

PRODUCTION OF OH/H₂O IN LUNAR SAMPLES VIA PROTON BOMBARDMENT. A. P. Zent¹, A. I. Ichimura², T. B. McCord³, L. A. Taylor⁴, ¹NASA Ames Research Center, Moffet Field CA (Aaron.P.Zent@nasa.gov), ²San Francisco State University, San Francisco, CA, ³The Bear Fight Center, Winthrop WA, ⁴Planetary Geosciences Institute, University of Tennessee, Knoxville, TN

Introduction: Absorptions in lunar spectra between 2.8 and 3.0 μm have been reported in Moon Mineralogy Mapper (M³) data from the Indian Chandrayaan-1 mission [1]. These features are strongest at high latitudes and from fresh feldspar-rich crater ejecta, and have been interpreted as due to OH/H₂O. This interpretation is supported by neutron [2] and spectral flyby data [3, 4]. Indeed, this water may be a partial-source for the water-ice detected more recently by LCROSS observations [5]. The LCROSS presence of OH/H₂O had been predicted, with possible sources including cometary impacts [6] and solar wind implantation [7].

It had been speculated by the M³ team that a feasible explanation for this water, which it has observed virtually all over the Moon is based upon solar-wind proton implantation causing a bonding with unsatisfied oxygen ions [McCord *et al.*, this volume]. Here we report on a laboratory simulation of this solar-wind hypothesis, and demonstrate that we are able to dehydrate/dehydroxylate lunar samples, expose them to moderately energetic H plasma, and detect the presence of newly formed OH/H₂O.

Experimental: Sample tubes were constructed by joining a 3/8" Pyrex tube, ~20 cm in length, to 15 cm of 3 mm o.d. quartz (Figure 1). The sample tubes were baked out at 500°C, then filled with ~40 mg of lunar sample, and evacuated to $<10^{-3}$ Pa for 1 hour. The sample was collected at the quartz end of the tube, and sealed by tipping off the quartz. Apollo 17 lunar soil sample, 70051,136, sieved to $<45 \mu\text{m}$, was used. IR spectra from 2400 – 5000 cm^{-1} (4.2 μm – 2 μm) were acquired through the quartz (green line, Figure 2). Gas phase water was subtracted from both spectra and baseline corrections were applied. The y-axis is $-\log(R/R_0)$, where R is the diffuse reflectance of the sample and R_0 that of KBr. These spectra show a strong absorption relative to a KBr standard at 2.84 μm , indicating that substantial OH/H₂O was still chemisorbed to the sample. This sample constitutes

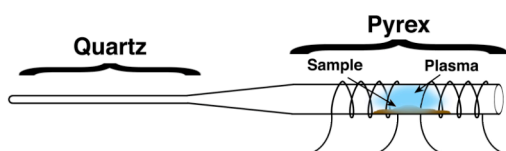


Figure 1. Exposure of the lunar sample to the H plasma.

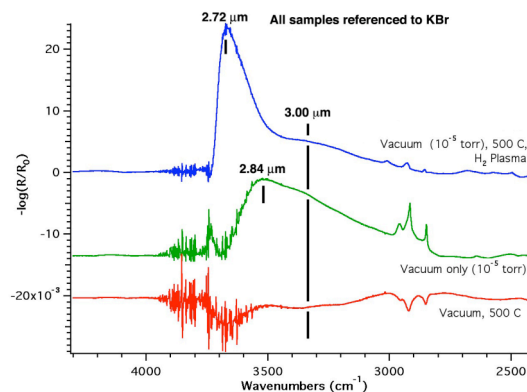


Figure 2. IR spectra of the evacuated sample (green), the evacuated + heated sample (red), and the evacuated, heated, and H exposed sample (blue).

our blank.

A second sample was evacuated to 10^{-3} Pa and baked for an hour at 500°C in a tube furnace while still under vacuum on the manifold. The sample was sealed in quartz as shown in Figure 1. Spectra of the evacuated and baked sample shows essentially no IR absorptions due to OH/H₂O (red line, Figure 2). The samples were not exposed to air subsequent to sealing.

