VIPER Site Selection Ross A. Beyer[1,2], A. Colaprete[2], M. Shirley[2], E. Balaban[2], M. Siegler[3], and J. Martinez-Camacho[3]. [1]SETI Institute (rbeyer@seti.org), Mountain View, CA, [2]NASA Ames Research Center, Moffett Field, CA, [3]Planetary Science Institute, Tucson, AZ, and Dept of Earth Sciences, Southern Methodist University, Dallas, TX

The Volatiles Investigating Polar Exploration Rover (VIPER) mission will use a suite of instruments to conduct exploration science by mapping volatiles, especially hydrogen bearing volatiles, near the south pole of the Moon [1] starting in late 2023. NASA has selected and announced VIPER's "Mission Area," which is approximately 5 × 5 km centered at 31.6218° E, 85.42088° S near the western edge of Nobile crater within which VIPER will land and carry out its primary mission. Selection of the landing site within this area and the traverse route are still pending, and selections are expected later this year (2022). This abstract describes the criteria for selecting the VIPER Mission Area.

Rover Characteristics: VIPER is a solar powered rover that will be tele-operated from Earth via a line-of-sight radio link. The rover can survive in darkness up to 50 h in a low-power, hibernation mode. It can move and operate its instruments in sunlight indefinitely and in darkness for up to 9 h. The drill's auger can bring material up (from a depth of 1 m) and put it on the surface within the fields of view of the belly-mounted instruments. VIPER can achieve speeds of 20 cm/s on flat terrain. However, accounting for commanding, localization, navigation , and obstacle-avoidance delays, the effective speed is closer to 1 cm/s. The distance driven is expected to be 20 km but may be less as science planning is refined (e.g., spending more time drilling and exploring closely spaced thermal environments vs. driving farther over dry surface to reach other interesting thermal environments).

Map Products: Analysis of candidate Mission Areas was based on the LOLA 20 m gridded data product [2] and maps derived from it. These include slope, permanent-shadow, and ice stability depth (see below). Time-series lighting, communications, and temperature maps were calculated over a five month period covering the lunar south pole's summer solstice in 2023.

Areas Studied and Selection Criteria: Prior to NASA's selection of the Mission Area, multiple candidate areas were studied and evaluated. Fig. 1 shows the areas that were considered, and simplified rationale for rejecting most of them. For a candidate area to be viable, it had to meet the criteria below. Some areas could be rejected directly based on these criteria, while those that remained were evaluated by generating and comparing families of traverses originating from suitable starting locations throughout the areas.

Science Criteria: Candidate areas had to be associated with elevated hydrogen and thermal environments suitable for volatile sequestration. Orbital hydrogen maps are low resolution and provide only rough preferences. Thermal environments where volatiles could be present can be modeled at high resolution, i.e., rover-relevant scales, from the topography and physical properties of the regolith. To define distinct thermal environments to explore, we modeled ice stability depth [3], which is the depth at which the rate of ice sublimation would be less than 1 mm/Ga (i.e., stable over long periods). This is modeled from the terrain data, and is a time-independent quantity that we create maps of for use in planning.

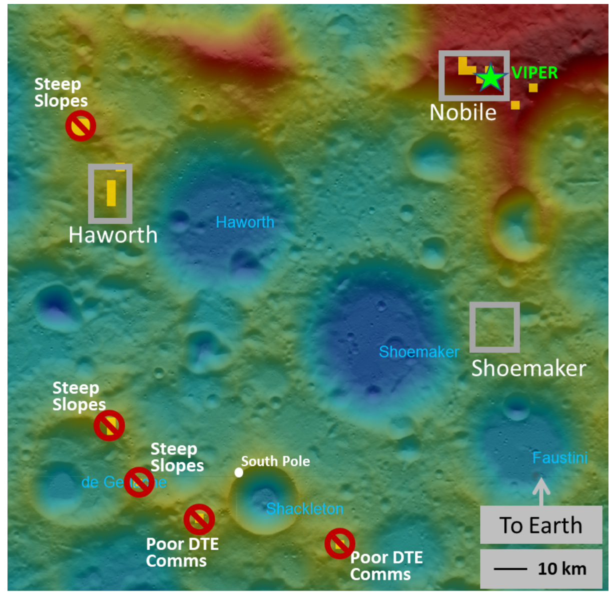

Figure 1: Colorized shaded-relief LOLA map of the lunar south pole. Possible Safe Havens are located in gold boxes. Areas outlined in gray were studied in more detail.

Since VIPER is looking for volatiles that can be sampled by its 1 m drill, we defined four depth ranges: Surficial at 0 m; Shallow (0, 0.5] m; Deep, (0.5, 1] m; and Dry, (1, ∞] m. This divides the map into contiguous Ice Stability Regions (ISRs). Candidates with a variety of ISRs within driving distance of each other were preferred.

