LUNAR RESOURCES CATALOG (LRC): VIPER PATHFINDER DATASET. K. Ennico-Smith[1], L. Keszthelyi[2], R.A. Beyer[3,1], A. Colaprete[1], J.A. Coyan[4], C.I. Fassett[5], J.L. Heldmann[1], J. Kleinhenz[6], [1]NASA Ames Research Center, Moffett, Field, CA 94043 (kimberly.ennico@nasa.gov), [2]U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ 86001 (laz@usgs.gov), [3]SETI, Mountain View, CA 94043, [4]U.S. Geological Survey Geology, Minerals, Energy, and Geophysics Science Center, Spokane, WA 99201, [5]NASA Marshall Space Flight Center, Huntsville, AL 35805, [6]NASA Johnson Space Flight Center, Houston, TX 77058.

Introduction: A new era in lunar exploration has recently begun. Through NASA's robotic Commercial Lunar Payload Services (CLPS) initiative, international and the human Artemis programs, multiple assets are being deployed to explore the Moon and at a rapid cadence. There will be a huge expanse in lunar surface exploration with mobility (e.g., rovers). Several missions are focused on collecting data for assessing lunar resources for potential In-Situ Resource Utilization (ISRU). With this expansion in exploration there will be a commensurate expansion in the volume and variety of data. Work has begun on establishing a measurement plan (i.e., what data is needed) for ISRU [1] but how to integrate these data into the broader Planetary Data Ecosystem (PDE) following FAIR (i.e., Findability, Accessibility, Interoperability, and Reuse) data practices has not been addressed. The VIPER team intends to engage this challenge.

Opportunity: A wide range of potential users (e.g., government, industry, academia, international) could benefit from a common repository of environmental and other attributes related to lunar resources. The *status-quo* is that each research team makes its own resource models and maps. Additionally, related data repositories and assets do exist, but each have limitations that hamper resource modeling and mapping assessments.

The VIPER team's effort in providing a definition for and pathfinder dataset to a Lunar Resources Catalog (LRC) will not be done in a vacuum. The goal is to maximize reuse and interoperability with the existing and evolving PDE for lunar data products particularly relevant to ISRU.

A precedent for a catalog focused on resources exists for the Mars Community: the Subsurface Water Ice Mapping (SWIM) project. This multi-year effort delivered an integrated set of mapping products (e.g., ice consistency, thermal, WEH, geomorphology maps) created by ingesting data from multiple spacecraft plus modeling. This database and products are used by mission planners and the scientific community to identify the location and nature of potential water resources on Mars [2].

In 2021 the Lunar Exploration and Analysis Group (LEAG) and Mapping and Planetary Spatial Infrastructure Team (MAPSIT) jointly commissioned a group of experts to address the identification of Lunar Critical Data Products (LCDP). The LCDP list includes a formalized lunar coordinate reference schema, more tightly controlled cartography and topographic data, and a working list of higher-order data products (e.g., illumination models, geologic maps, resource maps for mission design and surface operations) [3].

Related Repositories and Assets: The Design Specification for Natural Environments (DSNE) is a cross-program specification reference that includes basic information on lunar surface environments (e.g., topography, rock distributions, regolith geotechnical properties, thermal environments) [4]. It is a valued resource for engineers and mission planners. The DSNE is focused on the lunar environment and not so focused resource evaluation and prospecting. The proposed LRC will not only build on the lessons from the creation of the DSNE but can provide relevant data products to inform documents such as the DSNE for mission planning.

NASA's Planetary Data System (PDS) is the primary data repository for NASA-funded planetary missions [5]. Raw, calibrated, and derived products are submitted and undergo peer-review for PDS archive compliance and are stored and made available to the public for years after a mission is completed. PDS standardizes the data format (e.g., binary images, delimited tables) but not the units nor organization as each mission defines their archive criteria differently. The proposed LRC does not replace the PDS, but offers a dynamic repository, hosting multi-mission data, with emphasis on the eventual resource model and map requirements. Defining a standard data input interface will promote data retrieval and enable easier computational assessment (e.g., correlation comparisons).

Multiple platforms featuring a user-friendly interface (e.g., QuickMap [6], MoonTrek [7], JMARS [8] allow overlaying different datasets and serve as a "browsable PDS." However, database retrieval is frequently non-trivial and long-term maintenance plans are unknown. Map layers directly related to resource identification and mapping are not yet available.

Published papers remain a vital resource of repositories or derived products (e.g., Cannon & Britt 2020 on ice favorability maps [9]). However, traditional publications cannot be dynamically updated as is needed when new observations are being rapidly acquired and new models are being developed. Recently, some online forms of publications are attempting to address this issue (e.g., Laura & Beyer 2021 on geospatial primers [10]).

Requirements: For a Lunar Resources Catalog (LRC) to be usable, it is essential to embrace FAIR data practices, the foundation of which are comprehensive and widely accepted metadata. This requires clearly defined organization of inputs (e.g., data type, format, units, quality factor, etc.). An LRC also must accept several types of data (e.g., spectra, imagery, derived parameters) from both surface and orbital assets. A relatively new challenge is to include depth information with the data (e.g., from a drill, ground penetrating radar, etc.). For resource assessments to be trustworthy, it is important that the full process from raw data to derived data and information (e.g., calibrated data, map products) to knowledge must be stored, cataloged, and efficiently searchable. The data structure must also be reactive to community needs (e.g., ISRU mission planners, lunar science and geostatistical researchers, commercial).

It would be cost-prohibitive for the VIPER team to produce different data products for the PDS archives and for broader use through the LRC. One option is to engage in collaborative discussions with the PDS on how long-term archival needs can be balanced with the need to be interoperable with rapidly evolving software tools, especially in the realm of machine learning. One avenue that has worked recently for other missions is to provide multiple versions of the metadata via multiple detached labels associated with the data. This allows the same product to be used in multiple settings with only modest additional effort.

Another goal is to create a community resource that continues to grow even after the VIPER mission is complete. Because the PDE is in a period of rapid evolution, we remain flexible in the specifics of where and how a LRC is implemented and housed.

VIPER Pathfinder Dataset: Equipped with spectrometers, cameras, and a drill for sub-surface access, the VIPER mission will provide an unprecedented dataset for exploring lunar resources (especially ice) at the human/rover scale [11]. VIPER collects data to allow the first assessments of lunar ice resources at spatial ranges relevant to possible extraction efforts. VIPER will generate raw and calibrated data from each instrument, plus derived products such as surface maps of temperature and spectral parameters and vertical profiles of volatile species and concentration. Equally important is that the data is collected with a geo-statistically robust approach (e.g., sampling different ice stability regions, separation, and number of drilling sites) [12]. The VIPER dataset should replace the semi-arbitrary weights used in today's qualitative resource favorability assessments with data-driven weights that are a key and needed step in quantitative assessment of lunar resources.

Conclusion: In constructing a catalog focused on resources, we will leverage experience from USGS mineral resource assessments. Previous studies have shown that many of the concepts and methods used to conduct quantitative mineral and energy resource assessments on the Earth can be applied to the Moon with only modest adjustments; lunar ice is likely to be especially similar to some types of mineral resources on Earth [13, 14]. Some of the key data products used in terrestrial quantitative mineral assessments are (1) descriptive geologic models, (2) spatial models laying out tracts that are favorable for a particular type of deposit, (3) deposit-density models in the form of probability density functions, (4) probabilistic grade-tonnage models, and (5) economic models. The economic models are the most difficult to translate from the Earth to the Moon, but it is important to include at least some constraints related to technical feasibility of extraction even in the absence of typical market forces.

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