INTERCOMPARISON OF HYDROGEN DISTRIBUTIONS AT HIGH LATITUDES ON MARS.

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Introduction: It has long been known that water ice should be stable at decreasing depth with increasing latitude poleward of about 50º [1,2,3,4]. The first measurements of the hydrogen content of near-surface regolith [5,6,7] verified that these predictions were basically correct. The measured distributions were found to be closely symmetric in latitude with the south containing a slightly-higher hydrogen abundance [8]. In these studies, measured epithermal neutron currents were interpreted under the assumption of a single semi-infinite regolith layer that extends uniformly throughout the field of view of the Mars Odyssey Neutron Spectrometer (MONS), which has a FWHM of 600 km. A constant chemistry was assumed throughout, having elemental abundances that were measured at the Mars Pathfinder landing site [9]. We now return to this study by extending the analysis to a two-layer model using the global measurements of both the thermal and epithermal neutron currents. The symmetry in latitude, or lack thereof, can provide insight into the mechanisms that control the present-day, near-surface distribution of water-equivalent hydrogen, WEH.

The Regolith Model: The near-surface regolith is assumed to consist of two discrete layers [10]. An atmosphere having the composition measured by the Viking Orbiters [11] and a column thickness that varies over the planet according to the elevation measured by the Mars Odyssey Laser Altimeter [12] under the assumption of a constant scale height of about 11 km, was used in all simulations of neutron currents at the orbit of Mars Odyssey. Thermal and epithermal currents measured using the MONS were then corrected to a single atmospheric thickness of 16 g/cm^2 using a large number of numerical simulations made with the Monte Carlo Neutral Particle code, MCNPX [13].

The only element of the regolith that is allowed to vary between the two soil layers is hydrogen. The model can therefore be specified completely by the thickness of the upper layer, D, its hydrogen abundance, specified by its mass fraction of water-equivalent hydrogen, Wup, and the hydrogen abundance of the semi-infinite lower layer, also specified by its mass fraction of water-equivalent hydrogen, Wdn. Because we only have two measurables, the thermal and epithermal neutron currents, we need to specify the WEH mass fraction of the upper layer to be constant, chosen here to be, Wup=0.01.

Although the simplicity of this model and its assumptions lead to significant systematic uncertainties in the resultant estimates of D and Wdn from the measured neutron currents, they still yield an improved description of the global hydrogen distribution over that obtained using a single layer model. The method used to transform measured thermal and epithermal neutron currents to D and Wdn and the systematic uncertainties that result from the assumptions of our model are given in Diez et al. [10].

Results: Maps of both Wdn and D are shown in stereographic projection poleward of ±45º in Figures 1a and 1b, respectively. The parts of the maps poleward of 70º S were not included because of significant contamination by the large thermal neutron currents emitted by the CO_2 cover of the residual south polar cap [14]. Starting first with the maps of Wdn, inspection of Figure 1a shows that WEH abundances generally increase from a minimum of 2% near the equator to about 90% within the residual north-polar cap. Within the latitude range available to this study in the south, the WEH abundance observed maximizes at 65% at about 65º S.

Inspection of Figure 1a shows a relative maximum in WEH abundance within Scandia Colles, centered at about 70º N and -125º E. This maximum arcs around to the west at a nearly constant latitude thereby surrounding a relative minimum centered within the sand dunes of Olympia Undae, at about 80º N and -170º E. The south also exhibits a relative maximum centered at about 65º S and 95º E. This maximum overlies high terrain just south of Promethei Terrae.

Inspection of Figure 1b shows similar depth profiles at high northern and southern latitudes. These reveal a constant latitudinal zone of relative maxima centered at ±(55º to 60º). Within these rings, the depths are a relative minimum at longitudes where Wdn are maximum in both hemispheres. Poleward of both these rings, the depths decrease monotonically with increasing latitude toward zero.

A transect through both the Wdn and D distributions at a longitude of -171º E that shows most clearly the north-south symmetry of the WEH distributions, is given in Figure 2. Inspection shows that Wdn (given by the blue dots) is moderate to low near the equator and begins to increase sharply at about 55º latitude in both hemispheres. This longitude was chosen because although it illustrates that WEH abundances in both hemispheres differ from each other in detail (this cut goes through the center of Olympia Undae revealing a relative minimum that is not seen in the south), the overall northern and southern abundance distributions have similar magnitudes. Also seen clearly are the nearly symmetric depth profiles that maximize at about ±60º latitude.

