Lunar Polar Regolith - SSERVI virtual Workshop without Walls

Objective: To discuss the regolith properties of Permanently Shadowed Regions (PSRs) that might affect the trafficability of robotic rovers, such as NASA's Resource Prospector mission.

Date: Thursday, December 3, 2015. 8a – 1:15p PST (11a – 4:15p EST)

8:00a Introduction

Ben Bussey – HEOMD Chief Exploration Scientist
Yvonne Pendleton – SSERVI Director

8:10a - Convener
Regolith properties of permanently shadowed regions (PSRs) in polar regions of the Moon and implications for rover trafficability: Outlining the problem

David A. Kring, Lunar and Planetary Institute, Houston, TX 77058 (kring@lpi.usra.edu)

8:30a
Resource Prospector: Stepping into the darkness

Anthony Colaprete, NASA Ames Research Center, Moffett Field, CA 94035 (anthony.colaprete-1@nasa.gov)

The Resource Prospector (RP) expedition has as one of its primary goals to venture into shadowed lunar polar terrain, and specifically to enter a Permanently Shadowed Region (PSR). The conditions within a PSR are either extreme (e.g., cold temperatures and lack of sunlight for power), not necessarily well constrained, especially at the scale of the rover, or there is evidence that the conditions may be significantly different than those experienced at the Apollo sites, this activity is considered to be one of the more risky endeavors. However, the data return is deemed critical in terms of understanding the viability of using cold-trapped volatiles as a resource. In the PSR the RP rover will prospect for hydrogen and volatiles using its neutron and near infrared spectrometers and, once a suitable spot is identified, will collect subsurface samples from as deep as one meter for analysis with its gas chromatograph / mass spectrometer system. In the process of prospecting RP will gather a range of other data, including imaging from the rover navigation and hazard cameras, high spatial resolution (<100 microns/pixel) images at multiple wavelengths between 410 and 1050 nm, surface emission measurements at 8, 10, 12 and 25 microns, subsurface temperatures up to one meter, and a number geotechnical measurements derived from drill and wheel performance. All these measurements will help to constrain the environment within PSRs, and especially the operating conditions as they may influence future resource expeditions. This talk will summarize what RP activates are planned, especially those in PSRs, and what regolith properties are considered important for design and planning, and what measurements RP provide with respect to polar regolith properties.

8:50a - Invited
Trafficability considerations - icy dirt or dirty ice? – based on Apollo Geo-logical deductions

W. David Carrier III, Lunar Geotechnical Institute, P.O. Box 5056, Lakeland, FL 33807 (wdcarrier@verizon.net)

9:10a - Invited
The LCROSS impact experiment and implications for regolith porosity in a permanently shadowed region with volatiles within Cabeus Crater

Brendan Hermalyn and Anthony Colaprete, NASA Ames Research Center, Moffett Field, CA 94035 (anthony.colaprete-1@nasa.gov)

9:30a - Invited
Orbital LAMP measurements and implications for regolith properties in permanently shaded regions

G. Randall Gladstone, Southwest Research Institute, San Antonio, TX 78238 (rgladstone@swri.edu)

9:50a - Invited
Regolith properties in the Moon's permanently shadowed regions from Diviner temperature measurements

Paul Hayne, Matthew Siegler, David Paige, and the LRO Diviner Science Team (paul.o.hayne@jpl.nasa.gov)

10:10a - Invited
Regolith properties within icy permanently shadowed regions as inferred from orbital radar observations

Paul Spudis, Lunar and Planetary Institute, Houston, TX 77058 (spudis@lpi.usra.edu)

10:30a – BREAK

10:45a
Radar mapping of hazards in permanently shadowed regions of the Moon

Bruce A. Campbell, Gareth A. Morgan, and Jennifer L. Whitten; Smithsonian Institution, Center for Earth and Planetary Studies, MRC 315, PO Box 37012, Washington, DC 20013-7012, campbellb@si.edu.

Selection of landing sites and planning of rover traverses in the Moon's permanently shadowed regions (PSR) must rely on radar mapping, augmented by thermal infrared and scattered-light visible imaging, for detection of hazards. Radar mapping offers the advantages of fine spatial resolution, sensitivity to rocks of varying size, and probing depths of up to several meters below the surface. Earth-based and/or orbital radar sensors have used 12.6-cm and 4.2-cm wavelengths to map almost all of the PSR, but echoes at these wavelengths are strongly affected by cm-scale rocks and regolith clods that pose minimal challenges to surface operations. Earth-based radar mapping at 70-cm wavelength provides a view of the abundance of decimeter-scale and larger rocks that are of greater importance, and particularly where these rocks occur in the shallow subsurface. Such "unseen" rocks are critical to planning for rover experiments and eventual in-situ resource utilization. We review an earlier study of extensive impact melt sheets that lead to boulder fields around even small craters in many southern PSR, and present initial results from our 70-cm mapping of the northern PSR during a favorable libration in March, 2015.

