Lunar Surface Science Workshop 17

Defining a Coordinated Lunar Resource Evaluation Campaign

Final Report with Findings and Recommendations

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Program: https://www.hou.usra.edu/meetings/lunarsurface17/pdf/lunarsurface17_program.htm

E-posters: https://www.hou.usra.edu/meetings/lunarsurface17/eposterindex/

Recordings: https://lunarscience.arc.nasa.gov/lssw/defining-a-coordinated-lunar-resource-evaluation-campaign/

Background and Motivation

To date, undertaking a coordinated evaluation of lunar resources has not been proposed nor implemented. This session is intended to define the architecture(s) for such a campaign that will inform another session on implementing a coordinated lunar resource evaluation campaign later in 2022.

Evaluating the potential of local resources, particularly ice deposits at the lunar poles, in sustaining human exploration of the Moon has important implications for science, exploration, and commerce. At this time, NASA is investing in technology to harvest and use such resources and in missions to identify such ice-rich deposits [SMD missions VIPER, TrailBlazer, LunaH Map, PROSPECT in partnership with ESA, and the ShadowCam instrument that will fly on KPLO; STMD missions Polar Resources Ice Mining Experiment-1 (PRIME-1) and Lunar Flashlight; HEOMD/ESDMD mission Lunar IceCube]. Besides the United States, other countries have also proposed lunar orbiter and surface missions to the lunar poles for similar reasons. However, while the data to be obtained from these missions are quite synergistic and represent a good start to evaluating such resources, they do not represent a coordinated effort to understand them. In order to understand if these lunar resources could be used to sustain humans on the surface of the Moon, much more diverse and detailed information regarding the locations, amounts, distributions (heterogeneity), composition, accessibility, extractability, etc., is needed. A coordinated lunar resource evaluation campaign could obtain the required data.

Structure of LSSW-17

On 11 July 2022, 167 individuals participated in Lunar Surface Science Workshop 17 (LSSW-17): Defining a Coordinated Lunar Resource Evaluation Campaign. This workshop comprised of 8-minute overview talks, 4-minute specific subject talks, and poster presentations that were also summarized by 1-minute lightning talks.

The LSSW-17 workshop had three goals:

- Identify the basic information needed to evaluate ice deposits at the lunar poles, including the constraints/ranges required (i.e., local form, distribution, depth, composition, minimum viable abundance, data fidelity, variability, accessibility, extractability), which would inform measurement methods.
- Identify the measurement types and characteristics (such as resolution, coverage, etc.) that can be obtained to provide this information and the types of missions that could supply these data, including the areas on the Moon to be evaluated.
- Identify ways of consolidating and compiling the information into an accessible, usable form (e.g., geostatistical modeling leading to resource favorability maps).

These were focused through three themes and two questions.
Themes:

- The Link Between Science and Resource Evaluation
- Measurements Needed for Resource Evaluation
- Techniques for Resource Evaluation with a Focus on Relevance to Potential Inclusion into a Resource Evaluation Campaign

Questions:

- What constitutes a coordinated lunar resource evaluation campaign?
- What information does a coordinated lunar resource evaluation campaign need to obtain?

After the talks and poster presentations, the participants were divided into three breakout groups with dedicated note takers, to whom we are eternally grateful!!

- <u>Breakout Group 1</u>: How to Leverage Current 'Science' Information, Database, and Mapping Tools to Generate Resource-Driven Data Products. Note taker: Alexandra Sehlke
- <u>Breakout Group 2</u>: Measurements Needed for ISRU Resource Identification and Implementation, Including Measurement Types and Characteristics (Resolution, Coverage, etc.). Note taker: Lauren Galien
- <u>Breakout Group 3</u>: Specific Methods, Tools, and Mission Approaches to Accomplish Resources Evaluation Objectives. Note take: Caitlin Ahrens

Following the meeting, findings and recommendations were created using the products of the breakout group note takers, individual notes, and meeting recordings (especially of the discussion periods). The initial findings and recommendations were circulated to the steering committee for comment and revision, and then shared with all 167 participants for their input. Below is the list of final Findings and Recommendations from LSSW17.

