# APOLLO LUNAR SCIENCE PROGRAM,

# REPORT OF PLANNING TEAMS.



NASA TMX 57274

PART II: APPENDIX



Lunar Science Branch
Manned Space Science Program Office
Office of Space Science and Applications
NASA Headquarters
Washington, D. C.

December 1964

5

Section II

# PROJECT APOLLO
# GEOLOGICAL FIELD INVESTIGATIONS

N66-18667

by

Edward N. Goddard, J. Hoover Mackin,
E. M. Shoemaker and Aaron C. Waters

November 1964

## Contents

# Project Apollo
# Geological Field Investigations

by

Edward N. Goddard, J. Hoover Mackin,
E. M. Shoemaker and Aaron C. Waters

## Objectives of Apollo Geological Field Investigations

Manned lunar landing in Project Apollo will present the first opportunity to carry out reasonably comprehensive scientific studies of selected areas on the Moon's surface. The importance of this opportunity lies in the possibility of applying on the Moon many investigative techniques that have been developed to explore the physical nature, chemical constitution, geologic history, and origin of the Earth. Without application of such techniques the nature of the Moon's surface, its geologic ancestry, and its ultimate origin can never be adequately known or understood.

The unmanned lunar flight program will provide high resolution imagery and a limited amount of physical and chemical information about some areas on the Moon--data specifically needed to guide the selection of safe landing sites. Project Apollo, on the other hand, provides the additional opportunity to examine the Moon's surface directly, and to obtain numerous samples to be returned to earth for detailed laboratory investigation. It also affords opportunity for a variety of in situ measurements of physical properties and structure. The verbal description of the astronauts while on the Moon's surface--when correlated with this additional data--is capable of providing a thorough understanding of the composition and structure of the Moon around each landing site.

Direct knowledge from in situ observation and sample collecting is required to identify the rocks and minerals that compose the Moon, and to understand the nature of the lunar surface. Once correctly identified, rock layers can be recognized and mapped over most of the Moon's area by earth-based telescopes, and with the aid of remote sensors carried on lunar orbiting spacecraft. The combined data on the chemistry and geology of the Moon, acquired by direct examination and by remote sensors, is fundamental to interpretation of the evolution and long geologic history of the Moon, and for any critical examination of questions of its origin and relation to other objects in the solar system. It also provides the basic data for later scientific missions of broader scope in astronomy, physics, and other sciences.

Stated in broadest terms, the objectives of the geological field investigations in the Apollo scientific program are to obtain complete and accurate knowledge of the nature and structure of the lunar surface, and so far as possible, to determine the regional stratigraphic and petrologic character of the Moon at each landing site. Such detailed knowledge of the field relations at each Apollo landing site is not only of basic scientific and engineering value by itself, but is essential for the complete interpretation of most chemical, physical, mineralogical, petrographic, and biological analyses of the samples collected, and is fundamental to the interpretation of most physical measurements of the lunar surface that can be made at these sites. The field geological investigation of the lunar landing sites is, therefore, viewed as preliminary and necessary to the planning and execution of most other studies that will be carried out by lunar landing missions.

## Fine structure of the lunar surface

One of the outstanding scientific problems to be attacked is a geological problem that is likely to be solved in early Apollo landings: What is the nature of the rocks and minerals that form the Moon's crust, and what is the detailed "fine" structure of the lunar surface? Physical studies of the Moon's surface, by means of telescopic photometry, radiometry and reflected microwave signals, and observations of the lunar crater distribution may be combined with empirical knowledge of the phenomenology of cratering, cratering theory, current data on the flux of meteoroids in the vicinity of the earth, and estimates of the effects of other processes acting on the lunar surface, such as sputtering produced by solar bombardment, to derive models of the local fine structure. From such studies we already know that the lunar crust is demonstrably heterogeneous in composition. The fine structure of the surface also may be expected to be heterogeneous. In particular, details of the fine structure probably depend on the age of the surface, or more specifically on the period of time the surface has been affected by cratering and other processes.

On the basis of the available data, it appears highly probable that most parts of the Moon's surface are covered with a layer of finely-broken rock fragments, the upper surface of which is pitted with craters. The thickness of the layer, the size distribution of the rock fragments, and the size and spacing of superimposed craters probably all vary abruptly from place to place. Employing the data available from the photographs acquired from Ranger VII, in addition to the information obtained at the telescope, a reasonable model of the fine structure of a typical local area on a mare surface, for example, can be described in the following way:

1. A layer of shattered and pulverized rock covers more than 95 per cent of the mare. It is of variable thickness and rests with irregular contact on the underlying solid substance of the mare.

