SCIENCE BACKROOM TRAINING FOR LUNAR EXPLORATION: ANALOG TRAINING IN NORTHERN ARIZONA.

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Introduction: The science backroom was a critical component of maximizing the science return from the *Apollo* missions. Scientists interacted closely with astronauts, engineers, and flight controllers before, during, and after missions to ensure the most effective and efficient ways to conduct human exploration and return the greatest scientific output. As NASA makes plans for returning to the Moon through the *Artemis* program, crucial improvements can be made to the involvement of scientists in the mission timeline by assessing lessons learned from Apollo.

Here, we focus on the involvement of scientists in field training, including geologic mapping, localization and traverse planning, prioritization of science observations, sample collection and tracking, and the development of hand tools and instrumentation. We review the involvement of scientists in the *Apollo* program and discuss current capabilities to support science backroom training in northern Arizona.

Science training during *Apollo*: Throughout the 1960s and into the early 1970s, geoscientists supported the *Apollo* program in a variety of roles with the main hubs of effort in Houston, Texas and Flagstaff, Arizona. Eugene Shoemaker moved the U.S. Geological Survey's "Astrogeology Branch" to Flagstaff in 1963 with the intent of providing geologic maps of the Moon and assistance with training the *Apollo* astronauts [1]. Northern Arizona provided ready access to world-class analog training sites including the San Francisco Volcanic Field, Barringer Meteorite Crater (aka Meteor Crater), Verde Valley, Hopi Buttes Volcanic Field, and the Grand Canyon, among others. The proximity and logistical availability to such diverse geologic terrains provided excellent "real world" sites to teach field geology, sampling protocols, navigation, and instrument deployment to Apollo astronauts, as well as to test lunar rover prototypes and hand tools [1,2]. Scientists from academic and research institutions across the U.S. converged in Flagstaff, AZ to support Apollo training, with the USGS playing a key coordinating role in field testing and training.

Scientists were tasked with adapting terrestrial field methods of geological description and sampling to the lunar environment, including the limitations of the Extravehicular Activity (EVA) suites and timelines. Field training and testing led to the recognition of the essential role of live television in acquiring and recording geologic observations. Efficient procedures for verbal and photographic notetaking, as opposed to the more traditional use of field sketches and notes, were also developed. Tools were tested and modified with some traditional instruments of field geologists being abandoned (e.g., the pocket transit and Jacob staff), or substantially modified (e.g., aluminum instead of steel hammers). Entirely new tools, such as the "gnomon" (which provided a vertical reference, a sun compass, and color calibration chart in a single device) were developed [3]. Training in the use of all these techniques also had to be developed and implemented [1,2].

Although it is easy to focus on the engineering issues that were solved and the direct training provided to the astronauts, the most profound impact of the work done by the scientists was the creation of an integrated team of astronauts, mission managers, and scientists. A common language and purpose were established with clear lines of communication and trust. The science backroom was a key component for this teamwork. The consistent inclusion of a simulated science backroom in the activities coordinated from Flagstaff was one of the main contributors to this success. This coordinated communication allowed learning to flow in both directions: "Although there was a need for scientists to train the Apollo crews in the procedures and scientific background for the tasks on the lunar surface, there was also a need for training the scientists in how to train the crews" [2]. It was equally important for the scientists to be fluent in NASA procedures as it was for the astronauts to be able to distinguish key rock types. Critically, this rapport included not only the scientists and astronauts, but also the mission operations staff.

Several key lessons learned from *Apollo* that are pertinent to science backroom training as summarized by Phinney [2] are as follows:

1) Field training is essential, and should replicate as closely as possible the communications, personnel, procedures, and traverses that will occur in the planned missions.
2) Planning for human exploration missions requires frequent interaction between scientists, engineers, traverse planners, site selection representatives, equipment personnel, astronaut trainers, flight controllers, and astronauts.
3) Simulations should be as realistic as possible and involve all relevant personnel identified above.
4) Scientists need to be trained on how to train the crews.

Some differences between *Apollo* and *Artemis*: Although the experience from *Apollo* emphasizing the need for training the entire operations team together is directly relevant to *Artemis*, the two programs do have non-negligible differences. Perhaps the most significant of these are *Artemis'* (1) high-latitude landing site, (2) technological advances, and (3) goal to create a sustainable human presence on the Moon.

One significant factor for human exploration of high-latitude regions is the initially disorienting effect of the perpetual low elevation of the Sun. Furthermore, the extreme environmental differences between sunlit and shadowed locations can create unintuitive hazards. Future training sites should consider high-latitude terrestrial analogs or the simulation of such conditions for *Artemis*.

Technological advances since the *Apollo*-era provide some major opportunities and challenges. These new technologies can greatly enhance the capabilities of humans on the lunar surface but can also increase the complexity of the mission. Field tests continue to be the most robust way to find the optimal uses of capabilities such as field portable instrumentation, human-robot partnerships on the lunar surface, and virtual reality in the science backroom [c.f. 4-6].

The sustainability goal raises the importance of volatiles and In Situ Resource Utilization (ISRU) relative to *Apollo*. Arctic and Antarctic training sites should be considered, but some work with volatile deposits can be conducted at much lower cost during the winter at more accessible low-latitude but high-elevation localities. The ISRU-related work also brings an element of applied science that was not emphasized during *Apollo*. Practical questions such as comparing methods to move substantial volumes of regolith will need to be balanced with more fundamental science questions such as the origin of the Moon.

In short, the level of teamwork needed for *Artemis* and *Apollo* is not expected to differ, and extensive joint trainings and simulations are the best way to develop this. However, the diversity of scientific expertise involved, and the range of field sites used will need to be adjusted for *Artemis* to address mission-specific goals.

Current capabilities and training efforts: The USGS maintains its capabilities and expertise in northern Arizona via the Astrogeology Science Center (ASC), which provides access to a variety of analog sites that have long been used as training grounds. These analog sites include well-preserved analogs for key lunar geologic processes, especially volcanism and impacts. The high elevation of the region allows some training with surficial volatile deposits, at least for part of each year. ASC has also recently enhanced its ability to provide similar support more globally.

The USGS Terrestrial Analogs for Research and Geologic Exploration Training (TARGET) program was established to respond to community needs regarding training, research, sample collections, and data archiving related to terrestrial analog work. Through this program we have developed a number of training resources and field guides for the planetary science community and aim to facilitate research and training trips. Although our initial products have focused on northern Arizona, other widely used analogs in Iceland and Hawaii are high on the list of future areas for attention. We are also supporting community needs for archiving of field data and seek to expand the curation of geologic sample collections from key analog locations.

These capabilities have been used in recent years in coordination with colleagues at NASA's Johnson Space Center, Goddard Space Flight Center, and academic partners to facilitate astronaut training and NASA Engineer/Manager training [7-8]. ASC has also been involved in support of science backroom activities at nearby analog locations as part of the NASA Desert Research and Technology Studies (RATS) exercises. Current training efforts at nearby lunar analog locations can be expanded to include science backroom training relevant for *Artemis*, and facilities support via existing resources at the USGS.

Summary: The *Apollo*-era demonstrated the importance of involving scientists at all stages of crewed operations, and the integration of scientists, engineers, managers, astronauts, and others in field simulations. Science backroom training to support the *Artemis* program would benefit from a similar approach. A number of lunar analog training grounds are found in northern Arizona, and the USGS ASC is prepared to support additional field training opportunities.

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