11:00a
Signatures of volatiles in the lunar proton albedo

N. A. Schwadron, J. K. Wilson, M. D. Looper, A. P. Jordan, H. E. Spence, J. B. Blake, A. W. Case, Y. Iwata, J. C. Kasper, W. M. Farrell, D. J. Lawrence, G. Livadiotis, J. Mazur, N. Petro, C. Pieters, M. S. Robinson, S. Smith, L. W. Townsend, and C. Zeitlin (n.schwadron@unh.edu)

We find evidence for hydrated material in the lunar regolith using "albedo protons" measured with the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on the Lunar Reconnaissance Orbiter (LRO). Fluxes of these albedo protons, which are emitted from the regolith due to steady bombardment by high energy radiation (Galactic Cosmic Rays), are observed to peak near the poles, and are inconsistent with the latitude trends of heavy element enrichment (e.g., enhanced Fe abundance). The latitudinal distribution of albedo protons anti-correlates with that of epithermal or high energy neutrons. The high latitude enhancement may be due to the conversion of upward directed secondary neutrons

from the lunar regolith into tertiary protons due to neutron-proton collisions in hydrated regolith that is more prevalent near the poles. The CRaTER instrument may thus provide important measurements of volatile distributions within regolith at the Moon and potentially, with similar sensors and observations, at other bodies within the solar system.

11:15a

How dielectric breakdown may affect permanently shadowed regolith on the Moon

A. P. Jordan[1,2], T. J. Stubbs[3,2], J. K. Wilson[1,2], N. A. Schwadron[1,2], H.E. Spence[1,2], and N. R. Izenberg[4], [1]EOS Space Science Center, University of New Hampshire, Durham, NH (first author email address: a.p.jordan@unh.edu), [2]Solar System Exploration Research Virtual Institute, NASA Ames Research Center, Moffett Field, California, USA, [3]NASA Goddard Space Flight Center, Greenbelt, MD, [4]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723.
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Large solar energetic particle (SEP) events may cause dielectric breakdown in the top ~1 mm of regolith in the coldest regions of the Moon. In particular, we predict that the impact gardened regolith in permanently shadowed regions (PSRs) could have experienced ~10^6 of these events. Dielectric breakdown occurs when a strong electric field rapidly vaporizes a conducting channel through a dielectric, and we can estimate the rate at which very large SEP events deposit breakdown energy into the regolith in PSRs. We find that breakdown may have affected ~10-25% of gardened regolith, which is comparable to meteoroid impact weathering. This could enhance comminution in PSRs, possibly affecting trafficability. All this suggests that breakdown weathering may significantly affect the evolution of regolith in PSRs, which could have important implications for interpreting observations from Resource Prospector. Furthermore, SEP events that may cause breakdown still occur: two likely candidate events have been detected by the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) aboard the Lunar Reconnaissance Orbiter (LRO). We will discuss how instruments on the surface could measure the effects of breakdown weathering.

11:30a

Rover wheel-regolith charging in plasma-starved locations

W. M. Farrell, T. L. Jackson, and M. I. Zimmerman (william.m.farrell@nasa.gov)

South polar permanently shadowed regions typically have a reduced plasma content compared to nominal solar wind. In some cases, the plasma content can be as low as 1/10000 that of the nominal dayside plasma content encountered by Apollo rovers. When a wheel travels over regolith, the rover tire will collect charge via regolith-wheel surface contact electrification (or tribocharging). On dayside regions, this wheel charge is quickly dissipated since the ambient environmental plasma currents exceed the tribocharging current to the wheel. However, in shadowed regions in reduced/blocked plasma flow, the surface triboelectric currents can exceed those in the plasma environment, allowing charge buildup on the wheel. We also note that the cold surface itself is a very poor conductor. As such, the moving wheel could charge to large negative voltages. Jackson et al. [2015] recently calculated this expected charge build-up in a rover wheel under various speeds and regolith conditions. These calculations will be presented along with recommendations to both monitor and minimize this possible wheel charging effect.

