FORMATION AND TIME EVOLUTION OF HYDROXYL ON LUNAR REGOLITH BY PROTON IMPLANTATION AND DIFFUSION

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Introduction: Increasing evidence supports the notion that water is present on the Moon in significant quantities, both from primordial and exogenic sources [1-5]. The mechanisms of retention and the stabilities of hydrogen absorption from such sources are poorly constrained, though ongoing theoretical and experimental work is being pursued to address these issues [6-8]. We present results of models of H evolution (as OH) in the upper 10s of nm of a grain as if the sole source were solar wind and compare these results with the observed distributions of both OH and H_2O on the surface of the Moon.

Model Details: The model is a 1D discretized source-sink-transport simulation over a revolving 1 cm^2 patch of regolith surface in the course of time. The source term for H is implantation of solar wind protons onto O-defect sites, forming OH groups. OH concentration at any given depth is restricted to known saturation values, with any excess protons being rejected. The implanted OH is permitted to diffuse, with appropriate diffusion parameters chosen from the literature in keeping with the range of possible materials found on the Moon. Most OH that diffuses the few 10s of nm to the surface (i.e. the vacuum interface) is lost rapidly from the system by either photo or thermal desorption. Source fluxes and temperature are systematically passed through cycles representing the changing conditions based on local sun angle (time of day).

The proton implantation mean depth was taken to be ~ 15 nm based on solar wind proton kinetic energies, while the width of the distribution was taken to be between 3-30 nm based on simulations and experiments.[Starukhina sims, LPSC abstract measurements] Solar flux incident on the surface is taken as the cosine of the subsolar angle at each given latitude, longitude and time of day.

Activated diffusion is included using diffusion coefficients of the form $D(T) = D_0 \exp(-E_d/k_b T)$ where E_d are the activation energies to diffusion and D_0 the pre-exponential coefficients taken for various minerals from [ref], k_b is the Boltzsmann constant, and T the regolith surface temperature.

Losses are taken only at the terminal vacuum interface. They include thermal recombinative desorption, $S_1(T) = A*R*(C(0)^2) \exp(-E_r/k_b T)$, where $C(0)$ is the surface concentration of OH, R is a dimensionless surface roughness factor that accounts for the highly textured regolith grains (taken to be 10^3 to account for the ratio of effective grain size to actual grain size), A is the Polanyi-Wigner pre-exponential and E_r is the experimentally determined recombinative desorption activation barrier for formation of H_2O from adjacent surface OH.

Another loss term is included for solar photon induced surface desorption. Photon induced desorption occurs only at the vacuum interface where energetic atoms can escape without chance of recapture. The solar flux of photons presumed to have enough energy to desorb atomic species is taken as 10^{15} /cm^2 s [Johnson]. The resultant loss term is $S_2 = \sigma C(0) \Phi R$, where σ is an conservatively overestimated photodesorption cross section (10^{-16} cm^2), $C(0)$ is the surface OH concentration, and Φ is the solar UV flux component incident per cm^2 as a function of location and time of day. R is the same dimensionless surface roughness described previously.

Results and Discussion: Models have been run reflecting the evolution of OH over the first 10 lunar days after beginning implantation from solar wind. Over this geologically-short time period, trends in OH with depth can be observed based on duration and shape of the proton implantation with concurrent diffusion, local time of day, and material (mineral vs glass vs highly-defective glass).

OH distribution trends with shape and duration of proton implantation. Fig 1 shows the growth and diffusion of the implanted OH distribution. Peak satuaration (~10^{19} cm^{-3}) occurs within the first two lunar days and inhibits further implantation. Diffusion then dominates the rate of implantation, with new OH being formed only as existing OH diffuses out of the implantation region (either toward the surface or to greater depth). OH that diffuses to the surface is removed, while OH concentration at depth continues to increase during the entire duration of the simulation.

OH distribution trends with local time of day. Both implantation rate and temperature depend on the local sun angle, which varies by time of day. The simulation results show a slight asymmetry between morning and evening OH distribution. Diffusion dominates in the
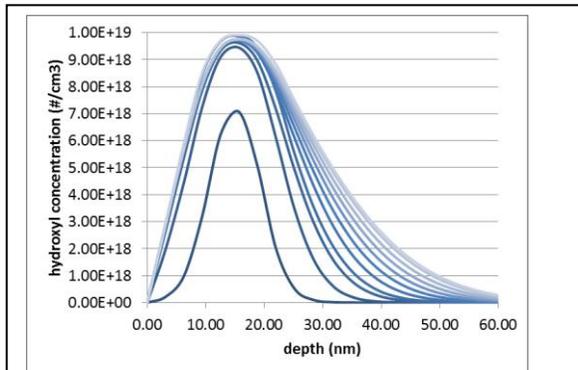
Figure 1. OH distribution within the lunar regolith as a function of depth. Curves progress from dark to light blue with increasing days of exposure, beginning with the first lunar day and proceding to the tenth. Note the depletion near the surface compared to at depth, which is due to the removal processes mentioned in the Model Details.

evening as the regolith near-surface remains warm, broadening the distribution and supplying OH both to the interior where it is stored and to the surface where it can be removed by photo or thermal desorption. The temperatures at night are too low for significant diffusion, thus the evening distributions become immobilized and the distribution at dawn is essentially the same as that just after dark. At morning, heating of a surface grain is near instaneous, and diffusion initially dominates over implantation. At mid-morning, implantation begins to dominate over diffusion, and the OH rapidly returns to saturation near the peak of the implantation function.

OH distribution trends by material. Minerals contain a relatively ordered crystal lattice, while glasses are highly amorphous. Radiation damage will further disrupt a material, creating a high concentration of dangling bonds, vacancies, and other defects. Space weathering on the Moon should produce a highly defective material, which may significantly increase proton implantation and diffusion rates compared to values measured for terrestrial analog materials. Thus, parameters have been varied to reflect the range of possible values relevant to the Moon.

Consistent with Fig 1, OH continues to accumulate each day, but the ability to build up more OH is limited by how quickly diffusion can broaden the distribution and make room for additional implantation by the solar wind. Thus, the material with the highest diffusion rate is able to build up the most OH. Additionally, the high diffusion rate implies a greater amount of OH reaching the surface and being removed from the system.

OH distribution trends by latitude. Similarly to the trends with diffusion constants of varying materials, lower temperatures at high latitudes shut down the dif-

fusion. There is still sufficient proton flux to eventually saturate the material within the implantation region, but without significant diffusion the total OH concentration remains lower at higher latitudes.

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