme with fully implicit (backward Euler) time stepping and modified Newton iteration to resolve nonlinearities at each time step.

The model domain is a 2D cross-section of a spherical Mars extending from equator to pole and to a depth of 20 km. The vertical discretization varies from 10 to 100 m. The horizontal discretization of 5° is relatively coarse in these preliminary models but still resolves the key features of lateral flow. The permeability was limited to 10^{-10} m^2 near the Martian surface and decreases with depth according to [5], after rescaling depth inversely with gravity [6,7]. Porosity was then calculated from permeability using the classical Kozeny-Karman relationship. The total available pore volume in the model is equivalent to 154 m GEL.

The first set of simulations [8] assumed saturated conditions below 1 km depth as the initial state, with a vadose zone above. This initial condition was arbitrarily chosen but reflects initial H_2O inventory about one-half of available porosity. Here we show results with the pore volume saturated to 100 m of the surface.

The model start is assumed to be the switch from a denser and warmer atmosphere to the present cold and dry conditions. This transition occurred sometime in the Hesperian epoch, whose age, including uncertainties, could span 1.8–4.3 Ga [9]. The basal heat flow is taken to decline exponentially with time, but uncertainties in the absolute start time lead to a wide range of initial heat flow. Vigorous boiling at the water table, caused by conditions of low pressure and "high" heat flow, presently introduces numerical instabilities, so a lower initial heat flow 54 mW/m^2 was selected (also see discussion in [8]). A model runtime of just 1 b.y. then leads to a contemporary chondritic heat flux ~28 mW/m^2 [10]. Most important changes in the distribution of subsurface H_2O will be seen to occur within about one billion years.

The surface was treated as an open boundary with free exchange of heat and mass to the atmosphere. Atmospheric vapor as a function of obliquity and surface temperature as functions of obliquity and latitude were derived from [11]. Obliquity variations were represented by sampling a probability distribution [12] at 10-Myr intervals and linearly interpolating.

Results. The sudden imposition of subfreezing surface temperature initiates global subsurface freezing, which reaches greater depths at higher latitudes (Fig. 1). By 200 Myr, low-latitude ice is largely sublimated and underlying water is evaporating. This lowering of the water table creates a horizontal hydraulic gradient, causing groundwater flow from high latitude toward the equator (e.g., 700 Myr). By 1000 Myr, groundwater exists only in deeply unsaturated states. Note also that available pore volume and vapor migration toward the equator has caused sublimation from the base of the cryosphere, and further H_2O loss. At later times (beyond our model), the low vapor pressure will strip the vadose zone of capillary water to a few monolayers of adsorbed water, and the depth of freezing will increase.

Essential features of the model were independent of the particular realization of obliquity history. However, the results of these chaotic histories more closely resemble outcomes from constant low obliquity than constant high obliquity. This implies that H_2O transport under secular chaotic obliquity is controlled by excursions to low obliquity, in which the exponential dependence of vapor pressure on temperature causes rapid sublimation and evaporation.

If only vertical (1D) flow is permitted [8], massive depletion of H_2O at low latitudes still occurs due to sublimation and evaporation, but the mid- and high-latitude evolution is dominated by progressive freezing as heat flow declines. Without lateral flow, confined groundwater can remain below high-latitude ice until the freezing front consumes all locally interconnected porosity. Compartmented groundwater on Mars is suggested by the localization of outflow channels [13].

Discussion. Our results do not support the concept of present-day, globally distributed groundwater [14]. The dearth of low-latitude groundwater is a direct consequency of the instability of low-latitude ice. Radar soundings [15,16] do not see any indication of basal melting and groundwater recharge in the contemporary north polar ice cap; indeed, all of the water lost in our model is insufficient to initate basal melting [8].

If large-scale lateral subsurface flow is possible on Mars, almost all H_2O would have been lost through the low latitudes, and only a few monolayers of adsorbed water would remain. This tightly held water cannot support microbial life [17]. A lithologically compartmented subsurface is not unreasonable, however, and could retain zones of habitable groundwater. Such groundwater would be nearest the surface at the lowest latitudes of secular quasi-stability, say 30-45°. Because low-altitude plains are preferred for landings, these considerations point to Arcadia/Amazonis, Acidalia/Chryse, and Utopia as favored sites for groundwater exploration on Mars.

New Models. Several updates and improvements to the model are in progress: higher overall storage capacity, adaptation to higher heat flow, inclusion of the long-term (10^8-yr) obliquity behavior, and a "dusty gas" treatment of the diffusion-permeability relationship [18,19].
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Figure 1. Time series through 2D global flow model with chaotic obliquity variations. Initial freezing of cryosphere is followed by sublimation and evaporation at low latitudes, which in turn cause net flow toward equator, including erosion of high-latitude cryobase. Residual zone of unsaturated liquid will continue to evaporate beyond model runtime, until only a few monolayers of adsorbed H_2O remain.