The close overall similarity in the Wdn and D distributions in both hemispheres is clearly illustrated in Figure 3. Parameters derived between +60º and +70º N are plotted in red, and those between -70º and -60º N are plotted in blue. Inspection shows that although both distributions show a strong and very similar anticorrelation between Wdn and D, WEH abundances are generally a little higher in the south. The correlation coefficient for both data sets considered as a single entity is R = 0.91. When the north and south data sets are analyzed separately the correlation coefficients are 0.94 in the north and 0.91 in the south. The regression equation in Figure 3 was derived from an average of correlations derived from plots of Wdn versus D and separately from D versus Wdn in order to remove the bias in all regressions when the correlation coefficient is less than unity. The separate correlations for the north and south portions of the data are given by:

North	Wdn = 0.85 – 0.037 D
South	Wdn = 0.86 – 0.034 D.

An interesting byproduct of the overall correlation shown in Figure 3 is that Wdn is equal to 0.92 when D = 0, while the separate zero intercepts are 0.85 and 0.86 in the north and south, respectively. Similar correlations using chemical abundances that bracket the distribution of abundances measured at Meridiani Planum and Gusev crater [10] give Wdn zero-depth intercepts that range between 0.80 and 0.94. It is interesting to note that these abundances are equal to the estimates of water ice mass fractions of the polar-layered deposits derived from MARSIS and SHERAD data [15,16], within measurement uncertainties.

Summary and Conclusions: Measurements of thermal and epithermal neutron currents using the MONS were used to estimate the WEH abundances of a lower layer and its burial depth below a relatively desiccated cover layer in a two-layered model of the near-surface regolith of Mars. The distributions of WEH are found to be closely similar in both hemispheres at high latitudes, with the WEH content in the south being slightly higher than that in the north. This close similarity is expected because both WEH distributions are fundamentally controlled by the general reduction in solar insolation with increasing latitude and the physical structure of the topmost meter of soil. Reduced solar heat input at higher latitudes in both hemispheres results in surface temperatures at high latitudes that are lower than those near the equator. A lower surface temperature, in turn, then allows water ice to be stable ever closer to the surface at increasing latitudes.

However, the increasing Wdn abundance with decreasing burial depth could have several explanations. A possibility is that it reflects past climate variations that somehow conditioned the soil to contain more pore volume, permeability, or water-ice lenses with decreasing depth. Another possibility is that the structure of near-surface soil at latitudes higher than 60º has been conditioned over time by the action of thermal stresses driven by seasonal temperature variations [17,18] to contain increasing pore volume with decreasing depth. The observed correlation between Wdn and D cannot reflect the geology of the Martian lithosphere because the geology and geological history of the highlands in the south are very different from those of the low altitude Vastitas Borealis formation in the north.

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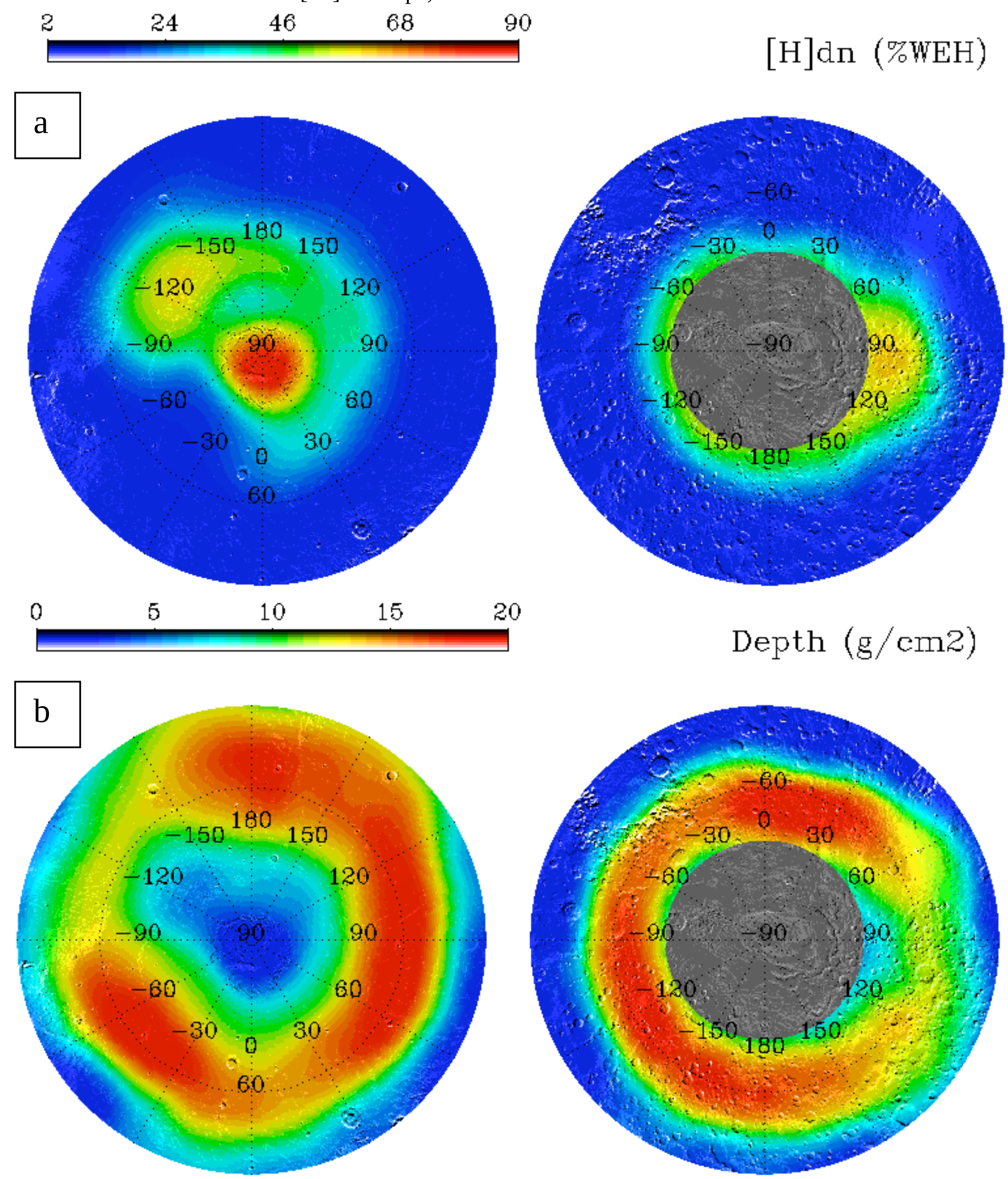

