

DETERMINATION OF THE LAYERING OF HYDROGEN IN THE TOP METER OF MARS. B. Diez¹, W. C. Feldman², S. Maurice¹, O. Gasnault¹ and T. H. Prettyman³, ¹Centre d'Etude Spatiale des Rayonnements, Université Paul Sabatier, CNRS, Toulouse, France, ²Planetary Science Institute, Tucson, AZ, ³Los Alamos National Laboratory, Group ISR-1, Los Alamos, NM (benedicte.diez@cesr.fr).

Introduction: The Mars Odyssey mission has provided considerable insight into the present state of the Martian cycle of water. Maps of the subsurface water content have been estimated using the Gamma Ray Spectrometer suite of instruments [1, 2, 3]. Thermal, epithermal and fast neutron leakage currents are known to provide a sensitive measure of the hydrogen content of the top ~meter of ground [4]. However the investigation of hydrogen deposits is complicated because the neutron currents depend on both the elemental composition and its stratigraphy.

We propose a method to infer depth distribution of the hydrogen rich layer in the top meter of Mars from the neutron currents measured using the Mars Odyssey Neutron Spectrometer. Assuming the soil can be modeled by two layers of different hydrogen content, simulations using the Monte Carlo code MCNPX [5] allow an inversion of the neutron data into knowledge of the hydrogen content and its depth. We quantify the contribution of the composition in terms of chemical elements individually and in terms of macroscopic cross sections. To get as free as possible from this source of error, an average composition was calculated from MER data. Compositions of a wide range of macroscopic cross sections were used to evaluate the uncertainties associated with our calculations.

The data used in this study extends between Feb 2002 and Sep 2005. Two different processing schemes have been applied to the raw data issued from the Los Alamos built neutron spectrometer [6, 7]. The difference between the two data sets is lower than 1.6% for thermal neutrons and 2.6% for epithermal neutrons, so our choice of using the second data reduction has no major impact. This data has been corrected among other things for satellite height, cosmic ray variations and atmospheric pressure. Only measures not contaminated by CO₂ frost were kept.

Detecting layering with the Mars Odyssey Neutron Spectrometer: In order to quantify the influence of the layering of the soil on neutron emission, simulations have been performed with a model incorporating two layers [6]. The topmost layer is relatively desiccated (it is chosen to have a hydrogen content of a few percent of Water Equivalent Hydrogen) and has a thickness D . The lowermost layer is relatively rich in hydrogen and is assumed to be semi-infinite. The neutron spectrometer provides three measurables consist-

ing of three ranges of energy: thermal, epithermal and fast neutrons. Only thermal and epithermal neutron currents are used in our analysis. Fast neutron currents are not used because their variation with hydrogen is not sufficiently different from that of epithermal neutrons to provide discriminating information.

In addition to our three parameters of interest (the thickness of the uppermost layer D , the hydrogen content in the upper and the lower layers, respectively $[H]_{up}$ and $[H]_{dn}$) the concentrations of all chemical elements are also needed as a function of depth. Most important are the strong neutron producers and/or absorbers: Cl, Fe, Ti, S, Gd and Sm. However the composition and layering of the soil is not well known so no layering of an element other than hydrogen will be handled here. $[H]_{up}$ will be fixed at the constant value 1%, so that only two variables remain: $[H]_{dn}$ and D .

Simulations have been made for a discrete range of values of $[H]_{dn}$ and D . Our analysis procedure consists of superimposing measured thermal and epithermal currents on a thermal-epithermal grid of simulations, shown in Figure 1. Inferred values of $[H]_{dn}$ and D are determined by interpolating between the points of the grid.

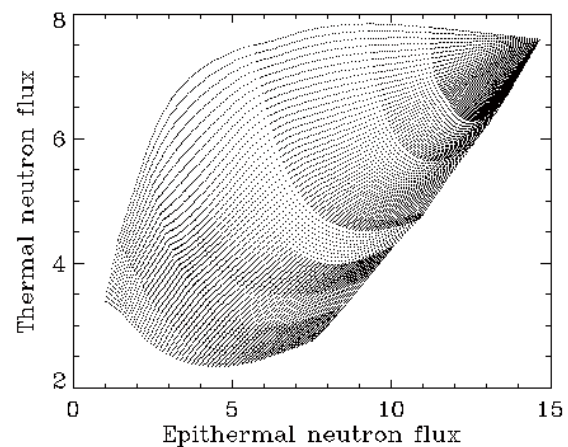


Figure 1: Grid of thermal counting rates as function of epithermal counting rates for increasing values of $[H]_{dn}$ (from right to left) and increasing D (from top to bottom).

