AN EXPLORATION OPERATIONS SYSTEM. David A. Kring[1,2], James W. Head[3], Harald Hiesinger[4], and Debra H. Needham[5], [1]Center for Lunar Science and Exploration, Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd., Houston TX 77058 USA (kring@lpi.usra.edu), [2]NASA Solar System Exploration Research Virtual Institute, [3]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912 USA, [4]Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany, [5]Exploration Science Strategy and Integration Office, NASA Headquarters.

Introduction: Artemis operations can draw on the Apollo Program and its six human landings. It can also draw on the Constellation Program, which conducted six years of study, training, and mission simulations for a modern era of lunar polar exploration, like that anticipated in Phases I and II of Artemis. From this experience, we suggest eight operational tenets:

- **Integrate science & engineering.** Lunar surface expertise resides in the planetary science community and should be embedded in the exploration process. NASA's Solar System Exploration Research Virtual Institute (SSERVI), which integrates Science Mission Directorate (SMD) and Human Exploration and Operations Mission Directorate (HEOMD) objectives, could be expanded, and Constellation programs like Directorate Integration Office (DIO), Lunar Surface Systems (LSS), and Desert Research and Technology Studies (DRATS), should be reestablished.

- **Lunar surface operations should be crafted in the framework of an exploration plan.** Artemis III will focus on a safe landing, return of crew, and initial polar science. Future missions will need to be prepared to explore a more diverse set of geologic processes (Panel A) and *in situ* resource utilization (ISRU) deposits across the surface of the entire Moon. Science and exploration are evolutionary processes. It will be important to have a coordinated plan that efficiently explores the Moon while developing the technological capabilities for a sustainable exploration program that can carry us deeper into the Solar System. It will be important to avoid decisions that produce an impediment to a future landing site or surface operation.

- **Integrate robotic & human exploration.** Mobile robotic assets can validate precursor data and reduce risk, requirements, and human exploration cost; they can go to hazardous locations that crew cannot access; and they can expand geographic distribution of exploration sites; *but robotic assets should not be used to conduct the types of science and exploration best done by well-trained astronauts*.

- **Produce well-trained crew.** The most efficient and productive assets in space exploration are well-trained crews with appropriate tools. Geologic training of Apollo crews was an essential element of their success and will be even more essential in longer-duration Artemis missions. For the initial Artemis missions in the impact-cratered highland terrain of the lunar south pole, training should feature impact craters (e.g., Meteor Crater, Arizona (Fig. 1) and Ries Crater, Germany) and locations with highland lithologies (e.g., the anorthosites of the Duluth Complex, Minnesota) among other locations discussed [1] in a preceding portion of this Lunar Surface Science (LSS) series of meetings. The south pole resides on the rim of Shackleton crater. That impact event excavated 4×10^{11} m^3 and nearly a billion metric tons of rock that were deposited on the crater rim and the surrounding terrain [2]. Knowing which rock samples to collect from those deposits takes skill that will need to be developed. Moreover, the Shackleton impact event and other impact events in the region modified the distribution of volatiles. Understanding those impact-imposed consequences and evaluating them while engaged in EVA also takes skill that will need to be developed.

Figure 1. *Meteor Crater [6] is a classic astronaut training site and is an ideal locality to prepare for lunar south polar operations. (Photograph by David A. Kring).*

- **Provide crews with appropriate sampling tools.** Tools will be needed to collect samples (Fig. 2) and explore subsurface heterogeneities; avoid, however, burdening crew with devices for measurements best made on returned samples.

Figure 2. *Artistic rendering of Artemis astronauts sampling lunar surface material. (Credit: NASA)*

- **Conduct integrated lunar surface mission simulations.** Such simulations, an extended part of a crew training program, must involve all anticipated participants in lunar surface missions.
- **Lunar samples are key to transformative lunar science** and must be part of every lunar surface mission. Because of a relatively small lunar gravity well and proximity to Earth, and lunar samples/soils complexity (Fig. 3), returning samples to Earth will be preferred to analyses *in situ* or on orbiting platforms. As outlined during the Constellation program (e.g., [3]) and in a previous contribution to this LSS series of meetings, plans for adequate sample mass need to be made [4]. On the other hand, volatile materials may lend themselves to *in situ* analyses, particularly when transport may alter important physical/chemical properties. Techniques that provide elemental and isotopic information about volatile constituents will be needed to address National Research Council [5] objectives.
- **Engage the international community.** All activities above will benefit from international partnerships. Such collaborations were an integral part of Apollo and should be part of Artemis; they include astronaut training, flight hardware, implementation of missions, and post-mission analyses.

Figure 3. *Microscope view of Apollo 12 olivine basalt sample 12005. (Credit: LPI/CLSE/David Kring).*

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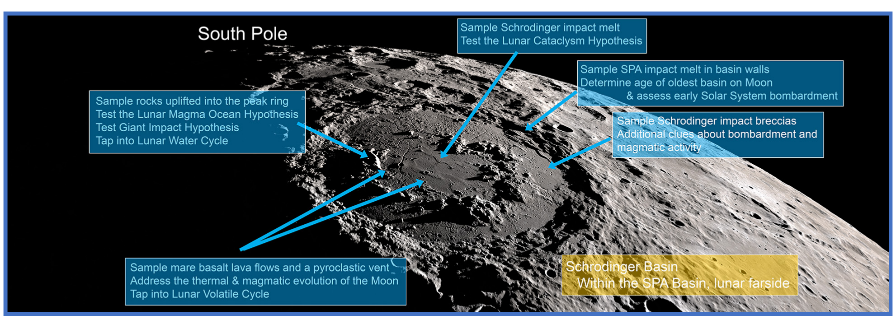

Panel A. *Approximately 450 km beyond the impact-cratered terrain of the south pole, lava flows and an ISRU-relevant pyroclastic volcanic vent occur on the floor of Schrödinger impact basin [7]. Other remnant lava flows exist nearby in the South Pole-Aitken basin [8,9]. Those sites and other sites around the Moon should be part of a global lunar exploration plan.*