2. The fragments in this layer or blanket of shattered rock have been derived by ejection from craters, most of them nearby, but some lying great distances away. About 50 per cent or more of the fragments have come from within one kilometer of the site, but there is a finite probability, decreasing with the distance to the source, of finding a rock fragment derived from any place on the Moon. Except along the margins of a mare, therefore, the pieces of debris will be composed predominantly of mare material.

3. Fragments occurring at the base of the debris layer will, on the average, have been transported on ballistic trajectories a smaller number of times than pieces near the middle or top of the layer. Progressing upward from the base, the layer has been stirred or reconstituted an

increasing number of times by smaller and smaller and more and more numerous cratering events. The uppermost millimeter of the debris layer is probably completely reorganized once every 10 to 100 years by the formation and filling of minute craters.

4. The average grain size tends to decrease from base to top of the debris layer because fragments in the upper part, on the average, have been shocked and broken a greater number of times and have been ejected, on the average, from smaller craters. Near the base, fragments as large as several centimeters in diameter will be common, whereas the material of the uppermost few millimeters more likely will be finely pulverized. Throughout the debris layer the bulk of the rock fragments will probably average less than a millimeter in grain size, but heaps of coarse blocky rock from the larger craters may be expected at many places.

5. Beneath this blanket of shattered rock, the mare substance will in many places show evidence of having been broken to greater depths by shocks of varying strength produced during development of the larger craters.

6. The contact between the underlying solid rock and the pulverized surface blanket has considerable local relief, consists chiefly of the intersecting segments of the original floors of numerous older and larger craters that range from a meter to a few tens of meters across. Most of these are now buried beneath younger impact debris.

7. The upper surface of the debris layer is pockmarked by craters ranging from less than a millimeter to several tens of meters across (or larger depending on the local area). Craters larger than one meter in diameter occupy about 30 per cent of the surface; smaller craters occupy the rest of the surface and are also superimposed on the large craters. Minute craters, with dimensions of the order of a millimeter or less, probably cover nearly all of the surface and are superimposed on nearly all other features.

8. The debris layer typically varies in thickness from a few tens of meters to less than a millimeter. It is thickest where it covers the floors of some of the oldest and largest craters present, and is thin or even absent along the walls of very young craters that cut through the debris layer into the underlying mare material.

A similar layer of pulverized rock probably covers nearly all parts of the Moon's surface. It may be expected to vary in average thickness as a direct function of the age of the rocks or terrain on which it is formed. Terrain older than the maria will have a thicker blanket of debris than the typical mare surface, and the blanket will be thinner, on the average, on younger terrain. The average crater size on the surface of the debris layer will be larger on older terrain and smaller on the younger terrain.

Examination of such a debris layer, and verification or revision of this model, presents a challenging problem for the astronauts, but one that can be solved by straight-forward field procedures. Direct visual examination of the surface will answer most of the critical questions. The scale of needed observations ranges from features observable through a hand held lens to the largest features the astronaut can observe in the surrounding field of view. Features to be described include not only the kinds and sizes of rock fragments in the debris layer, but also a statement and analysis of the spacing, size, and nature of the craters and of all other small and large elements of the local topography.

If the astronauts have been fully trained in the techniques of accurate and thorough observation and reporting, such visual descriptions of the landing site, recorded verbally on tape or by radio communication, will be invaluable. Abundant high resolution photography by film and television or facsimile cameras provides another form of record from which much of the on site description and analysis can be amplified and verified after the lunar missions.

By digging, probing, and manipulating the surface materials with a suitable penetrating device the astronaut can probably gain an insight into the vertical distribution of rock fragments. Information obtained by this means would necessarily be limited to depths of a half meter at most, but might be supplemented by observation of the wall of a nearby crater. To determine total thickness and variations in thickness of the debris layer active seismic techniques would have to be employed. A properly designed field seismic system operated by the astronaut might give information not only on the thickness and physical properties of the debris layer, of considerable engineering importance for planning of future missions, but also clues to the nature and origin of the deeper structure of the Moon's crust.

One of the principal problems presented by a surface covered by a fragmental layer of the kind described will be to select appropriate samples for return to Earth. With a wide variety of rock fragments to choose from, the astronaut will be faced with the difficult task of deciding what specimens best represent the material at hand. He will need to estimate the relative abundance of different rock types in order to select representative samples, and, in addition, he will want to collect as many of the infrequently occurring rock types as possible, as these will provide information on the more distant parts of the Moon.

