

GRADUAL SEQUESTRATION OF WATER AT PROSPECTIVE LANDING SITES IN THE SOUTH POLAR REGION OF THE MOON. Norbert Schörghofer, Planetary Science Institute, Tucson, AZ & Honolulu, HI, USA (norbert@psi.edu).

Introduction: The distribution and abundance of water in the polar regions of the Moon remains poorly understood. Three types of water ice storage in lunar soil have been proposed:

I) In *cold traps* the sublimation into vacuum is less than the amount that was delivered over time [1]. The approximate criterion is that the peak surface temperature remains below about 110 K.

II) *Vapor pumping & subsurface cold trapping:* Water molecules can migrate into the porous subsurface until they reach depths where they remain indefinitely. Temperature cycles accelerate this migration. The rule-of-thumb is that subsurface temperatures have to remain below about 110 K and the surface temperature amplitude should be large [2,3].

III) *Relic buried ice:* Buried ice retreats far slower than ice exposed on the surface [4]. The rule-of-thumb is that subsurface temperatures have to remain below 140 K [5]. Although this condition is less restrictive than (I) and (II), it is only relevant for locations where ice was once quickly buried.

The topic of the present study is vapor pumping by temperature cycles (II) [2,3,6]. This sequestration mechanism works best with a quasi-continuous supply of water molecules to the surface. Even low surface concentrations (less than a monolayer) suffice. The area where this sequestration might occur is more than five times larger than the cold trap area [3,7].

Improved quantification of desorption rates: A quantification of molecular residence times or desorption rates is necessary that spans concentration regimes from a fraction of a monolayer to ice. The desorption rate S depends on temperature T and the adsorbate surface concentration θ . For ice, S is the sublimation rate into vacuum, which only depends on T . Here the Brunauer-Emmett-Teller (BET) isotherm model is used. A BET isotherm was fitted to the reversible H_2O isotherm measured for a lunar sample [8].

Surface and subsurface temperatures: Three study sites are selected in the south polar region, all prospective landing sites (Table 1). The exact coordinates will not be known until after the landings, so the selected coordinates only represent examples in the vicinity and outside of cold traps. Moreover, temperatures vary over rover traverses.

Surface temperatures are obtained from Diviner data binned into 96 solar longitudes (local time) bins and 2 ecliptic longitude bins (winter and summer) using the data products of Ref. [9]. The sublimation rate of crys-

talline ice is $100 \text{ kg m}^{-2} \text{Gyr}^{-1}$ at 109 K and $1000 \text{ kg m}^{-2} \text{Gyr}^{-1}$ at 114 K. The study site west of Howarth Crater has a mean temperature close to the cold trap threshold (Table 1).

Subsurface temperatures are obtained by solving the one-dimensional heat equation, using the measured Diviner temperatures as upper boundary condition and a geothermal heat flux as lower boundary condition.

Location (coordinates)	T_m (K)
Shackleton Conn. Ridge (89.46°S, 137.4°W)	150
West of Nobile Crater (85.43°S, 31.56°E)	129
West of Haworth Crater (86.79°S, 21.1°W)	113

Table 1: Study locations with Diviner-derived mean surface temperature. T_m . . . mean surface temperature

Equilibrium concentrations from continuum model calculations: In equilibrium, the net vapor flux vanishes, and the time average of S is the same at all depths, and determined by its value on the surface. Outside of cold traps, where no net accumulation occurs on the surface, the time average of the desorption rate is the time average of the infall rate, e.g., $1000 \text{ kg m}^{-2} \text{Gyr}^{-1}$.

At depths where the temperature amplitude is negligible, θ will be constant after it has assumed its equilibrium value. To calculate the equilibrium value of θ even at depths where temperature varies, it is assumed that the local adsorption dynamics follows an isostere.

Figure 1 shows the subsurface temperatures and the number of monolayers adsorbed at one of the study sites. Within the thermal skin depth there is little adsorption because of devolatilization by periodically high temperatures. For $100 \text{ kg m}^{-2} \text{Gyr}^{-1}$ the maximum concentration is about half a monolayer; for $1000 \text{ kg m}^{-2} \text{Gyr}^{-1}$ even ice is stable in the subsurface. At increasing depth, the geothermal gradient leads to decreasing adsorbate concentrations.

