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HANDBOOK OF LUNAR SOILS

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INTRODUCTION

The Moon is covered with a complex layer of unconsolidated debris (regolith). Our understanding of the character of this debris and the processes affecting it are dependent on studies of the samples of soil returned by the Apollo and Luna missions. The purpose of this handbook is to serve as a data base for the material properties of lunar soils. It is a resource for present and future sample investigators in selecting soil samples for detailed study, for investigators conducting syntheses studies, and for scientist and engineers designing manufacturing processes utilizing lunar soil. The scope of this handbook is restricted to all non-core samples of soil returned by the Apollo missions.

Tools Used for Collecting Lunar Soil

Contingency Sampler: For Apollo 11-15, this was a special grab-sample Teflon bag mounted on the end of a collapsible handle. This sample was collected as soon as possible after the first astronaut left the LM as a random surface scoop. This would provide at least one sample of the site if the crew were forced to leave due to an emergency. The first documented sample fulfilled the contingency sample requirement on Apollo 16 and 17, eliminating the need for a contingency sampler.

Scoops: All of the sample scoops carried on the Apollo missions could be attached to an extension handle with a quick-disconnect mount. The "large" scoop (7x12x12 cm) constructed of anodized aluminum was used during Apollo 11, 12, and 14. The "small" scoop (about 6 cm wide and 8 cm deep) was used during Apollo 12. It had a flat bottom that was flanged on both sides and was partially covered on top; it was constructed Of anodized aluminum with a steel-alloy inset on the front edge.

An adjustable scoop, with a flat bottom and flanged on the sides with a partial cover on top, was used on ApollO 15, 16, and 17. The 14 cm long, 12 cm wide scoop was adjustable from 0° (horizontal) to 55° for scooping and to 90° for trenching. The pan and adjusting mechanism were made of stainless steel and the handle of aluminum. It replaced both the scoop and trenching shovel of previous missions.

Trenching tool: An anodized aluminum, folding, trenching tool was used during Apollo 14. It was a simple spade-like tool with the spade measuring 15 cm wide and 20 cm long.

Lunar surface rake: The rake was a basket-like scoop about 30x30x4 cm which consisted of a partially solid aluminum frame holding tines with 1 cm spacings. To collect a sample, the rake was drug through the surface regolith several times, sifting out the fine grained material to leave a collection of small rock samples. Procedures required that a soil sample be collected with each "rake" sample. This was accomplished by tilting the rake to use the solid frame for collecting soil samples. The rake was used on

Apollo 15, 16, and 17.

Special environmental sample container (SESC): This was a thin-walled stainless steel container (6 cm diameter and 12 cm long) with a knife-edge machined into the top rim. The lid had a press which forced the knife-edge into an indium-silver alloy gasket. The sealed sample was returned in a vacuum to Earth. SESC's were carried on Apollo 15, 16, and 17.

Lunar roving vehicle (LRV) sample container: The LRV samples consisted Of a ring holding 12 numbered Teflon bags which could be attached to a tool handle. The tool allowed the crew to collect surface soil samples without dismounting from the LRV. After the sample was removed from the stack, it was sealed by closing, crimping and twisting the aluminum rim around the mouth of the bag. This means of sampling was used only during Apollo 17.

Documented sample bags: Each documented sample bag was a pre-numbered Teflon bag with dimensions 19x20 cm. The bags were stored in a dispenser in quantities of 20. The bags had two Teflon tabs; one was attached to the dispenser and the other used to pull the bag open. After sample collection, a thin aluminum rim was crimped to seal the bag. These bags were used during Apollo 15, 16, and 17.

Round documented sample bags: Each teflon bag ("dixie cup") was 8 cm in diameter and 12 cm deep. Twelve bags were carried as a cluster. The bags were sealed in the same manner as the documented sample bags. They were-used during Apollo 12-17.

Apollo lunar sample return container (ALSRC): The ALSRC is made of aluminum with exterior dimensions of 47.5x28.75x20 cm. A strap-lash system provides the force necessary to provide a vacuum seal, but not all ALSRC's retained vacuum integrity. Padding for sample protection was provided by a York-mesh liner. These containers were used on all Apollo missions, but not all samples were returned to the Earth in them.

Sample Collection Procedures

Apollo 11: No special procedures were developed for soil sampling during Apollo 11. The contingency sampler was designed to scoop up rocks and soil without leaving the safety of the LM footpad. During Apollo 11 the commander stepped onto the surface and collected a full bag, scooping several times. A large bulk sample was collected at the end of the sampling period by scooping soil into the ALSRC to fill the void space left between rock samples.

Apollo 12: The contingency sample was collected in the same manner as Apollo 11. Selected soil and rock samples were collected over an area 300 m NW of the LM. As in Mission 11, the void space between rocks was filled with soil in the sample collection bag. Apollo 12 was the first mission to use documented sample bags. After noting the location and documenting some of them with photographs, one astronaut held the bag while the other scooped soil into it. The bag was sealed then dropped into the sample collection bag. All documented samples were returned in the D-ALSRC. Two small vacuum containers (gas analysis sample container and lunar environment sample container) were filled with soil in the same manner as the documented bags.

Apollo 14: The contingency sample was collected as during the previous missions. Whenever possible, other sampling locations were documented by photography taken cross-sun, down-sun, before and after sampling, and in the panoramas. In several cases the locations are based on transcripts, astronaut identification, and reference to the sample bag number. Samples were collected by scooping, with the astronaut holding the bag while the other filled it.

Apollo 15: Samples collected with the adjustable scoop were "skimmed" (upper 1 cm), "scooped" (upper 1-5 cm) or selected from layers exposed in trench walls. Soil samples collected to accompany rake samples were collected with the solid wall of the rake or with a scoop. Whenever possible, the sample location was photographed before and after sampling and cross- and down-sun. A stereopair was generally taken before collecting the sample. Additional photographs were taken as necessary to document the location. One astronaut held a documented sample bag, identifying the number on it while the other scooped soil into it.