In certain respects the model described for the fine structure of a mare surface is similar to terrain on Earth which has been covered by deposits left by melting of a continental glacier. Like glacial drift, the debris layer on the Moon obscures the "bedrock" in most places, is heterogeneous in character and irregular in thickness and contains rock fragments of widely diverse individual histories. Thorough study of such a layer in a local area either on the Moon or on the Earth can provide a great amount of information about the geology and history of a broad segment of the planetary crust, provided that the origin of the fragmental layer is understood. Failure to understand the nature and origin of the lunar microstructure can lead to serious scientific misinterpretation and confusion. For this reason we regard the role of the astronaut as a trained field observer to be fundamental to most of the lunar scientific investigations to be performed in Project Apollo, and of paramount importance to the success of later missions.

## Methods of investigation

### General methods

The principal task of the astronauts while on the Moon's surface will be to study the morphology of the surface and the character of the material exposed. This study will be made as the astronaut walks about carrying certain instruments. It will depend heavily on his visual observations. Understanding of the geology of the surface rests on the discrimination of different kinds of materials and determination of the three dimensional relationship of these materials one to another and to the surface features. Both sampling and in situ measurement of physical properties and engineering properties of the lunar surface materials should be based on the observed distribution of different geological materials.

We believe it extremely important that the astronaut have as much free or unprogrammed time as possible for observation of the surface. It is only by such unprogrammed observation that important unanticipated facts will be discovered. The time on the surface will be very short at best and there is a general tendency to require too many preplanned tasks for the astronaut to carry out. In order to relieve the astronaut of as many chores as possible to allow him the essential time for observation, all data recording procedures should be automatic or semi-automatic and not require,in most cases, conscious decision or movements on the astronaut's part. Our plan for the field investigations, therefore, includes the use of equipment which will take pictures, measurements of orientation, and physical properties measurements with a minimum of manipulation or attention from the astronaut. He should not be required to plot or find his position on a map, unless he so desires in order to visualize the relationships of the materials he is observing. Rather his position should be tracked automatically from the LEM and the data transmitted to Earth and plotted out by computer driven XY plotters in real time. We believe the availability of real time communication between the astronauts and the investigator team on the ground can aid in removing the burden of data assimilation and plotting and can provide considerable aid to the astronaut in interpretation of his observations.

The following elements we regard as essential parts of a system designed to relieve the astronaut of as many chores or burdens as possible and to maximize the opportunity for scientific discovery.

1. Automatic data recording: All geologic data acquired by the astronaut on the lunar surface or from the LEM should be automatically recorded. Verbal observations and descriptions should be recorded on tape or transmitted in real time by RF link or both. Instruments used to obtain positional information or to measure attitudes of observed forms or structures on the Moon's surface should have an automatic readout. Imagery obtained both by film cameras and video systems should be taken at regular intervals as well as on command by the astronaut. Video imagery coverage should be continuous. Instruments carried with the astronauts measuring bearing strength of the surface, radioactivity, and magnetic fields should have automatic data readout. Sample bags and containers used by the astronauts should be prenumbered and should be opened and closed by mechanisms that operate semiautomatically. The astronaut can note positions and numbers of samples verbally as a part of his continuous record of description. Wherever possible, he should not use verbal description where a picture or an automatic measurement can provide the information more efficiently.

2. Real time transmission of data: Video, facsimile, audio and other scientific data should be transmitted in real time to the earth where reduction and synthesis can be performed while the astronauts are on the Moon's surface. All making of maps and the plotting of traverses, the position of samples, and the location of measurements and observations on maps can be done quickly and effectively on the earth with the aid of computers. These data can then be studied by the investigator team in real time and a synopsis of positional information, and possible interpretations should be available to the astronaut at any time that he desires help.

3. Relay of maps and graphical information from Earth to Lunar Excursion Module: If possible it would be highly desirable to be able to transmit maps and graphs compiled by the investigator team via facsimile or video systems to the astronauts in the LEM. This information can then be used by the astronauts in planning traverses and determining the best strategy for observation and measurements. They should be able to revise their strategy as the work proceeds, incorporating the results of previous traverses into the planning for the traverses yet to be made.

## Activities of astronauts

It is expected that the two astronauts who we send to the Moon's surface in the LEM will work as a team. One man will stay in the Lunar Excursion Module while his companion reconnoiters the surface. Before each traverse the astronauts will jointly plan the approximate path to be followed, on the basis of maps and information they have brought with them, prepared from pre-flight information about the landing site, and on the basis of what they can observe directly from the windows of the LEM. This plan may be determined entirely after landing on the lunar surface, with consultation with the investigator team on the ground if desired, or it may be a nominal plan which has already been worked out from pre-flight information, if the LEM lands on a site for which a great deal of data has already been obtained.

