DISTRIBUTION OF HYDROGEN AT THE SURFACE OF THE MOON.

S. Maurice[1], W. C. Feldman[2], D. J. Lawrence[2], O. Gasnault[1], R. C. Elphic[2], and S. Chevrel[1], [1]Observatoire Midi-Pyrénées (14 av. Edouard Belin, 31400 Toulouse, France; maurice@obs-mip.fr), [2]Los Alamos National Laboratory (MS D466, Los Alamos, NM 87545, wfeldman@lanl.gov).

Introduction: We now have information from the fully reduced Lunar Prospector Neutron Spectrometers. Interpretation of these data yields distributions of rare earth elements (REE) Sm and Gd [1], major oxides and hydrogen on the Moon. Once both contributions of REE and major oxides are accounted for, we can construct the first global map of hydrogen implanted within the first 2 meters of the lunar regolith. It is interpreted as a maturity clock, reset locally by recent impact events. We make the connection of this new data set to the already-discovered reservoirs of hydrogen at the Lunar poles [2,3].

Origin of hydrogen: Although several theories have been proposed to explain the origin of the Moon, the present consensus favors birth initiated by a giant impact of the proto-Earth by a Mars-sized planetoid. If correct, the Moon was born depleted in volatiles. However, hydrogen embedded in regolith grains has been found in returned samples: ranging from near zero to >100 ppm [4]. Two processes compete to explain the presence of H on the Moon:

- Solar wind implantation. It is a slow process to deliver H but a very efficient one over time. People have presented models of solar fluence that consider variations due to shielding of the nearside when the Moon is in the Earth's magnetotail, as well as variations due to latitude [5]. However, the exposure of regolith grains at the surface (10^4- 10^5 years) is larger than the time to saturate a grain (10^2-10^3 years [6]) so that the whole regolith surface is saturated in H, independently of latitude or longitude.
- Delivery by comets and asteroids: After the impact, a sizable fraction of water (up to 20%) will migrate to both poles [7]. If water molecules encounter spots that are sufficiently cold (primarily within permanently shaded craters near both poles), they will cover the surface where they can remain stably trapped for eons. Impacts are inefficient to implant H at mid-latitudes. On the contrary the energy released during the impact vaporizes volatiles. The water molecules are dissociated by solar UV (except for those migrating rapidly to cold spots) and by-products escape the Moon's gravity field

Epithermal Neutrons: From January 1998 to July 1999, epithermal neutrons have been collected by the Neutron Spectrometer (NS), a Cd-covered proportional counter filled with ^{3}He pressurized at 10 atm [8]. We use an acquisition rate of 0.5 sec, rebinned in 8-sec packets. The spatial resolution of the maps is ~25 km (HWHM) when the spacecraft was 30 km above the surface. The fractional error which comprises both systematic and statistical errors is typically 1.5% at the equator and less than 0.5% poleward of $\pm 85^o$. This value corresponds to 18 ppm of hydrogen. Finally, the data have been smoothed by a two-dimensional, equal-area Gaussian (HWHM=18 km).

The information content of the epithermal energy range reflects also the composition of major oxides (predominantly FeO and TiO_2). We reduce the contribution of major oxides by subtracting a fraction of the thermal counts. This is acceptable because both thermal and epithermal detectors have the same response function.

As mentioned in the introduction, rare earth elements (REE) are strong absorbers of neutrons above 1eV because of their unusually high cross sections. As a result, epithermal neutrons may be used to map REE on the Moon [1]. To know the distribution of REE we use their well-known relation to another incompatible element, Thorium [4]. With the Lunar Prospector best thorium map [9] as a proxy for REE distribution (absolutely correct at the spatial scales we are looking), we have removed the REE contribution.

Another delicate process, the correction for the distance to the surface (because of topography), has been also reviewed to build our best map of hydrogen data. It shows several region of low counts in epithermals, besides the poles.

Solar Wind Implantation: Johnson et al. [10, 11] initiated the mapping of solar wind implanted hydrogen on the Moon. Although the epithermal data used at that time were not corrected for REE, and therefore contained an observational bias, the authors have shown interesting correlations of low epithermal counts with immature terrains.

Solar wind implants continuously on the regolith. It saturates the surface (~500 µm) very rapidly, but then it takes approximately 2 billion years to saturate down to 2 m because of regolith gardening [12]. Since epithermal neutrons probe the regolith over a couple of meters (peak at 40 g.cm^{-2}), the technique is sensitive indeed to the regolith maturity. New insights on the Lunar surface maturity will be presented at LPSC. Here we mention only:

Mineralogy: The concentration of solar wind elements is affected by the local mineralogy. Elevated concentrations (up to 2 order of magnitude) of He and Ne have been observed in ilmenite relative to olivine, plagioclase, or pyroxene, likely because of diffusion differences [13, 14]. At orbital distance we see indeed a correlation between the distribution of Ti, representative of ilmenite, and epithermal neutrons.

Young Craters: All young craters, as defined from the geologic maps [15] are seen in neutrons. Levels of epithermal neutrons match broad age categories. Tycho has indeed less hydrogen than any other, followed by Jackson, Hayn, Anaxagora, King, and Clavius… A time scale based on hydrogen distribution can be built, as it was done from spectral reflectance [16]. The comparison between the 2 scales is promising.

Global Distribution of Hydrogen: Figure 1 sketches the global distribution of hydrogen on the Moon, as seen by Lunar Prospector. The narrow band 50 ± 20 ppm corresponds to the mean solar wind implantation [17]. Spot-1 represents the polar deposits, i.e. ~ 190 ppm of hydrogen, that is equivalent to 1.5 ± 0.8% of water, considering that H above the mean solar wind implantation is concentrated in small dark craters [3]. Low points represent local regions that have lost their hydrogen. Spot-2 corresponds to Tycho, which is youngest (~65 millions years) and has the lowest hydrogen concentration.

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Figure 1 : Schematic of hydrogen distribution within the first 2 meters of the lunar regolith. See text for details.