Sequestration (pumping) rates from random-walk calculations: Diffusion and adsorption are modeled in a one-dimensional setting where molecules move up or down in discrete steps. Every incoming molecule is assigned a residence time τ , picked from a probability distribution. Temperatures and adsorbate concentrations are updated in time intervals Δt , chosen as 1/96th of a lunation. Within each such time interval, molecules can jump repeatedly. The model calculations are initialized with a completely dry domain. At each time step, one computational particle is added on the surface. Those that move upward from the surface are assumed lost. The mean free

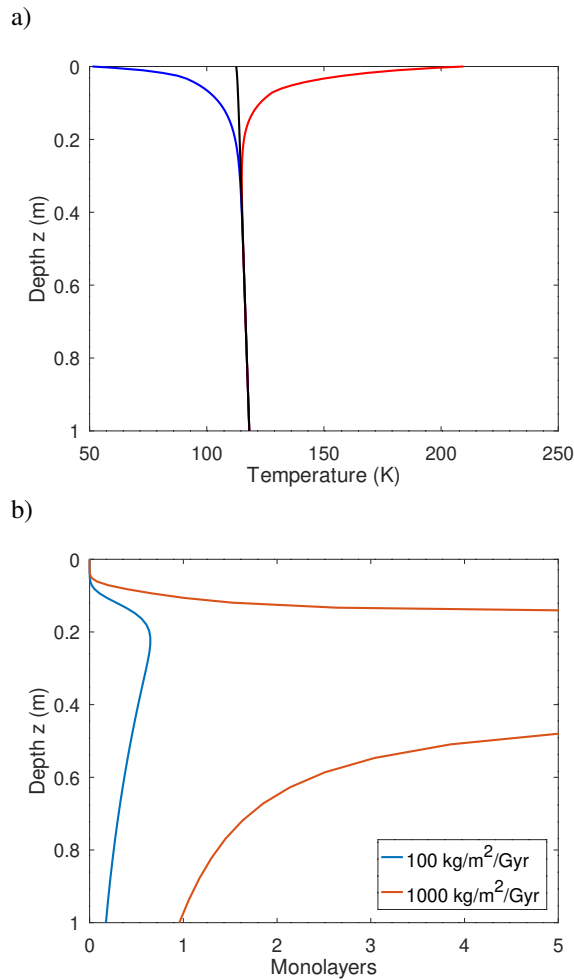


Figure 1: a) Mean, minimum, and maximum subsurface temperatures, and b) Equilibrium H₂O concentration for two water delivery rates at a study site west of Haworth Crater (Table 1).

path is set to 100 μ m, which is of the same order of magnitude as the grain size of lunar dust in Apollo samples [10].

Figure 2 shows the amount sequestered at the site with the lowest mean temperature among the three study sites. The development of a hydrated layer separated from the surface by an adsorbate-poor layer is apparent. The pumping pushes molecules into the slowly hydrating layer, where the molecules are barely mobile. As a fraction of the amount delivered to the surface, the column-integrated sequestered H₂O mass is 0.13% over the first 100 kyr, but decreases with time. Extrapolating to 1 Gyr, the fraction may be 0.05% or 0.5 kg m⁻²Gyr⁻¹.

The Moon has been in its current spin axis orientation probably for the past 2–3 Gyr [1]. Overall, a column-integrated abundance on the order of 1 kg m⁻² (1 mm) is expected for the abovementioned rate of supply to the

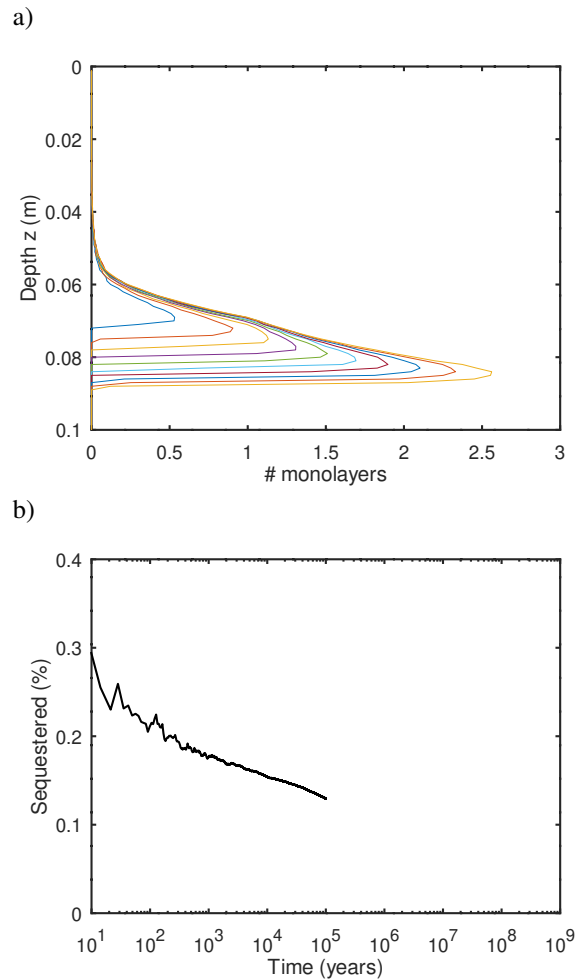


Figure 2: Result of microphysical model calculations with a delivery rate of 1000 kg m²Gyr⁻¹. a) Histograms of H₂O concentration in intervals of 10 kyr. b) Fraction of H₂O sequestered as a function of time.

surface. When concentrated within the top few decimeters, this amount could be easily detected with upcoming neutron spectrometers on rovers, such as carried by VIPER and MoonRanger.

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