The man who remains in the LEM will follow the man on the surface as continuously as time permits both visually and by monitoring his verbal descriptions. If assistance is needed by the astronaut on the surface the astronaut in the LEM may help direct him to points of observation which are obscured by the topography, and help guide him back toward the LEM.

The astronaut on the surface should follow the traverse planned before egress from the LEM in most cases but should be free to change his mind if new facts and situations arise and, with concurrence of his companion in the LEM, should be able to plan an entirely new or revised traverse once he is on the ground, should unexpected observations indicate this is required. The astronaut on the surface should concentrate his energy and time on visual observations and sample collecting and maintain a running verbal commentary on what he sees and does. His description should be focused on those features which can best be studied while on the Moon's surface, and he should consciously avoid spending time describing things which will be readily portrayed by photography or which can be determined later by study of samples returned to the Earth. It will be of great importance for him to maintain alertness in both observation and sample collecting; he should attempt to acquire as many small samples of material that attracts his attention as possible. It is better to collect too many samples, some of which will have to be left on the Moon, than to return to Earth with less than the maximum allowed weight of sample material. It will be important for the astronaut to be able to stoop or otherwise pick up pieces from the surface frequently along the course of the traverse in order to examine them at close range.

## Function of the investigator team

We recommend that the investigator team serve not only to development instruments and methods of data reduction prior to the mission but also serve as a scientific board actively synthesizing the transmitted data while the astronauts are on the Moon. This board should be available for consultation with the astronauts on scientific questions and for analysis and interpretation of data for use in evaluating mission safety by the flight operations personnel. In addition, the investigator team will be responsible, together with the astronauts, for post-flight analysis of the data obtained in the field geology investigations.

We also recommend that all of the astronauts in Project Apollo be considered members of the investigator team to the extent that they are able to participate. In particular, we recommend that some of the astronauts be assigned major responsibilities for the scientific aspects of the mission and spend a significant part of their time working with the investigator team in the planning and development of the field geological investigations.

Premission activities.--The premission activities of the investigator team will be concerned primarily with updating the information on the detailed geology of the Moon's surface, primarily with the aid of data obtained from the unmanned lunar exploration program, and with the development of the detailed methods and procedures to be used during the missions. As data from each successful flight of Ranger, Surveyor, and Orbiter come in, we should be continuing to improve our model of the lunar surface. Great improvement should be possible after the first successful Apollo flight, and advantage should be taken of the knowledge gained in the design or redesign of the methods and procedures used in following Apollo flights.

The investigator team will make a detailed study of the geology of each of the potential Apollo landing sites for which information is available from successful Surveyor and Lunar Orbiter missions. This study will be the basis of planning tentative traverses by the astronauts and for familiarizing the astronauts in detail with the features to be expected at the landing site. Both topographic and geologic maps of the landing site should be a part of the information that accompanies the astronauts to the Moon in the Lunar Excursion Module.

Several instruments yet to be fully developed are planned for use in the field geological work by the astronauts on the Moon's surface. These include a geologist's walking staff, or alternatively a walker, which will carry a wide variety of small instruments providing physical measurements and cameras that will provide imagery for photometric and photogrammetric reduction (See section on instruments). Not only will the development of the lunar instruments need to be completed but the ground recording instruments and the data reduction methods must also be developed. Principal among these will be the photogrammetric methods, to be used with the imagery obtained from video, facsimile, and film cameras, to prepare a detailed topographic map or improve the available topographic maps that provide the base for compilation of the geology. Of special importance will be the development of rapid data reduction techniques to be used in real time during the astronaut traverses. These techniques include preparation of rough maps of landing sites from data transmitted from a facsimile system mounted on the LEM, for use in case of landing on unanticipated sites, and for plotting the traverses and data points on existing maps or the rough maps so prepared.

The geological field investigations team expects to participate in the development of integrated scientific mission plans and in tests for the check out and use of the instruments under simulated mission conditions. We strongly recommend that many simulated missions be carried out at terrestrial field sites to provide practice in using prototype and flight configured equipment and to familiarize the astronauts thoroughly with all the procedures. Another important premission function of the investigator team will be to participate in the scientific training of the astronauts in the techniques of field geology and in briefing the astronauts on known and inferred facts about the geology of selected potential landing sites.