Apollo 16: Collection and documentation of soil samples in documented sample bags was the same as for Apollo 15.

Apollo 17: Collection and documentation of soil samples in documented sample bags and an SESC was the same as for Apollo 15 and 16. The LRV samples were collected on traverses between stations without the LRV. The area to be sampled was located and photographed before reaching it, then sampled. The passenger collected the sample; it was passed to the driver who pulled the full bag out of the stack, identified the number, and then sealed it.

Initial Sample Processing

Apollo 11: The contingency sample was returned with the crew to the Lunar Receiving Laboratory (LRL) and then transferred to the vacuum chamber in the sample lab. The bulk soil sample was initially processed a vacuum chamber, but was later moved to N_2-filled glove cabinets in the Bio-prep laboratory. Due to the quarantine requirements, negative pressure was maintained in the cabinets and the exterior of the sample containers were sterilized with steam or peracetic acid. The quarantine conditions were maintained at considerable cost to the sample's integrity. The work area was very crowded with equipment, increasing chances for contamination of the samples. Soil samples were used for the monopole experiments, soil mechanics tests, sieving, etc: Aliquots were removed to the physical chemical test lab (PCTL) for chemical and petrographic analysis. Coarser sieve fractions were described and photographed in the Bio-prep laboratory.

Apollo 12: Rock and soil samples were processed in a vacuum (about 10^{-6} torr). The documented and contingency samples and cores were processed in N_2-filled glove cabinets. Fifty gms of core material and 450 gms of rock and soil were designated for biological testing. Most of the bags were opened, given a preliminary description (color, texture, etc.) and aliquots were removed for closer examination. The soils were then placed in stainless steel slip-top cans for storage. Several of the documented samples were sieved at 1 cm and 1 mm intervals. The coarser fractions (>1 mm) were described superficially during the preliminary examination. Aliquots were transferred to PCTL for chemical and petrographic analyses.

Apollo 14: The Apollo 14 samples were processed in stainless steel, N2-filled glove cabinets that were held under negative pressure as required by quarantine procedures. The exhaust N_2 was monitored for contamination by H_2, 0_2, CO, CO_2, CH_4, and H_20 by gas chromatography. Soils were described superficially in the lab by looking into open documented sample bags. Each sample was then sieved into >1 cm, 4-10 mm, 2-4 mm, 1-2 mm, and >1 mm fractions. Each fraction was weighed, assigned a sample number, then stored in stainless steel bolt top cans. Aliquots of several soil samples were used by the Preliminary Examination Team for grain size, chemical; and petrographic analyses. The <1 mm aliquots were wet-sieved (with Freon) at 500 um, 250 urn, 125 um, 62.5 um and 31 um intervals using 3-inch diameter stainless steel sieves. Thin sections were made of the 250-500 um and 125-250 um size fractions.

Apollo 15, 16, and 17: Commencing with Apollo 15, no quarantine was required and the samples were processed in stainless steel glove boxes filled with dry N_2 under positive pressure. The exhaust N_2 was analyzed for contaminants (H_20, 0_2, Ar, H_2 CH_4 CO_2, and CO) by gas chromatography.

The documented bags were opened and observations and photographs were made of the sample. Any rocks >1 cm were removed. One-quarter to one-third of the sample was scooped from the bag, placed in a preweighed container, weighed, and stored as an unsieved reserve sample. In special cases, larger reserves were obtained or the entire sample remained unsieved. The remaining sample was sieved to produce the size fractions <1 mm, 1-2 mm, 2-4 mm, and 4-10 mm. Each fraction was weighed and numbered with its own five-digit sample number. Each coherent piece >10 mm was processed as a rock. The sieve fractions were superficially described.

FORMAT

The remainder of this handbook is divided into six sections - one for each of the Apollo missions that returned samples from the Moon. The format of each section is the same. First are given sketch maps showing the locations that the soils were collected. Data sheets and bibliographies then follow for each soil in increasing numerical order of sample number. The bibliographic lists were derived from the compilation at the Lunar and Planetary Institute.

It is the intent of the data sheets to give some basic data about lunar soils. Because of space limitations and because the handbook would become ponderous, the data sheets are not comprehensive in terms of either including all the various types of data or including every analysist`s value for a given parameter. Data compiled on the data sheets include sampling location, masses of generic subsamples, maturity parameters (I_s/FeO, grain-size parameters, and agglutinates), chemistry (major and trace elements), and petrography. For references to other types of data, the bibliography can be consulted. Except as noted below, a citation is given for the data compiled in the data sheets.

The values for agglutinates, grain-size parameters, and the FMR maturity index I_s/Fe0 were obtained from just a few references and thus for clarity the references were not cited on the data sheets. These data were taken from papers by David S. McKay, Elbert A. King, Richard V. Morris, and their co-workers; the specific papers are given in the bibliographies.

Commencing with soils returned from the Apollo 15 mission, almost all soils were sieved into >10, 4-10, 2-4, 1-2 (the "coarse" fines) and 1 mm (the "fine" fines) sieve fractions at the Johnson Space Center. The sieving information is given on the data sheets, and, unless otherwise noted, all physical and chemical properties pertain to the 1 mm sieve fraction.

An examination of this handbook will reveal that there are a significant number of soils for which there is a great deal of information and a significant number of soils for which very little is known. The data sheets are formatted so that individual users can incorporate information as it becomes available. Individual analysists are encouraged to send data appropriate for this handbook to the Planetary Materials Curator (KT/NASA Johnson Space Center, Houston, TX 77058) for inclusion in subsequent editions.