

## Preparing for Artemis III EVA Science Operations

David A. Kring\*

**Introduction.** An Artemis III landing site within 6° of the lunar south pole will be in an impact-cratered terrain (Fig. 1). Because impact craters are pervasive and occur at all scales, from micrometers to >1000 km, it is impossible for an astronaut to take a single step on the Moon without stepping into or onto an impact crater. Previous papers (e.g., [1,2]) have outlined a few steps needed to prepare for lunar surface science operations in that type of terrain. Here I expand those remarks (items 1 to 5) and draw attention to specific training sites (items 6 & 7) that are particularly relevant for south polar operations.

I begin by pointing out that Armstrong and Aldrin and the science staff supporting them had 5 years 4 months to develop surface science plans before the first Apollo landing; and Cernan and Schmitt and the science staff supporting them had more than 8 years to develop surface science plans for the final Apollo landing. We have far less time remaining prior to the scheduled 2024 Artemis III landing, so we need to quickly draw upon those scientists in the nation who have extensive experience with both lunar sample analyses and field studies in impact-cratered terrains. With that expertise:

**1. Evaluate the landing site:** Evaluate the scientific and exploration potential of the landing site using existing data and fill in or mitigate missing data to reduce mission risk while enhancing mission productivity.

**2. Integrate program elements:** Develop notional extravehicular activities (EVAs), integrate with hardware systems, iterate with engineering teams and flight operations personnel, and modify as needed, echoing the work we did with 3- to 28-day mission simulations between 2008 and 2012. Routine communication between all teams involved in a lunar surface mission needs to be established early.

**3. Train crew for surface ops:** Expand our work with astronauts during their basic geologic training and in 3- to 28-day mission simulations. It is important to recall the experience of Apollo astronauts who found field training and traverse exercises to be the most important component of their EVA preparation. Charlie Duke said “The geology field trips were outstanding. The monthly trips we did from the time we started on the crew were just right.” John Young added that a field exercise “helps you get a team work pattern and I think that’s real important. You are not very effective unless you’re working as a team up there. Otherwise you’re just going to be spinning your wheels on the Moon and that’s not where they want you to spin them.”

**4. Train scientists for mission operations:** In a series of mission simulations between 2008 and 2012, we established protocols for an integrated mission control center with a science team and traditional flight operations personnel working side-by-side. In those simulations, when crew went EVA, the Flight Director turned operations over to a SciLead who managed a science team sitting at their own consoles. Scientists who will support lunar surface EVAs need to be trained in mission operation procedures that involve crew (e.g., Space Flight Resource Management Training for Science Operations [3]).

**5. Conduct mission simulations:** All personnel who will be involved with an actual lunar flight need to participate in mission simulations. The simulations will uncover unanticipated challenges, produce a

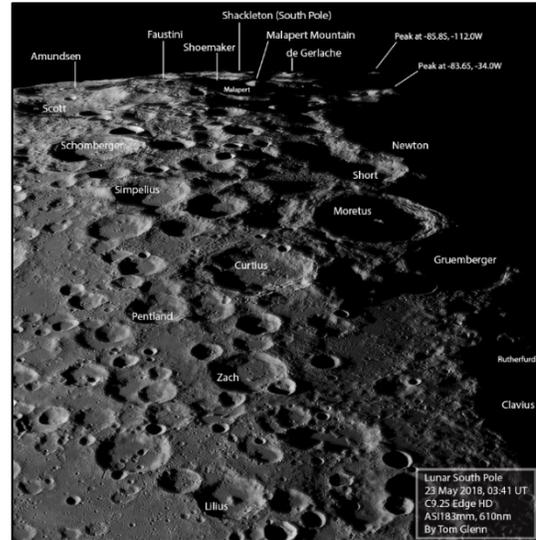


Figure 1. The lunar south polar region is an impact-cratered terrain.

\*[kring@lpi.usra.edu](mailto:kring@lpi.usra.edu)

well-working team, and give that team the resiliency needed to successfully resolve unexpected conditions that may arise during a lunar surface mission.