Activities during mission.--During the lunar missions when the astronauts are on the Moon's surface, the investigator team plans to follow the motions and observations of the astronauts with the aid of the transmitted video, audio and automatic tracking system data. This will require that a data receiving facility be established, linked by appropriate communications to the mission control center and to available computing facilities. At the data receiving site the investigator team will prepare rough maps of the geology and revisions of already prepared maps from the incoming data. On request, they will be prepared to advise the astronauts on the Moon of likely interpretation of observations, possible geologic relations, critical areas or features for examination, position of astronaut relative to such features of interest, possible importance of samples picked up, loss of data in transmission, and possible safety hazards to be encountered along the traverse. This data should be available either by direct communication with the astronaut or to members of the mission control staff. A preliminary synthesis of the observed geology should be available at any time the astronauts are ready to leave the Moon. This will aid in determining the degree to which the scientific mission has been successfully completed, in making potential decisions as to what samples to bring back, and, if unusual circumstances arise, whether additional scientific information to be gained by extending the stay time on the lunar surface is commensurate with the risk involved.

Post-mission activities.--In collaboration with the astronauts and the other investigator teams, the geological field investigations team will prepare an exhaustive analysis of the video, audio and other field geological data acquired from each mission. Part of this data will be extracted from study of the returned samples. Information in the final report will be presented in the form of topographic and geologic maps, a detailed description of the geology, and interpretation of the geologic history of the landing site and the processes which have led to the present configuration of the Moon's surface.

## Instrumentation

Instrumentation required to acquire, transmit, and analyze the field geological information includes equipment to be carried by the astronaut on the Moon's surface, instruments that will be mounted on the Lunar Excursion Module, and equipment to be used in recording and analysis of the data on Earth

### Equipment carried by astronaut

1. Jacob's staff. The principal item of equipment to be used by the astronaut for the field geological work will be a specially designed Jacob's staff, or geologist's walking staff. The staff serves as an aid to walking, as a basic surveying instrument, as a probe and sampling device, and as a calibrated carrying device for a number of instruments. A number of instruments will be built into the staff. These include a slow scan vidicon camera (500 kc bandwidth), for semi-continuous photographic recording, and a film camera which will provide photographs to be used both for photogrammetric reduction and for close up recording of details of the Moon's surface. Both cameras will be calibrated so that photometric information can be extracted from the photographs. An automatically recording vertical meter will be built into the staff, along with a sun compass, so that its orientation will be known at all times. In addition, a number of other alternate special instruments will be designed for incorporation as modules into the staff. These include a calibrated penetrometer to be mounted in the base of the staff, and a continuously recording magnetometer and gamma ray detection system. A rough mockup of such a staff is illustrated in figure 1. A number of alternate designs will be tried in the field before a final configuration is decided upon for lunar use.

2. Audio system and recorder. An audio system with out reunication to the LEM and from the LEM to the Earth is required to record the commentary of the astronaut. The transmitter for this system could be designed for incorporation into the walking staff if necessary. For backup in case of loss of transmission, the astronaut should carry a miniaturized tape recorder which will be driven automatically off of the audio system. If completely satisfactory transmission of all audio data has been received, the tape records need not be returned to Earth.

3. Geologist's accessory field tools: In addition to the staff, which can serve partly as a probe and a scoop, the astronaut will need a light weight geologist's pick, a magnifying lens, and a marking tool for use in probing the surface, observing the fine details of the surface and samples collected and for collecting samples. The marking tool is for use in obtaining a permanent record of the field orientation of certain samples. These simple tools probably will not require special design. A number of picks, lenses, and marking tools can be tried out under simulated lunar constraints to select those that are most suitable.

4. Sample collecting equipment: Equipment needed to collect samples for geological purposes include: 1) prenumbered sample bags, 2) a sample carrier, 3) a scale to weigh the collected samples, and 4) a vacuum sealed box which will be used to store the bags during return to Earth and before opening of the bags under controlled conditions. The bags should be simple to operate and of known simple composition--probably a bag of plastic or metal foil construction will be sufficient. It is important that they be very easy to open and close. They are to be used primarily for the purpose of identification of the individual specimens rather than to protect them from contamination. In addition, a few small rigid boxes will be required for bulk samples of weakly bonded fragmental material. It is understood that other special sample containers will be required for other investigations.

Instruments mounted on the LEM

Three instruments are planned for mounting on the ascent stage of the LEM.

1. RF tracking system: This is a simple radio frequency tracking system, which will determine distance, azimuth, and angle of elevation to a transmitting antenna mounted on the Jacob's staff. It will provide real time information on the location of the astronaut on the lunar surface at all times.