LSSW 17 Findings

a) Lunar resources are being described as if they are reserves, which they are not.

b) Lunar Exploration Analysis Group has championed the investigation and use of lunar resources to support human exploration of the Moon, as well as for scientific, exploration, and commercial uses.

c) The Lunar Reconnaissance Orbiter has and continues to be an invaluable orbital asset at then Moon for studying lunar resources as well as many other things about our Moon. However, LRO can no longer pass over polar sites so it will be of limited use for study polar resources beyond the data already obtained.

d) The Findings and Recommendations of the LEAG/SRR Lunar Polar Prospecting Workshop should be incorporated into defining a coordinated lunar resource evaluation campaign.

e) The data types needed from a coordinated lunar resource evaluation campaign are known:

Table 1: Datasets for lunar volatile resource evaluation

Dataset	Specific Data	Use	Measurement
Composition	Concentration of the resource Concentration & composition of impurities	Evaluate potential investment needed for refining the product	Required Fidelity?
Form	Cement in pore space; Layers; Irregular blocks; Loose ice grains with regolith	Develop efficient extraction techniques	
Distribution	Horizontal Vertical	Variability needs to be documented to understand the volume of the resource	
Geotechnical	Torque and power required for any drills to penetrate the deposit; Energy required to move loose regolith; Hardness of the deposit;	Understand the effort required to mine the deposit and investment needed in developing extraction capabilities.	
Near-surface Regolith Stratigraphy	Buried and surface rock populations Ice block/layer distribtuion	Will impact the extractibility of the regolith resource	
Accesibility	Traverse paths;	Ease of accessibility has an impact on cost of developing robotic miners.	

However, the data fidelity for each dataset needs to be defined.

f) The coordinated lunar resource evaluation campaign needs to use global datasets to reduce the number of targets to those that are most promising to send surface assets to – the surface assets should examine possible sites for volatiles and define which ones contain large quantities of volatiles.

g) In situ data are required at a given site to quantify the potential of utilizing resources

h) VIPER-like instrument suite will obtain a useful suite of data on ice and contaminants, as well as on the geotechnical properties of the top ~1 meter of regolith.

i) The campaign should focus on the top 10 meters as most of the ice is considered to be buried rather than at or close to the surface. Drills, such as the REBELS drill developed by Honeybee Robotics, may be needed for surface missions to promising resource sites.

j) An immediate orbital mission could be low altitude neutron, and possibly radar mapping of the poles, to better position surface assets to explore buried ice deposits at scales of <10 km per pixel.

k) VIPER will be an excellent pathfinder surface mission for the campaign as the concept of operations for resource evaluation will be tested and refined for subsequent surface missions based upon results obtained.

l) Implementing a lunar resource evaluation campaign will be challenging as many factors need to be considered:
   - How will the campaign be managed? Will this be a single entity? Does everyone who participates get a say?
   - Who participates and how?
   - How will the data obtained be used? Open data policy? Licensing and access need to be defined.
   - Can public-private partnerships enable more surface exploration (e.g., data buys)?
   - How will relationships be developed with those entities who don't participate in the campaign?
   - What sort of policy precedents will this campaign set both intentionally and serendipitously?

m) The lunar resource evaluation campaign should consider all surface assets have the ability to capture traverse data (e.g., LIDAR, 3D depth cameras, stereo cameras with lights), especially those that enter large PSRs.

n) There are several planned missions to the Moon that will investigate polar volatiles (NASA: VIPER, TrailBlazer, LunaH Map, Polar Resources Ice Mining Experiment-1 - PRIME-1; Lunar IceCube; Lunar Flashlight. ESA: PROSPECT on PRISM-2 to the South Pole. Korea: Korean Polar Lunar Orbiter - KPLO). Japan: Lunar Polar Exploration mission (LUPEX), along with LRO (now in extended science mission 5). Data from such missions should be integrated and where possible, coordinated, along with conducting observations on sites with higher probabilities of containing water ice.

o) LSSW-17 revealed a number of instruments under development that could yield important data regarding lunar resources through a coordinated evaluation campaign, including ground penetrating radar, next generation neutron detectors, surface penetrometer, and the VERITAS package,

