Brief Report
on
ISECG Lunar Polar Volatiles Virtual Workshop#4: Lunar Volatiles Acquisition Technologies

On September 14, 2016 the ISECG held its fourth virtual workshop on exploring and using lunar polar volatiles. The workshop focused on understanding what are the most needed lunar exploration technologies to demonstrate polar volatile acquisition (e.g., extraction, excavation, transfer), especially sampling and characterizing small amounts of volatiles (grams) in the near-term prospecting phase, but also mining much larger quantities (tons) in the longer-term. Approximately 55 participants from various countries met online for a 2-hour session, representing not only space agencies, but industry and academia as well. The participants included planetary scientists, students, engineers, mining professionals, and other space professionals. NASA/John Gruener and Nantel Suzuki moderated presentations by four expert panelists and addressed questions from attendees, while others participated simultaneously by exchanging text comments in an associated chat forum. All the presentation materials and a recording of the event were posted to the ISECG lunar polar volatiles website (http://lunarvolatiles.nasa.gov/).

Overarching question:

What are the most needed lunar exploration technologies to demonstrate polar volatile sample acquisition (e.g., extraction, excavation, transfer)?

Panelists:

Dr. Philip Metzger (University of Central Florida, USA)
Dr. Sachiko Wakabayashi (JAXA, Japan)
Dr. Andrea Zamboni* (Leonardo SpA, Italy)
Dr. Rob Mueller (NASA Kennedy Space Center, USA)

*presentation given by Dr. James Carpenter (ESA/ESTEC)

Findings:

1. The physical state of lunar polar volatiles and lunar polar regoliths is poorly understood. One dataset, the LCROSS near infrared spectrometer data, includes a 1.7 μm absorption feature that suggests crystalline ice was present in the LCROSS ejecta plume.

2. Our knowledge of the geotechnical and physical properties of the lunar regolith comes from the robotic and human missions to the lunar surface. These include NASA's Surveyor and Apollo missions of the 1960s and 70s, the Soviet Union's Luna missions of the 1970s, and more recently the Chinese Chang'E-3 mission that landed in December 2013. All of these were mid-latitude missions. A summary of the 1960s

and 70s data can be found in the Lunar Sourcebook (Chapter 7: The Lunar Regolith, Chapter 9: Physical Properties of the Lunar Surface).

3. There is evidence that the upper surface of lunar polar regoliths may have different physical properties than the mid-latitude regoliths, namely that the polar surfaces are less compacted and 'fluffy'. This evidence includes:
a. The steep ejecta angle of the LCROSS impact eject was replicated in experiments by using a 'fluffy' regolith.
b. The delayed flash of the LCROSS impact event was replicated by modeling up to 2 m of loose regolith at the impact site.
c. The LRO Diviner 'H' values suggest a deeper low-density, less-compacted, high-porosity surface layer at the lunar poles (~30 cm 'fluffy' layer compared to a few cm at mid-latitude locations).
d. The LRO LAMP far ultraviolet reflectance data suggests 'fluffy' regolith at the surface of lunar polar regions.
e. The LRO Mini-RF data, which probes to depths of 2 m, suggest more porous regolith in permanently shadowed craters, and the polar regions in general.
f. Recent laboratory experiments investigating the relationship between thermal cycling and regolith compaction suggests that less thermal cycling (as exists in the lunar polar regions) results in less regolith compaction.

4. To better understand the possible geotechnical and physical properties of ice-bearing lunar polar regoliths, several space agencies (e.g., NASA, JAXA, ESA) have conducted drilling tests into frozen, water-bearing regolith simulants. The tests indicated that regolith strength increases as the amount of water increases, and as the regolith temperature decreases. For example, drilling experiments in frozen lunar regolith simulant with 0.6-1.5 wt.% water at ambient laboratory conditions, showed that the frozen simulant behaved like weak shale and mudstone, while frozen lunar regolith simulant with 10-12 wt.% water behaved like strong limestone, sandstone, and high-strength concrete. This suggests that mining ice-bearing lunar polar regoliths may be more like rock mining, than digging into granular soils.

5. Simulations are just that; simulations. Terrestrial lunar simulants that can be made in bulk for drilling/excavation tests may match certain chemical or mineralogical characteristics of lunar regolith, but the physical nature of the lunar regolith (e.g., irregular, jagged agglutinate particles) is expensive and difficult to recreate. Hence, bulk terrestrial simulants do not behave like lunar regolith in a geotechnical sense. Also, in the drilling experiments mentioned above, liquid water was added to lunar simulant and then frozen in liquid nitrogen baths (~77 K). It is not known if this adequately mimics the physical state of ice-bearing lunar regoliths on the Moon, and whether or not the resulting geotechnical measurements (i.e., uniaxial compressive strength) are similar to what we might experience in drilling/excavation operations at the lunar poles.

6. Geotechnical investigations of the lunar polar regolith will have to be a part of any prospecting efforts at the poles of the Moon, in order to better understand the

physical properties of regoliths containing frozen volatiles. It is unknown whether a dedicated mission directed solely at determining geotechnical properties is required, or if geophysical investigations could be combined with volatile detection operations. Future excavation/mining of lunar polar regolith will require this information for proper design of robotic excavation vehicles or ice extraction processes.