2. Photogrammetric facsimile camera. A simple light-weight very low bandwidth facsimile camera should be mounted on the ascent stage of the LEM to provide panoramic photogrammetric coverage of the landing site. This system should go into automatic operation on command after landing, and the data transmitted in real time to the ground will provide sufficient photogrammetric control for

preparation of a rough topographic map. This system is considered a backup system, in that it will be needed only for accurate location of the spacecraft, if the LEM lands on a site which has already been adequately mapped from Orbiter photography.

3. Vidicon camera and time-sequence camera. A shuttered, slow-scan vidicon camera and a time-sequence camera should be mounted together on a gimble on the ascent stage of the LEM. These cameras will track the astronaut on the surface, with the tracking mechanism driven by information obtained from the RF tracking system. The video information will be transmitted in real time to the ground, and film from the time-sequence camera will be returned to Earth.

Ground recording and data reception and analysis equipment

Ground recording and analysis equipment required for the field geological investigations are as follows:

1. Video monitors and photo recorders.

2. Audio receiver and recorder.

3. XY plotter driven by data transmitted from RF tracking system.

4. A recorder for the facsimile camera system and a rapid photogrammetric plotting system which uses the facsimile pictures.

Details of the design of these instruments will be based on further development work.

## Samples and Sample Handling

### Selection of samples

In general it is not possible to collect samples which satisfy the requirements of all potential investigators. Many kinds of samples should be collected and it will be necessary to collect special samples for various specialized purposes. Three kinds of samples are required to meet the needs of the field geological investigations. We will not consider here special samples required by other investigator teams.

First of all bulk samples should be obtained of the surface material, which presumably is a weakly to strongly bonded porous aggregate of very fine particles. Such samples will be of great interest for determination of the abundance and physical state of different minerals and rock fragments, and their grain size and shape and for laboratory determination of the bulk physical properties. Special containers may be needed to preserve the texture of this material if it proves to be delicate More than one bulk sample of surface material is desired in order to study its variation from place to place.

A second kind of sample needed from each Apollo landing site consists of a suite of specimens selected to represent the dominant types of material present. The selection of these samples should be tied to estimates of the areal abundance of each sample type. These samples may be either fragmental debris, if variation in the debris layer can be detected, or individual specimens of solid rock. Such representative samples may be obtained either by collecting at specified intervals along a traverse or by selecting samples according to the distribution of observed geologic units.

The third type of sample needed is the "grab" sample. For the most part, grab samples should consist of small specimens (two to five grams) of different individual kinds of rock. Weight and space should be reserved for the astronaut to collect a large number of small grab samples which represent objects that have caught his attention or appeared to be of interest as he progressed along a traverse. All samples that appear to be of interest should be taken provided they are not too large. The selection of these samples will depend very much on the astronaut's judgment and his observational perspicacity. Taken together, the grab samples will probably provide information about the gross mineralogy, petrography and chemistry of the lunar surface. The total number of such samples which should be taken on each mission is of the order of 500 to 1,000. It is critically important that space and allowable weight be saved for these samples, for they, rather than the special purpose samples, which will be few in number, will probably provide the greatest scientific returns from Project Apollo.

It seems to us that coring for samples should receive low priority on the early Apollo missions unless such coring can be accomplished rapidly and simply using a push-type coring device. Drilling a hole would be a profligate use of the time available in the first lunar landings. There are certain kinds of information that can only be obtained by drilling, but so much is to be learned from what is exposed on the surface, and the information we gain from studying the surface exposures should be so important in selecting an appropriate spot to drill, that drilling should be delayed until late in the Apollo project. Core samples, when obtained, will need to be treated as special multipurpose types of samples. It will probably be necessary to displace the weight and space allowable for other samples in order to return to Earth any significant number of cores.

## Sample handling

No special handling will be required for most samples taken for field geological investigations other than biological quarantine. The samples can be packed in simple, soft, air-tight bags which in turn can be stacked together in a container that can be sealed to hold a very hard vacuum. On Earth, the container and the bags should be opened in a controlled atmosphere of nitrogen and should be readily available for study by members of the investigator team and by other mineralogists and petrologists who have legitimate interests and special talents for study of the samples. The samples should be stored and distributed from facilities at the Manned Spacecraft Center. We do not anticipate any requirement for major analytical facilities, however, at the Manned Spacecraft Center. Analyses should be performed in existing qualified mineralogical and chemical laboratories.