Breakout Group 1: ***How to Leverage Current 'Science' Information, Database, and Mapping Tools to Generate Resource-Driven Data Products***

- Prepare a "Reserve Report for the Moon" using the data we have and using the estimates of demand in the literature – will highlight gaps where specific data are needed, and build active support and appropriate messaging, at governmental and societal levels.
  - *What it is exactly, who makes it, how is it made, which data are included? - all have to be defined*
  - We have raw data (PDS) but we need advanced and combined data products. And those advanced data products should allow reserve maps to be developed.
- A lunar resource evaluation campaign is more than a series of coordinated missions - it is a vision for understanding the volatiles at the poles that can mitigate against individual

set-backs by shifting resources, responsibilities, using alternative approaches, etc., and accomplishing the mapping objectives.

Breakout Group 2: ***Measurements Needed for ISRU Resource Identification and Implementation, Including Measurement Types and Characteristics (Resolution, Coverage, etc.)***

a) Subsurface ice likely to be patchy because of macro-meteoroid impacts that excavate to >1 m.
b) The lunar resource evaluation campaign should focus on ice at depth in the polar regions. Initial data needs to understand how deep the ice resides (GPR instruments? The REBELS drill?).
c) GPR is still a critical observation as it provides very important subsurface context, but there is difficulty in bridging the gap between rover and orbital-scale GRNS measurements. It is important for the wider community to understand the simple but powerful relation that resolution scales with ~1-1.5x the altitude of the detector and sensing depth is limited to ~1m. These central challenges lead to a rich discussion on suggesting more rover-based GRNS measurements, exploring the challenges of low-altitude missions, and GPR applications.
d) Orbital Neutron Spectrometer (NS) measurements <10 km resolution are needed to refine the distribution of H-bearing species (e.g., water ice) within PSRs. Measurements should focus in areas near potential Artemis base camp sites and ISRU processing sites. Rover NS and additional measurements are needed to determine the quantity of subsurface H.

Breakout Group 3: ***Specific Methods, Tools, and Mission Approaches to Accomplish Resources Evaluation Objectives***

a) While VIPER may be a good first step, we need deeper PSR concepts/missions that probe deeper into PSRs
b) Sending a rover into a PSR is challenging, due to navigation and other issues (thermal environment, power, comms, etc.)
c) We need to narrow down the number of promising sites, at least down to 10 or so, for follow-up surface robotic evaluation
d) The number of robotic missions is not necessarily the challenge, it is the complexity and capability of robotics that could frustrate implementation; needs will likely be variable (mobility, power/comms capabilities, etc.).
e) The science is important, absolutely. But to get investment, we need to map resources at the meter scale to increase confidence and reduce risk of investing in resource development.
f) Lunar Resources Standards
    - Don't need a "new" one for space, but adapt existing terrestrial examples (e.g., the Lunar Ore Reserves Standards or LORS – Carlos Espejel)
    - UN committees may need to be involved to ensure international agreement
    - Easy to create a database, but gathering/interface/translation of the data will be time consuming and expensive
    - Dialogue with stakeholders in the campaign; need to develop standards that can be agreed upon (could this be done through the Artemis Accords?)

- Need to involve the terrestrial mining industry – USGS could broker this.

LSSW-17 Recommendations

1) Coordination of lunar resource evaluation efforts should be international in scope and led by NASA. These efforts include:
   - Coordinating data gathering efforts from the current and funded missions that are focused on lunar resources,
   - defining the data types and fidelity needed to derive useful products for future missions,
   - developing lunar resource standards and evaluation metrics
   - inclusion of partners in this effort
   - defining a data policy (or data policies)
   - leveraging private industry where possible
   - developing a list of high priority targets using existing orbital datasets to focus surface exploration
   - Developing mission concepts that could be conducted from orbit (neutron spectrometry, radar, IR reflectance) all at better resolution than current datasets.

2) Surface exploration of high priority targets should remotely characterize the top ~10 meters below the lunar surface (through GPR, for example) and be able to physically examine the top 1-5 meters through drilling or excavation.

3) A Reserve Report for the Moon should be prepared using the data we currently have.