11:45a

Thermal conductivity of cryogenic regolith

Matt Siegler, Fang Zhong, David Paige, and Rachel Woods-Robinson (matthew.a.siegler@gmail.com)

Measurements from the Diviner Lunar Radiometer aboard LRO have hinted at extremely low thermal inertia in the polar shadowed regions (PSRs). This could either be due to much lower than expected density or thermal conductivity. As density cannot vary dramatically, we present evidence that answer lies in the intrinsic lower than expected thermal conductivity of lunar regolith at the low

temperatures. At low temperatures, thermal conductivity can be approximated as $\lambda = 1/3\, c_v v l$, with specific heat (c_V), phonon velocity (v) and phonon mean free path (l). As mean-free path increases at low temperatures, generally so does thermal conductivity. However, recent measurements show that thermal conductivity of meteorite samples unexpectedly drop below 100K (Opeil et al. 2010, 2012). This is due to the polycrystalline nature of the material which prevents the mean free path from exceeding the crystal size of the material. We expect similar behavior for lunar regolith in the PSRs, which should also be polycrystalline in nature. We present preliminary laboratory measurements on regolith simulants as preparation for measurements on returned Apollo 11 and 16 samples. This work has been funded by the SSERVI Vortices node, LRO, and JPL internal funding.

12:00p

Compaction processes of lunar soil globally versus in the polar regions

Philip Metzger (Philip.Metzger@ucf.edu)

Thermal cycling may be the dominant process in producing the highly compacted state of the lunar regolith, and if so then the Moon's permanently shadowed regions and low insolation regions near the poles may have regolith that is much looser than observed during the Apollo program. The impact of the Lunar Crater Observation and Sensing Satellite (LCROSS) inside Cabeus crater suggests this view is correct, because there was a slight delay in the infrared flash of impact and no explanation has been found except perhaps the soil was fluffy to a depth of two meters. Ever since the Surveyor and Apollo programs when we first discovered the high compactivity of lunar soil at the low- and mid-latitude sites where we visited, we have assumed that vibrations, especially the tamping by micrometeoroids, is what made it so consolidated. However, a literature search shows that this hypothesis was never tested with any experiments, modeling, or analysis. For all we really knew, other mechanisms such as thermal cycling may have played an important or even dominant role. This talk will describe experiments performed by the author that compare vibrating and thermal cycling of lunar soil simulant, showing that thermal cycling appears to be the more important process. It will also present a new analysis showing that impact tamping appears to be inadequate to affect significant compaction. The role of lunar quakes, especially shallow moonquakes, will be discussed, along with features of lunar soil including "density inversions" and the looseness of soil around young impact craters. Together, the data show it is likely that both vibration and thermal cycling can compact (and vibration can sometimes loosen) lunar soil to create the complex state of the regolith we observe, and in many places thermal cycling may be the dominant process. It is highly likely that the soil is much fluffier in the polar regions where there is little or no thermal cycling than what was observed at the more equatorial sites. References: Gamsky, Jacob N., and Philip T. Metzger. "The Physical State of Lunar Soil in the Permanently Shadowed Craters of the Moon." *Earth and Space* (2010): 14-17.

12:15p

VIS-NIR reflectance of water ice/regolith analogue mixtures and implications for the detectability of ice mixed within planetary regoliths

Zuriñe Yoldi (zurine.yoldi@space.unibe.ch)

Permanently shadowed regions at the poles of the Moon and Mercury have been pointed out as candidates for hosting water ice at their surface. We have measured in the laboratory the visible and near infrared spectral range (VIS-NIR) bidirectional reflectance of intimate mixtures of water ice and the JSC-1AF lunar simulant for different ice concentrations, particle sizes, and measurement geometries. The nonlinearity between the measured reflectance and the amount of ice in the mixture can be reproduced to some extent by the mixing formulas of standard reflectance models, in particular, those of Hapke and Hiroi, which are tested here. Estimating ice concentrations from reflectance data without knowledge of the mixing coefficients—strongly dependent on the size/shape of the grains—can result in large errors. According to our results, it is possible that considerable amounts of water ice might be intimately mixed in the regolith of the Moon and Mercury without producing noticeable photometric signatures.

12:30p

Hawai'i ice caves as analogs to perpetually shadowed craters

John Hamilton and Rob Kelso, University of Hawai`i at Hilo / PISCES (jch@hawaii.edu)

Several lava tubes on the massive shield volcano Mauna Loa form natural analogs to the perpetually dark and frozen craters of the Moon and other locales (Mercury). These caves are shielded from sunlight and form their frozen icy interiors via several processes beyond surface runoff. They exhibit an icy floor that, once formed, can be augmented via the direct deposition of icy fog which can blow through the recesses of the tube. This slow build up represents a natural terrestrial analog to the depositional mechanism of the dark crater deposits. Additionally, interior regolith (cinders and tephra) on the sides and floor elevation features mix with this ice fog to form a matrix thought to be indicative of frozen regoliths on Moon and Mars. The insulation properties of the caves allow for a stable environment mimicking the conditions postulated in the interiors of the dark craters.

12:45p – FINAL DISCUSSION