## Astronaut training

Two aspects of the astronaut training are vital to the successful execution of the field geological investigations. First, each astronaut should be a qualified field observer and should have opportunity to gain the experience necessary to become a good geological observer. Secondly, each astronaut should maintain a basic familiarity with lunar research and specifically with current work on the detailed geology of the lunar surface. Primarily this means he should be intimately acquainted with the results obtained from the unmanned lunar exploration program but should also have a working knowledge of the principal results obtained from telescopic observations of the Moon.

There is no substitute for experience in field observations. The field observer sees only what his eye has been trained to see, and the accuracy and completeness of his observations improve in more or less linear proportion to the length of time he has spent in a field engaged in challenging observational work. All astronauts who participate in project Apollo should receive continued field training up to the time that they go into final preparations for a mission. They are currently receiving preliminary training in field geology which should lead to field exercises involving description and mapping of geology in the variety of local complex areas on the Earth. It will be important for them to have seen a wide variety of volcanic rocks, to be able to recognize the principal kinds of meteorites, and to be familiar in detail with the morphological and structural characteristics of volcanic, impact, and explosion craters.

The astronauts should have an up-to-the-minute familiarity with the current status of detailed knowledge about the lunar surface derived both from unmanned lunar spacecraft and from the telescope. Specifically they should know by heart the available facts about the potential landing sites chosen for each Apollo mission. During repeated practice in simulated lunar missions, working with the investigator teams, they should have built up a thorough understanding of how to proceed with the scientific mission and of the methods of deciding strategy in a given situation on the Moon. Ideally the preferred landing site will be known in advance and the astronaut will know its main features from having worked on a model of the site many times on the Earth. Whether this will be feasible or not will depend on the success of the unmanned lunar program in yielding definitive data for selection of sites.