Sensitivity of MONS to composition: The problem with our transformation method is that the compo-

sition is likely to change our results considerably. Considering separately the concentration of every chemical element is not possible at the present time because these concentrations are only known in sufficient detail at five discrete landing sites. However, transformation of measured neutron currents to hydrogen abundance and burial depths needs only a determination of the macroscopic energy-loss and absorption cross sections [4]. The macroscopic cross section for a given reaction is the sum of every elemental concentration multiplied by its corresponding cross section.

To evaluate the range of macroscopic cross sections likely to be encountered on Mars, we calculated them for all in-situ compositions measured to date [8, 9, 10]. The sensitivity to variability in observed chemical compositions determined at the two Mars Exploration Rover sites is given in Table 1. These results determine the influence of each elemental concentration on the macroscopic absorption of the soil. The most important elements on the neutron capture are found to be Fe, Cl and S.

	Δ MER in %wt	$\Delta \sum$ abs in m-1	$\Delta \sum$ abs in %
Na ₂ O	2,07	0,02	1,9
MgO	5,29	0,01	0,5
Al ₂ O ₃	7,7	0,02	2
SiO ₂	27	0,04	4,1
SO ₃	27,6	0,11	10,4
Cl	0,55	0,31	29,5
K ₂ O	0,4	0,01	1
CaO	2,21	0,01	1
TiO ₂	1,34	0,06	5,5
FeO	20,77	0,44	41,6

Table 1: Variation of absorption macroscopic cross section as a function of elemental concentration variation measured at the two MER sites.

The elemental composition measured by the Gamma Ray Subsystem (GRS) could provide an estimate more representative of our spatial scale of interest. But GRS does not presently measure the abundance of all chemical elements. However table 1 suggests that a fair determination of the macroscopic cross section might be obtained by using the GRS determination of Cl and Fe [11], and constant mean values for the other elements. We plotted the distribution of absorption macroscopic cross sections found for the MER and GRS data sets on Figure 2. Although there is an offset, they display almost similar ranges of values.

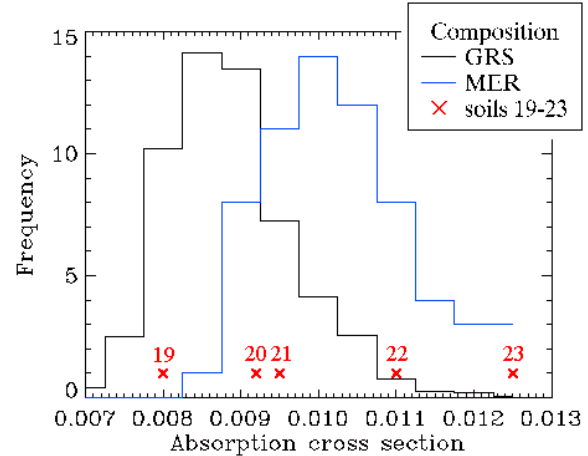


Figure 2: Histogram of the absorption macroscopic cross sections. The black line gives the GRS histogram. The blue line gives the histogram for the MER Opportunity and Spirit sites. The frequency scale has been normalized for data to be comparable. Red crosses represent the artificial compositions (soils 19, 20, 21, 22 and 23) created to cover the range of possible absorption macroscopic cross sections.

With this estimate of the variability of composition on the Martian surface, five artificial compositions have been created to cover the range of possible macroscopic cross sections. One of these compositions, soil 21, represents the average composition from the five Lander sites (MER (2), Viking (2), and Pathfinder) and is applied in our model to get simulations as representative as possible of the planet. The other compositions are used as a benchmark to assess the effects of the variations on our [H]dn and D estimates.

In order to estimate the variability of [H]dn and D due to uncertainties in soil composition, we simulated the thermal and epithermal neutron currents for each of the five compositions shown in Figure 2. The variation in epithermal counting rates is found to be negligible (less than 1%) and the variation in thermal counting rates reaches a maximum of 20%. We then transformed the measured neutron currents to [H]dn and D in order to estimate the uncertainties in our results.

Results: Our results consist of maps of the apparent depth (Figure 3) and content in H of the water-rich layer (Figure 4) assuming the average composition, soil 21. The hydrogen content of the lower layer has a behavior very similar to the hydrogen content determined with a semi-infinite model in previous studies. The low epithermal neutron currents at high latitudes had been very soon interpreted as evidence of the existence of a subsurface water ice reservoir [1, 2]. Our inferred depth exhibits a very sharp (of the order of the spatial

scale of the instrument response function) latitudinal pattern. For latitudes poleward of $\pm 60^\circ$ the behavior is that expected for stable water ice: the depth follows roughly the latitudinal variations predicted in [12, 13]. In equatorial regions however the depth is low as well as the hydrogen content. This reservoir of hydrogen might not be in the state of water ice.