Finally, a third aliquot of the sample was evacuated and baked, as above, then allowed to cool, and back-filled with ~130 Pa of H₂. The sample was kept within the pyrex length of the sample tube, attached to the manifold by a flex connect. The sample was placed inside an *rf* plasma generator, and the H₂ was ionized at a voltage of 680 V and frequency of 5 MHz. After one hour, the plasma was switched off, the sample was again evacuated to 10^{-3} Pa, and sealed by tipping off the sample tube under vacuum. Spectra of the plasma-exposed samples are shown as the blue line in Figure 2. A strong absorption, centered at 2.74 μm and stable under vacuum, has appeared in the sample. We interpret this to be due to monomeric, isolated OH situated within the crystal lattice of the sample material, and possibly the quartz sample tube. In addition, there is evidence of absorptions at longer wavelengths, particularly 3.0 μm in both the evacuated sample, and the proton-bombarded sample. Deep Impact spectra [4] of the lunar surface at midlatitudes show absorptions centered at 2.81 μm , with asymmetric increases in reflectance toward longer wavelengths, consistent with our observations. This indicates *in situ* production of OH or H₂O in the sample. Quantitative estimates of

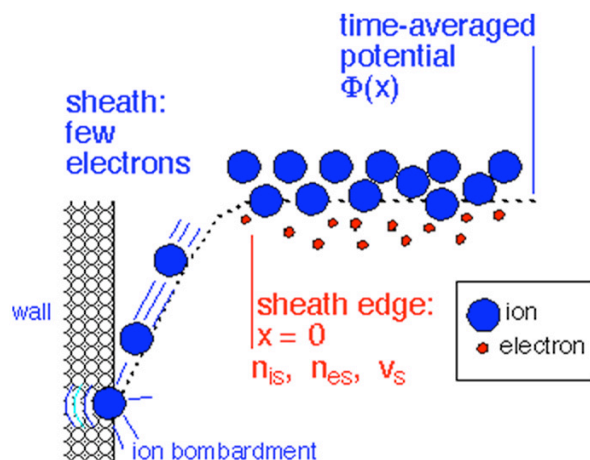


Figure 3. Protons are accelerated across the plasma sheath, and bombard electrically insulated surfaces at high energy.

the relative abundance of OH and H₂O will be discussed.

Discussion: We argue that the rather simple experimental arrangement described above is an adequate approximation of the solar-wind interaction with the lunar soil particles to form OH.

An electrically isolated object in the plasma will have a sheath around it, since the mobile electrons are lost more readily by diffusion to the surface, giving the plasma a net positive charge until a sheath forms to ensure charge balance. The potential difference between the positively-charged plasma and the negatively-charged surfaces are confined to this sheath. As a consequence, ions entering the sheath are accelerated across the potential, and bombard surfaces at high energy (Figure 3).

The objective of the experiment is to maximize the impacting flux of energetic protons. There are two ways in which protons lose energy: They can either run into a neutral, which will occur in the sheath at its background abundance, or they can go too slowly, and fail to cross the sheath before the *rf* field changes. The low H₂ pressure (~1 torr) and relatively low *rf* frequency are chosen to maximize the impact of protons of the appropriate energy. We estimate that the highest-energy impacts in our apparatus are several hundred eV, rather than the full 1 keV at the lunar surface.

The cohesive energy of mineral crystals, (the amount of energy required to pull the crystal apart into a set of free atoms) is in the range of 1 – 10 eV. Likewise, surface binding energies of most minerals are in the range of 3 – 5 eV. Therefore, several hundred eV are more than adequate to implant H⁺ into the amorphous rims of mature lunar dust grains [8].

To address the possibility that the OH signature arose from the quartz sample tube, a control experiment was conducted using KBr baked under vacuum to

500°C. The absence of oxygen in the sample means that any significant OH absorptions must arise from the quartz. Results of this control will be reported. A second control experiment, using D₂ instead of H₂ will also be reported. We argue that much of the OH signal comes from the lunar sample, based on the fact that the cohesive energies of the quartz and amorphous rims are likely to be broadly similar, but the total surface area of the dust (< 45 μm) vastly exceeds the surface area of the sample tube.

Pieters *et al.* [1] reported correlation of the OH/H₂O band strength with fresh feldspars. We hypothesize that this results from proton implantation into relatively unmodified tectosilicate structures that have not yet developed the amorphous rims of a mature soil, yet may have been activated by crushing [McCord *et al.*, this volume]. Preferential loss of O during sputtering and micrometeorite impact is a well-known phenomenon in lunar soils [9], and is ultimately responsible for the development of amorphous glass rims containing nanophase metallic iron, found in abundance in mature lunar soils. To test this hypothesis, we will report on a plasma exposure experiment using only feldspars hand-picked from rock interiors. If the hypothesis is valid, we would expect to see considerably more OH/H₂O production in the unaltered feldspar sample.

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