Also preferred were areas where the ages of the craters creating permanent shadow varied widely, particularly if some of the craters were at least 1 Ga in age. The VIPER Science Team will investigate a broad range of lunar science questions, but Mission Area selection was driven by the opportunity to investigate volatiles and volatile transport.

Traversability Criteria: The remaining criteria for selecting the Mission Area are related to the design of the rover and lander. The Mission Area must contain a variety of ISRs close enough together to be visited within the available lighting and comm time windows with less than 20 km of driving, and the terrain between them must be traversable. Slopes over scales larger than VIPER's 1.5 m wheelbase must be no more than 15°.

Illumination and Communication Criteria: During normal operations, the rover must always have a line-of-sight radio connection to a terrestrial ground station (except see safe havens below). In particular, the rover cannot drive behind terrain that would produce a radio shadow, and we require a 2° safety margin above terrain. Two candidate areas shown in Fig. 1 were rejected due to their limited periods of line-of-sight access to ground stations. Both were just past the south pole on the lunar farside. These areas would have been stronger candidates if a communications relay was available, e.g. through a satellite or an antenna on a ridge.

The rover must also stay in sunlight (to generate power) except when purposefully entering shadow to do science. Partially eclipsed Sun is allowable, except the details depend on the balance between power generation and usage.

Safe Haven Criteria: To operate VIPER for more than 14 days at the pole, there will be periods where we cannot satisfy the communications criterion because the Earth is below the horizon. Without communications, the rover will not move, but will await commands. If there are also long periods without sunlight, running heaters to survive the intense cold will deplete its batteries.

Given VIPER's instrument suite, the rover's design is a compromise between battery capacity, weight of the battery plus mobility system plus structure, and the capacity of the lander. This compromise has yielded an endurance of 50 h in continuous darkness, so we must find "Safe Havens" where we can park the rover where periods of darkness don't exceed that. A second period of 50 h of darkness can occur while we wait at a Safe Haven, as long as the batteries can fully recharge between the two periods.

Finding Safe Havens turned out to be the most limiting constraint that drove Mission Area selection. There were relatively few locations that were suitable, and this constraint generated the list of candidate areas that were considered. The gold boxes in Fig. 1 indicate areas which contain Safe Havens and correspond to a candidate. The Safe Haven areas are often no larger than a football field and would not be visible at this map scale. They're clustered on high crater rims or just down from the tops of hills on the poleward side. They tend to be poleward due to the vagaries of phasing between the Sun's azimuth and the Earth's elevation in late 2023.

Although not required (the mission could meet its requirements in only 10-12 days), the presence of Safe Havens would allow VIPER to operate a second month, and would allow more time for scientific investigation. Both NASA management and the VIPER team preferred a Mission Area which allowed for more mission time.

Candidates rejected for steep slopes generally had Safe Havens on prominent crater rims and slopes on both sides, which made the large interior PSR and smaller exterior PSRs unreachable. Very small PSRs along the rims were sometimes reachable but didn't allow for meeting all mission requirements.

Two candidate areas were found, near the Nobile and Haworth craters. The Nobile area offered a mission opportunity of several months while the Haworth site was limited to parts of two months. This longer mission is the primary reason the Nobile area was selected.

We also studied an area just east of Shoemaker that did not contain any Safe Havens to explore whether a 9 or 10 day mission could meet mission requirements. This area was closer to a high concentration of hydrogen in the orbital maps, but no traverses meeting requirements could be found.

Landing Criteria: The Astrobotic Griffin Lander will deliver VIPER to within 100 m of the landing site NASA designates within the Mission Area. To achieve this precision without GPS, an optical navigation system will estimate its position by imaging lit surface for several hundred kilometers during the descent. Landing early in the window of combined Sun and comm maximizes science time before hibernating which constrains the landing time. For the Haworth candidate, this time strongly limited lighting along the approach, which impacted the flexibility of trajectory design and launch date. These concerns contributed to the preference for the Nobile candidate area.

Next Steps: The VIPER team continues to study the Mission Area and has generated a new (1 m/pixel) terrain model and a broad range of products derived from it. This will allow us to propose a specific coordinate for landing and an update to the traverse plan later this year (2022). The traverse plan defines (roughly) the path the rover will take and the timing of its movement along that path, although one of the most exciting things about controlling an instrument suite on the Moon in real-time is the ability to react to what those instruments reveal and to adjust the plan to improve the science returned.

References: **[1]** Colaprete et al. In: *LPSC 52*. 2021, p. 1523. **[2]** Smith et al. In: *SSR* 150 (2010). DOI: 10.1007/s11214-009-9512-y. **[3]** Siegler et al. In: *Nature* 531.7595 (2016). DOI: 10.1038/nature17166.