The VIPER Mission, a Resource-Mapping Mission on Another Celestial Body. K. Ennico-Smith[1], A. Colaprete[1], D.S.S. Lim[1], D. Andrews[1] and the VIPER Team. [1]NASA Ames Research Center, Moffett Field, CA 94043 (Kimberly.Ennico@nasa.gov).

Introduction: The Volatiles Investigation Polar Exploration Rover (VIPER) mission is a lunar polar volatiles prospecting mission developed through NASA's Science Mission Directorate (SMD) Planetary Science Division with launch in late 2023 [1]. VIPER's mission goals are to (1) characterize the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith and (2) provide the data necessary for NASA to evaluate potential return of In-Situ Resource Utilization (ISRU) from lunar polar regions.

VIPER will be optimized for lunar regions that receive prolonged periods of sunlight (short lunar nights). The mission duration will be more than 90 Earth days and result in a traverse distance of up to 20 km [2]. The mission includes a rover-borne payload (**Figure 1**) that can locate surface and near-subsurface volatiles, excavate, and analyze samples of the volatile-bearing regolith, and demonstrate the form, extractability, and usefulness of the materials.

Figure 1 Artist rendition VIPER

Measurement Goals: A critical goal to both science and exploration is to understand the form and location of lunar polar volatiles. The lateral and vertical distributions of these volatiles can inform us of the processes that control their emplacement and retention, thereby helping to formulate ISRU architectures. While significant progress has been made from orbital observations [3-7], measurements over a range of scales from centimeters to kilometers across the lunar surface are needed to validate "volatile mineral models" for use in evaluating the resource potential of volatiles on the Moon.

Mapping Requirements: The VIPER data collection approach is based on visiting distinct thermal environments characterized by their ice stability depths, the depth at which water ice would be stable in the upper meter for at least 1 Gyr [8]. An area can be categorized into four categories of Ice Stability Regions (ISRs): (1) *surficial* (marked as red in **Figure 2**) where water ice could be present on the surface, (2) *shallow* (green) where it might be present in top 0-50 cm, (3) *deep* (yellow), where it might be present at 50-100 cm depth, and (4) *dry* (grey) or no water in the top 1 meter, which could be no water at all, or water buried much deeper.

Each ISR type surveyed must be at least 3800 m^2 in size. The path the rover takes must cover >10% (goal 15%) areal density with measurements over scales <5 meters to 1 km, to address scales of variability. This translates to driving a length of ~223-335 meters within an ISR type. At a minimum, the rover must visit each ISR type, plus two repeats at least 100 meters from the earlier visited regions. This addresses difference in similar thermal environments at 100 meter length scales. A minimum of three subsurface (drilling) characterizations, each separated by tens of meters, is needed per ISR type. For areas in permanent shadow (surficial ISR) one drill location is planned, but areal coverage and distance driven is maintained.

Rover and Payload Design: The VIPER rover design meets these science mapping requirements and requirements imposed by the unique lunar polar environment, schedule, and budget. Detailed analyses of traverses, including rover models that include power, data, and mobility models, have found that a solar powered rover with Direct to Earth (DTE) communications could meet all mission goals within about one and a half lunar days (i.e., mission length ~35 Earth days).

The rover navigation system (VIS) uses eight cameras, including gimbaled stereo navigation cameras located on a two-meter mast, fixed rear stereo cameras, and hazard cameras near each rover wheel [9]. LEDs provide illumination as needed. The rover position and

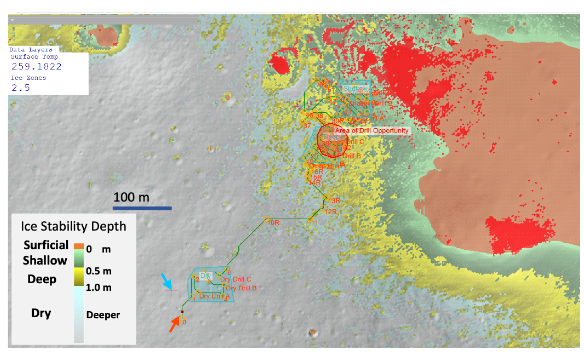

Figure 2 Example of a traverse (green line) planning against high resolution data products. The background colors indicate locations where predicted subsurface temperature allows for long-term water ice stability.

