SAMPLE CURATION AT A LUNAR OUTPOST.

C. C. Allen [1], G. E. Lofgren[1], A. H. Treiman[2], and M. L. Lindstrom[3]
[1]NASA Johnson Space Center, Houston, TX 77058 USA carlton.c.allen@nasa.gov gary.e.lofgren@nasa.gov
[2]Lunar and Planetary Institute, Houston, TX 77058 USA treiman@lpi.usra.edu [3]NASA Headquarters, Washington, DC 20546 USA marilyn.lindstrom-1@nasa.gov

Introduction: The six Apollo surface missions returned 2,196 individual rock and soil samples, with a total mass of 381.6 kg [1]. Samples were collected based on visual examination by the astronauts and consultation with geologists in the science "back room" in Houston. The samples were photographed during collection, packaged in uniquely-identified containers, and transported to the Lunar Module. All samples collected on the Moon were returned to Earth.

NASA's upcoming return to the Moon will be different. Astronauts will have extended stays at an outpost and will collect more samples than they will return. They will need curation and analysis facilities on the Moon in order to carefully select samples for return to Earth.

Apollo Sample Curation: The Apollo samples are curated at the NASA Johnson Space Center (JSC) in Houston, TX. To minimize contamination, the samples are stored in dry, high-purity nitrogen gloveboxes within class 1,000 cleanrooms. Only a limited set of materials is allowed to contact the samples. The lunar samples are distributed worldwide to support peer-reviewed research, as well as education and public outreach.

Curation of lunar samples can be divided into distinct, but interconnected, functions:

- Documentation and tracking
- Handling and subdivision
- Preliminary examination
- Contamination and environmental control
- Secure storage
- Allocation

The samples returned by the Apollo astronauts are the most intensively-analyzed rocks and soils in history. Sample analysis in the decades following Apollo established the current understanding of lunar geology and clearly demonstrated where continuing research in needed. New generations of scientists, new classes of analytical instruments, and new insights have resulted in continuing demand for theses samples, even 35+ years after their return.

Samples also provide the raw material for future utilization of lunar resources. Oxygen, for life support and propulsion, is a resource of high interest. Oxygen can be derived from oxide minerals in the lunar soil, particularly iron-rich pyroclastic glass and ilmenite-bearing material. Ice-rich deposits have been predicted in permanently-shadowed locations, and the verification of such deposits is an import goal for lunar exploration. Other volatiles, derived from volcanic emissions or implanted by the solar wind, may also prove valuable resources.

Lunar Outpost Curation Studies: Concepts for the collection of samples at lunar outposts were studied intensively in the years following Apollo. The 1988 "Geoscience at a Lunar Base" workshop [2] carefully considered the curation and analysis of samples on the Moon's surface. The workshop participants envisioned a complete curatorial facility at a lunar base, similar in concept to the facility at JSC, but on a smaller scale. Sample handling and analysis would be done outside the habitat, in a dust-controlled structure, using robotic and telerobotic operation as much as possible.

The 1989 Lunar Science Strategy Workshop [3] represented the input of the science community to NASA's 90-Day Study. The workshop report recommended that a lunar outpost should have a sample curation facility, at ambient lunar surface conditions, robotically operated and complemented by a preliminary examination laboratory.

The most detailed scheme for handling and curation of geoglic samples on the Moon is included in the "First Lunar Outpost Mission" (FLO) study conducted at JSC. Treiman [4] compiled specific recommendations for sample documentation and tracking, handling and subdivision, preliminary examination, contamination and environmental control, and continued storage on the Moon.

Lunar Outpost (2007): The current draft of NASA's Lunar Architecture [5, 6] envisions the progressive build-up of a crewed outpost, commencing with the first human mission. Crews on early missions will occupy the outpost for days or weeks, and the long-term goal is continual occupation supported by crew rotations every several months.

The outpost will likely be located at or near one of the lunar poles. The discovery and analysis of volatiles in permanently-shadowed polar craters is one of the high-priority science goals of this architecture.

Sample Curation at a Lunar Polar Outpost: Sample return to Earth is an essential part of the current Architecture. However, mission restrictions on mass and volume will undoubtedly constrain the number of returned samples to considerably less than the number of samples collected. The samples transported to Earth will need to be carefully selected to address specific, high-priority research questions. Other samples may be studied on the Moon, particularly if the aspects to be studied would be compromised by exposure to the spacecraft or the terrestrial environment.

The design of the spacecraft that will return crews and samples from the lunar outpost to Earth has not been finalized. However, preliminary planning includes a mass allocation of 200 kg for samples, including packaging. This compares to the total 110.5 kg of rock and soil (without packaging) returned by Apollo 17 following three extravehicular activity traverses. Clearly the Apollo-era practice of transporting all collected samples to Earth will have to be modified, and a method of hi-grading samples at the lunar outpost will be required.

Sample contamination at a lunar outpost is potentially a much larger problem than it was during the Apollo missions. The amount of infrastructure and off-gassing associated with the outpost, as well as the repeated landing and liftoff of rockets, can seriously contaminate unprotected samples.

The potential health hazard posed by lunar dust, as well as the hazard to equipment posed by this highly abrasive material, will significantly affect outpost design and operation. These concerns present a strong argument for conducting curation activities outside of the habitable volume of the outpost.

The basic recommendations of the previous studies remain valid for the curation of rock and soil samples collected at most locations on the Moon. However, as Treiman [4] noted, these schemes are "inadequate for curation and handling of volatile-rich materials, such as might be found at the lunar poles." In order to effectively study polar volatiles, the samples must be maintained cold until they are analyzed. This will require either the ability to extract the volatiles on the Moon or the ability to transport the samples in a frozen condition to Earth.

Based on these considerations, specific to the lunar polar outpost baselined in the current Architecture, the recommendations of the previous studies are modified:

- All geological samples must be completely documented and tracked.

- Contamination of geological samples must be limited according to potential uses, and all potential contaminating events and environments must be documented.

- Storage must ensure that the samples receive minimal contamination and alteration. This implies storage remote from the habitat, other human operations, landing areas, and flight paths.

- Adequate safeguards must be used to prevent human health hazards and equipment damage from lunar dust.

- The following practices for handling and curation of rocks, rake samples, and soil samples are recommended:

    - Upon collection a geological sample should be split into subsamples for preliminary examination at the lunar outpost, detailed analyses on Earth, and minimally contaminated storage on the Moon.
    - Storage at the lunar outpost should ensure that samples receive minimal contamination, and be readily retrievable.
    - Preliminary examination of the designated sub-samples may take place in a geosciences laboratory space in the outpost.
    - Samples expected to contain volatiles should be maintained at subfreezing temperatures until they are either analyzed at the outpost or transported at subfreezing temperatures to Earth.
    - The decision to transport a sample to Earth should be based in large part on preliminary examination.
    - Samples collected but not selected for transport to Earth should be curated on the Moon, under conditions of minimal contamination or alteration.

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