In addition to these maps, we have an estimation of the maximum and minimum values allowed by error bars for our variables D and $[H]_{dn}$. These constraints are important to help determine the nature of the buried hydrogen measured by MONS. This information can indeed discriminate between whether or not hydrated minerals are present.

We have used these extreme values to calculate the uncertainty associated to each variable. We define for each parameter his associated relative uncertainty as the difference between the maximum of the parameter and its minimum, divided by its average. We banish from this evaluation the very low values of parameters because they make the uncertainty tend towards infinite. This relative uncertainty ranges between 0 and 1 for $[H]_{dn}$ and between 0.65 and 3 for the depth in most of the regions of the planet (Figure 5).

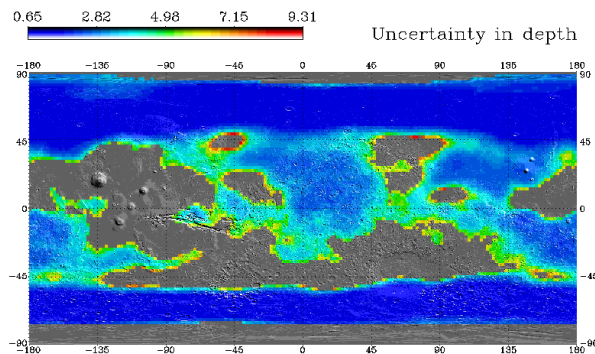


Figure 5: Uncertainty in depth = $(D_{max}-D_{min})/D$ for all $D > 3 \text{ g/cm}^2$ (else undefined). D is the depth obtained with the average composition, D_{max} the maximum and D_{min} the minimum of depths inferred from the variations of composition.

The hydrogen content is seen to be better constrained than the depth because it is mostly connected to the epithermal neutron counting rates, which do not

depend significantly on composition. The fact that both thermal and epithermal neutron counting rates are involved in the determination of the depth makes it more sensitive to the variations in composition.

The confidence in estimated depths appears quite low, especially in the equatorial regions (latitude lower than $\pm 45^\circ$). This result is not surprising considering the fact that the hydrogen content at these locations is not very high. Therefore the boundary between a desiccated layer and a water rich layer can not be as pronounced as in the polar regions. At high latitudes, the determination of the depth is more certain because the soil mass fraction is sufficiently small that details of its composition are not important.

Conclusion: We have proposed a method to evaluate two major parameters in the characterization of the layering of the soil near the surface of Mars: the hydrogen content of the lower layer, and its burial depth below a relatively desiccated layer. Our analysis results in global maps of these two parameters. Finally the impact of the compositional variations across the planet has been quantified through the relative uncertainty associated to both results.

References: [1] Boynton W. V. et al. (2002), *Science* 297, 81-85. [2] Feldman W. C. et al. (2002), *Science* 297, 75-78. [3] Mitrofanov I. et al. (2002), *Science* 297, 78-81. [4] Feldman W. C., W. V. Boynton, D. M. Drake (1993), Cambridge University Press. [5] Waters L. S. (Ed.) (1999), Document LA-UR-99-6058, LANL. [6] Prettyman T. H. et al. (2004), *JGR*, Vol. 109, No. E5. [7] Maurice S. et al., LPSC 2007, abstract 2036. [8] Wänke H. et al. (2001), *Space Science Review*, v. 96, p. 317-330. [9] Gellert R. et al. (2004), *Science*, 305, 829-832. [10] Rieder R. et al. (2004), *Science*, 306, 1746-1749. [11] Boynton W. V. et al. (2007), *JGR*, in press. [12] Farmer C. B. and P. E. Doms (1979), *JGR*, Vol. 84, 2881-2888. [13] Mellon M. T., W. C. Feldman, and T. H. Prettyman, *ICARUS* 169 (2004) 324-340.