**6. Training in impact-cratered terrains.** While the Artemis III mission may be limited to EVAs within 2 km of the lander, the expanded geographic scale of future Artemis lunar surface operations will be a new challenge. Excursion distances will be far greater than those of Apollo and even some of the topographical features have greater dimensions than those encountered during Apollo. The 1.2 km diameter Meteor Crater of Arizona (Fig. 2) is a perfectly good proxy for small craters scattered throughout the south polar region. I have also found the 300 m diameter Schooner crater at the Nevada Test Site to be a useful analogue for lunar-like terrains, because it has fresh features like those observed by Apollo astronauts. Both those craters are good analogues for many of the morphological features of Shackleton crater at the lunar south pole. However, the size of Shackleton crater (21 km diameter and >3 times deeper than the Grand Canyon) may require training activities at Sierra Madera Crater of West Texas (13 km) and the Ries Crater of Germany (24 km) to capture the operational issues (e.g., communication, rover mobility, and supplies) that are affected by greater distances. Ries crater training can be coordinated with European Space Agency astronaut trainer Prof. H. Hiesinger. Those field studies should also be supplemented by exercises at the Sudbury impact structure of Ontario, which is an analogue for lunar basins 300 km or larger in diameter. Training materials for several of these sites have already been developed for astronauts (e.g., by Apollo 15 trainer Dr. Gary Lofgren and Apollo 16 trainer Dr. Friedrich Hörz with the author) and supporting mission operations staff.

**7. Training among highland analogue terrains.** The south polar region hosts several large blocks of primitive lunar crust called massifs. Studies of Shackleton crater indicate it excavated material from a massif that is composed of nearly pure anorthosite [4-6], possibly a remnant of an ancient magma ocean the covered the Moon. For that reason, field exercises to impact craters should be augmented with one or more trips to an analogue site with anorthosite: e.g., the San Gabriel Mountains, Stillwater Complex, and Duluth Complex.

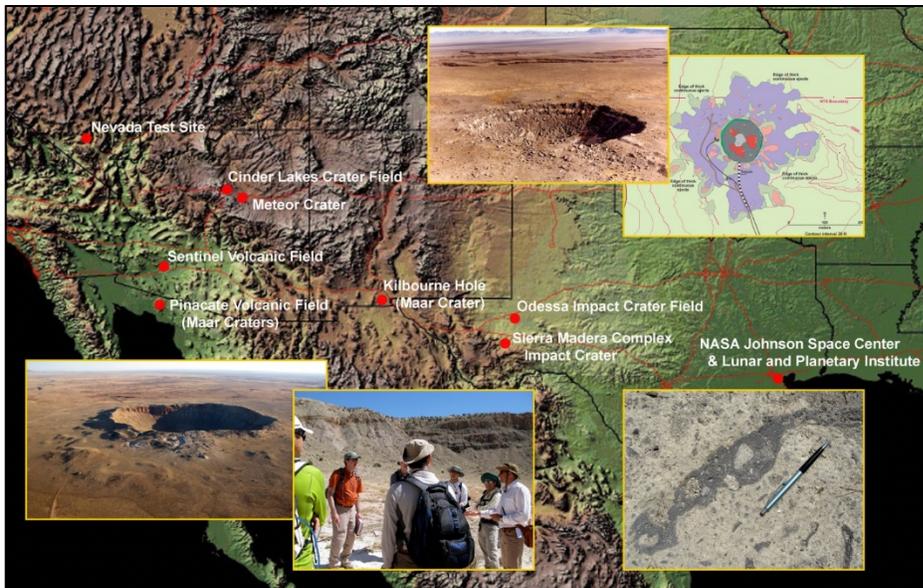


Figure 2. Training sites used previously by the author. (insets, counter clockwise from lower left) aerial view of Meteor Crater; the 2009 class of NASA, CSA, and JAXA astronauts with the author on floor of Meteor Crater; fragment of impact melt in a rock being examined by astronaut Stan Love and the author at the Ries Crater in 2010; map of Schooner Crater, Nevada Test Site; aerial view of Schooner Crater. NASA's Solar System Exploration Research Virtual Institute (SSERVI) currently supports the author's training programs at Meteor Crater & the Sudbury impact structure.

**References.** [1] Kring, D. A. (2010) What can astronauts learn from terrestrial impact craters for operations on the Moon and Mars? *Nördlingen 2010: The Ries Crater, the Moon, and the Future of Human Space Exploration*, Abstract #7036. [2] Kring, D. A. (2019) Preparing for lunar surface operations. *NASA Exploration Science Forum*, Abstract #NESF2019-127a. [3] [https://www.lpi.usra.edu/exploration/FlightOps\\_training/](https://www.lpi.usra.edu/exploration/FlightOps_training/). [4] Yamamoto et al. (2012) Massive layer of pure anorthosite on the Moon. *Geophys. Res. Lett.* 39, 6p., L13201. [5] Gawronska A. J. et al. (2020) Geologic context and potential EVA targets at the lunar south pole. *Adv. Space Res.* 66, 1247–1264. [6] Halim, S. H. et al. (2020) Numerical modeling of the formation of Shackleton crater at the lunar south pole. *Icarus* 354, 9p., 113992.