Defining a Coordinated Lunar Resource Evaluation Campaign.

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Introduction: A coordinated resource evaluation campaign is the next critical step in achieving a "*sustained long-term presence on the lunar surface*", because "*over the coming decades and generations, our presence will grow to use and develop the extensive resources of the Moon*" [1]. In addition, this goal is enshrined in the current U.S. Space Policy that NASA is charged with executing: *The United States will pursue the extraction and utilization of space resources in compliance with applicable law, recognizing those resources as critical for sustainable exploration, scientific discovery, and commercial operations*; and, *Encourage international support for the recovery and use of outer space resources* [2]. Without knowing the reserve potential of lunar resources in the requisite detail, it is not possible to fully *develop exploration technologies and enable a sustainable Space Economy with supporting utilities and commodities* [3], without significant risk. It has been shown (e.g., [4,5]) that a coordinated international lunar resource evaluation campaign is compliant with the Outer Space Treaty [6].

Evaluating Polar Volatile Resources: This requires a coordinated campaign because lunar resources encompass a variety of components (e.g., metals, building materials, volatiles), but regolith is the common denominator. Critical data are needed to define reserve potential of polar volatile deposits (Table 1).

Table 1: Datasets for lunar volatile resource evaluation

Dataset	Specific Data	Use	Measurement
Composition	Grade of the ore Composition of impurites	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.	

Table 1: Needed data for polar volatile resource evaluation.

Obtaining the Data: There have been several attempts to use current orbital datasets to evaluate the quantities of polar volatile deposits [7-9]. But orbital data do not give the granularity of data needed for composition, stratigraphy, and distribution. They can inform accessibility, but do not give clarity to the form and geotechnical properties ("extractability") of the deposits. There are critical orbital datasets that would inform stratigraphy and subsurface abundance that would better inform surface assets with data ~<5 km/pixel (e.g., neutrons – [10]). Point data, exemplified by the LCROSS mission [11], may also be obtained through instrumented penetrators [12]. However, the needed granularity of data informing composition (abundance of the "ore" and "gangue" materials), distribution and stratigraphy (at the meter/decameter scale), and extractability requires mobile surface assets. Understanding the geotechnical properties (and variability therein) is critical for developing cost-effective extraction techniques. Such data cannot be obtained from orbit, requiring mobile surface assets to ensure meter/decameter data are acquired to understand the extent, extractability, and grade of the resource.

Therefore, cooperation between international and commercial partners to define a coordinated international polar volatile evaluation campaign could be as follows: an immediate orbital phase that could yield critical data to better locate the resources within PSRs (low altitude neutron/radar, instrumented penetrators, etc.) in parallel with pathfinder surface missions for ground confirmation and reserve characterization. The initial surface campaign would select the top 10 PSRs (such as those accessible from potential Artemis Base locations or those highlighted in [7-9]) to be investigated by a fleet of small, limited capability rovers deployed from one lander to document surface and subsurface (top 1-3 meters) of regolith for volatiles (e.g., the small Lunar Outpost MAPP rover). These would have a limited life but should be able to traverse sufficiently around the landing site remotely probing the surface and subsurface. More capable rovers that could yield the types of data addressing the categories in Table 1 would then be sent to the best confirmed high-water-ice detection locations (e.g., VIPER-like rovers). Data obtained informs science, exploration, & commercial stakeholders, informing the origin & evolution of PSR volatiles, availability of life support consumables, prospectivity maps, and potential business models.

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