Figure 1 Maps of the WEH content of the lower layer in a two layer model of near-surface regolith (1a) and the burial depths of this layer beneath a relatively desiccated layer, here chosen to contain 1% WEH (1b).

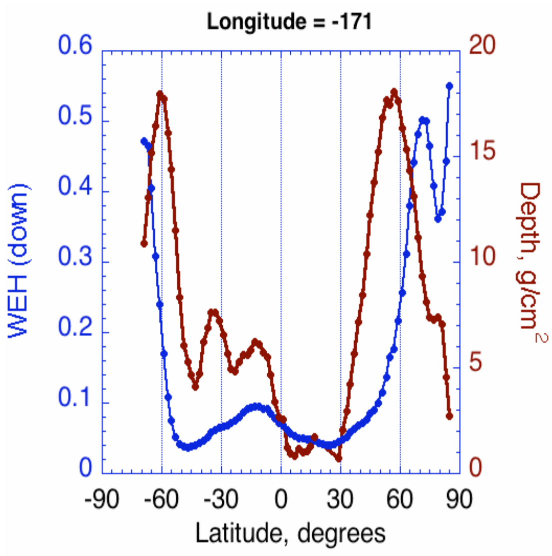

Figure 2 Plots of the WEH content of the lower layer (blue dots) and its burial depth below a relatively desiccated upper layer (red dots). The WEH content of the upper layer is chosen to be 1%.

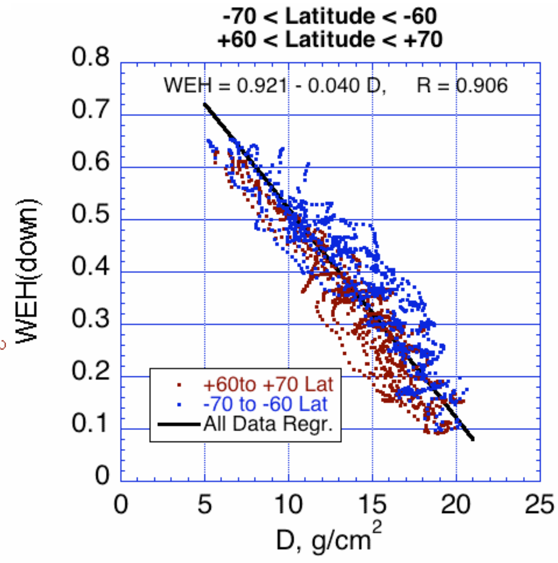

Figure 3 Regression between the WEH content of the lower layer and its burial depth below a relatively desiccated upper layer. The red dots give the measurements between +60º and +70º latitude and blue dots give them between -70º and -60º latitude.