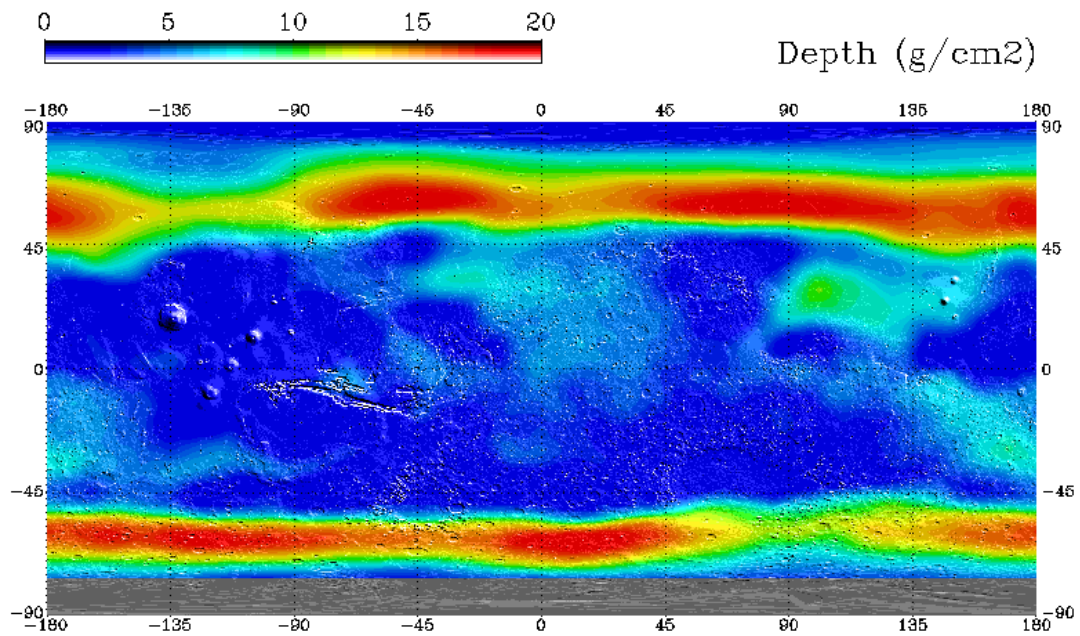


Figure 3: Depth of the water-rich layer in g/cm^2 in cylindrical projection. Note: the minimum value of depth 0 represents a soil that is not layered. When the inferred depth is less than 0, it is set equal to 0. The South Pole is not represented due to the presence of a permanent CO_2 ice cap which contaminates the thermal neutron signal.

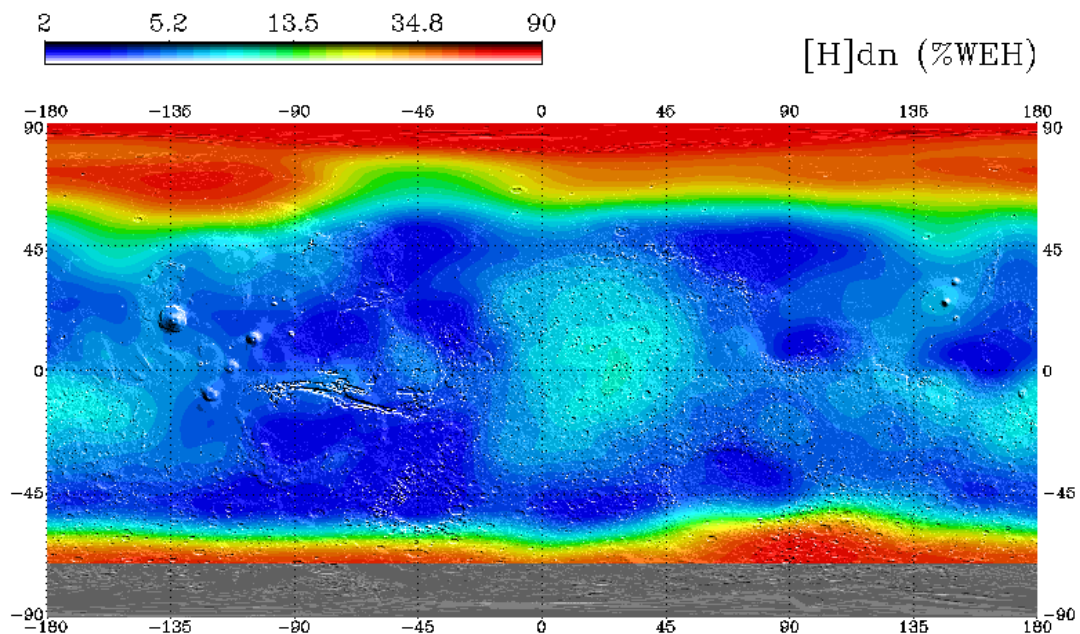


Figure 4: Hydrogen content of the water-rich layer in mass percentage of Water Equivalent Hydrogen in cylindrical projection. The South Pole is not represented due to the presence of a permanent CO_2 ice cap which contaminates the thermal neutron signal.