	Measurements	Observations
NSS	Thermal and epithermal neutrons	Water equivalent hydrogen and burial depth along traverse
NIRVSS	Near infrared reflectance spectra from 1300-4000 nm	Surface composition (mineralogy, hydration, frosts) along traverse and from drill cuttings pile
	Imaging (2048x2048 pixel max) with seven color LEDs from 348 to 940 nm	Context imaging below rover along traverse; high resolution imaging (<100 um/pixel) at drill sites
		Imaging of drill cuttings pile
	Thermal radiometry at 10, 14, 18, and 6-25 microns	Surface temperatures under the rover and during drilling down to <100 K
MSolo	Mass spectra between 1-70 amu	Subliming surface volatiles along traverse and from drill cuttings pile
		Key isotope ratios
TRIDENT	Excavation of subsurface material in 10 cm increments down to 100 cm	Regolith geomechanical properties, including discerning ice-rich from dry regolith
	Subsurface temperatures at two locations (separated by 20 cm)	Subsurface temperatures and thermal conduction
VIS	Resolve terrain and obstacles greater than 10 cm out to 15 m away from rover	Driving and hazard avoidance
		Topography and surface geometry, crater identification
		Rock and grain size frequency distribution
		Rover-surface interaction, regolith photometric behavior

Table 1 VIPER Key Science Measurements

pose are determined using a star tracker and Inertial Measurement Unit (IMU).

The VIPER payload [10] consists of three "prospecting" instruments which operate continuously: Neutron Spectrometer System (NSS), Near InfraRed Volatiles Spectrometer System (NIRVSS), and Mass Spectrometer observing lunar operations (MSolo). The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT), an auguring rotary percussive drill, is used to bring material up from a depth of one meter in 10 cm "bites". It places that material on the surface within the NIRVSS and MSolo fields-of-view. TRIDENT includes a temperature sensor at the bit and a heater/temperature sensor 20 cm above it, enabling downhole temperature and thermal conductivity measurements. A summary of VIPER's key measurements is provided in **Table 1**.

Mission Area and Multi-Lunar Day Mission Traverse: In September 2021, the VIPER Mission Area, an approximately 10 x 10 km area west of the crater Nobile, was approved by SMD, after a series of multiple landing site investigations [11].

Being teleoperated from Earth, VIPER must maintain DTE communications and stay out of radio shadows cast by local terrain. For half of each month when the Earth is below the horizon, the rover must be parked at a "Safe Haven" location that provides sufficient sunlight to keep the rover with enough power to survive until the next lunar day. Traverse planning to date has used 20 m/pixel map products based on LOLA Digital Elevation Models (DEMs) [12]. Planning continues with one meter per pixel products based on a Shape-from-Shading (SfS) DEM generated by the NASA Ames Stereo Pipeline [13]. An example of a traverse plan against high resolution data products (e.g., 1-m DEM and 4-m thermal maps) is shown in **Figure 2**. The mission planning is organized into two phases: (1) Phase 1, when rover traversing and observations follow a pre-planned scheduled to meet measurement goals and, (2) Phase 2, during which more real-time decision making is implemented and reactions to Phase 1 finds are enabled. Both periods take advantage of near real-time rover communications and real-time geostatistical analysis methods to maximize observation effectiveness.

Data Sets: 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. All science data will be archived at the Geosciences and Imaging and Cartography Nodes at NASA's Planetary Data System (PDS).

As VIPER data is collected with a geostatistical robust approach (e.g., sampling different ice stability regions, separation of sampling areas, number of drilling sites), this data is well positioned to 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. The VIPER dataset can thus serve as an anchor for a proposed Lunar Resource Catalog (LRC) [14]. The LRC is envisioned as a community-driven, standards-based, dynamic repository and a critical first step in integrate these lunar resource related data into the broader Planetary Data Ecosystem (PDE).

Conclusion: VIPER's payload and mapping mission design work together to (1) provide ground truth for models and orbital data sets, including temperatures at small scales, subsurface temperatures and regolith densities, surface hydration and hazards, (2) correlate surface environments and volatiles with orbital data sets, and (3) address key hypotheses regarding polar volatile sources and sinks, retention, and distribution. VIPER is a key next step in resource mapping on another celestial body.

References: [1] Colaprete, A. (2019) AGU #P34B-0; https://www.nasa.gov/viper. [2] Colaprete, A. et al. (2022) LPSC #2675. [3] Feldman, W.C., et al. (1998) Science 281,1496–1500. [4] Pieters, C.M. et al. (2009) Science, 326, 568-572. [5] Hayne, P.O. et al. (2015) Icarus 255:58–69. [6] Li S. & Milliken, R.E. (2017) Sci Adv 3:e1701471. [7] Li, S. et al. (2018) PNAS, vol 115, no 36, 8907-12. [8] Siegler, M. et al. (2019) LPSC #6038. [9] Beyer, R. et al. (2022) LPSC #2466. [10] Ennico-Smith, K. et al. (2020) LPSC #2898. [11] Beyer, R. et al. (2022) LPSC #2479. [12] Shirley, M. et al. (2022) LPSC #2874. [13] O. Alexadrov & R. Beyer, (2019) ESS 5.10 pp. 652–666. [14] Ennico-Smith, K. et al. (2022) LPSC #1730.