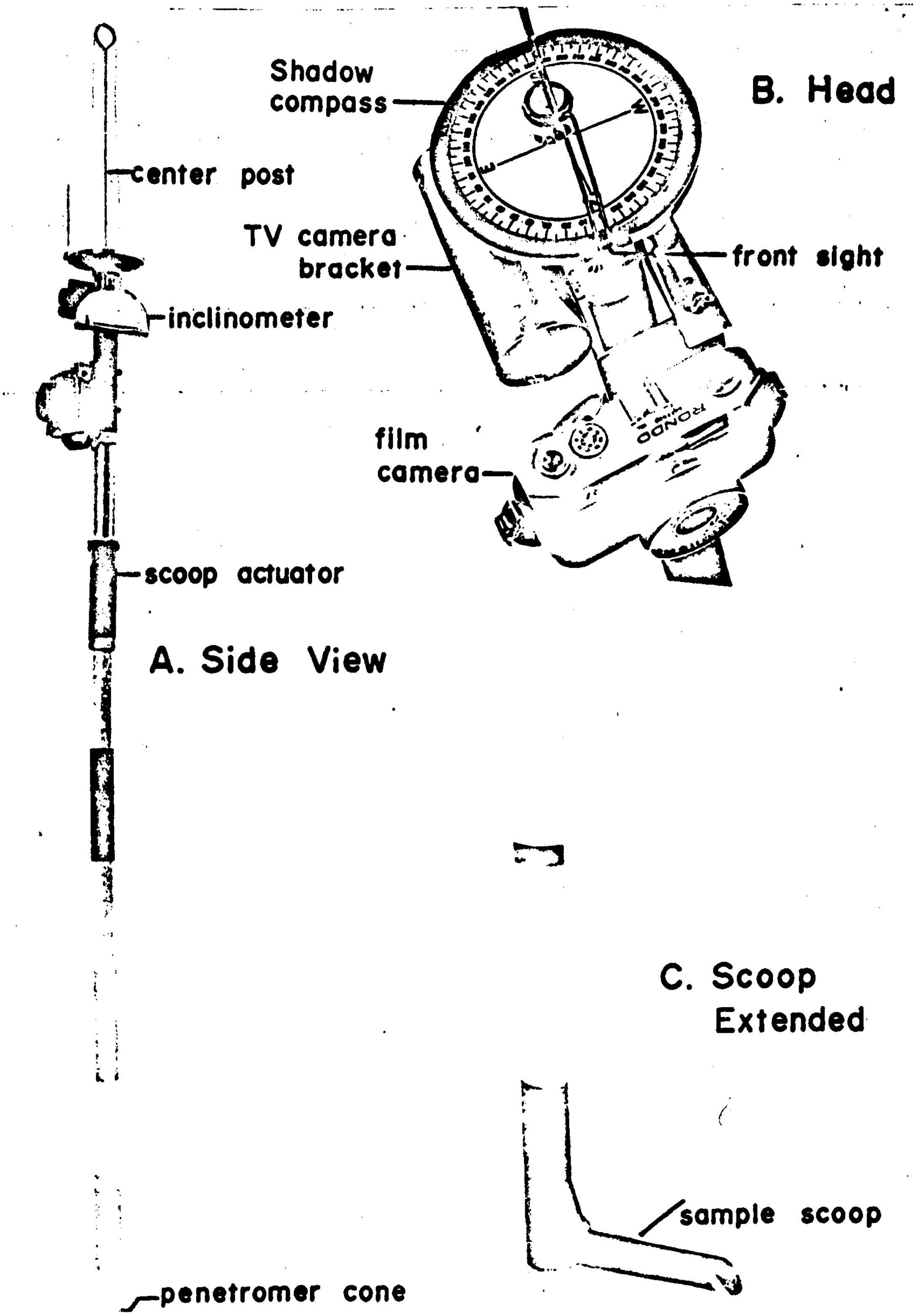



FIGURE 1. PROTOTYPE OF LUNAR SURVEYING STAFF USED BY USGS DURING MISSION SIMULATION FIELD TESTS.

## TABLE OF CONTENTS

# LIST OF FIGURES

# PART II: APPENDIX

## I. INTRODUCTION

This appendix contains reports and recommendations from planning teams for the science project of the approved early Apollo Landings on the Moon, on geological field investigations, mineralogy and petrography, geochemistry, passive seismology, active seismology, gravitational field measurements, magnetic field measurements, heat flow measurements, bioscience investigations, mission profiles, and the lunar atmospheric measurements.

These reports are either preliminary or first reports in the sense that they concern problems considered to date by the various teams with recommendations which represent the majority opinion of the more active planning team members but not necessarily unanimous opinions. In general there is good agreement among the planning teams and very little disagreement on subjects of mutual interest such as the collecting of lunar samples.

The summary given in Part I of this document is taken primarily from these reports with emphasis on basic objectives of the science program and highlighting of problem areas. The degree of completeness of summary from each report is of course a matter of judgment. The purpose is to outline as clearly as possible the scope of the experiments and measurements and how to implement and guarantee the success of carrying out this scientific project. Your comments regarding significant points that may have been left out in the Part I summary will be particularly appreciated.

33
12

Section III

# Preliminary Report on the Sampling and Examination of Lunar Surface Materials

N66-18668

Mineralogy and Petrography Group

Eugene N. Cameron, University of Wisconsin
Edward C. T. Chao, U. S. Geological Survey
Clifford Frondel, Harvard University (Chairman)
Harry H. Hess, Princeton University

June 22, 1964

## Contents

## Introduction

Some time before the year 1492, a group of workmen were standing in a shipyard looking at a half-constructed craft. One of them said "It won't float"; another said "If the sea monsters don't get it first, it will fall off the edge"; a third, more reflective than the others, said "What do they want to go for, anyway?".

The Apollo Project is primarily a glorious adventure, in which man will for the first time tread upon the surface of another celestial body. It will be a magnificent feat, and a milestone in the history of the human race. No other purpose or justification is necessary.

Important scientific knowledge will result from the landing. First among the scientific objectives of the Apollo mission will be the return of samples of the lunar surface materials. The study of such samples will tell us of the thermodynamic conditions under which they were formed; whether the moon is a differentiated body or not; and perhaps whether it was captured by the Earth or was formed from it in the distant past.

The samples also may give us a clearer picture of the Solar System and its origin; and a new understanding may be gained of some aspects of terrestrial geological history. Dating of the mineral samples combined with geological information obtained by photographic or direct examination could give us the lunar geological history in absolute terms. The probability exists that we will obtain information about the organic precursors of life, and possibly learn of the existence of life itself in the lunar environment. Practical information certainly will be obtained relevant to the evaluation of the moon as a station for the further exploration of space.

---

The function of our group in the Apollo Scientific Program is to examine in detail, in both descriptive and interpretive regards, the mineralogy and petrography of the lunar surface materials that are brought back. This information also provides the background necessary to the study of the samples for other purposes by other groups. Our recommendations and opinions on matters of sampling and of sample examination follow.

## Sample Size and Sampling

1. It is the opinion of our group that large individual samples of solid material are preferable. These samples should range in weight from a few pounds up to 5 or 10 pounds. Small pieces become more justifiable if of a widely diverse nature, or if of exceptional interest. In this event a mix of samples might be taken with the larger pieces representing bed rock or the more abundant or representative part of the local site. In any case a large dust sample should be taken.

While it is true that much valuable mineralogical and geochemical information could be obtained on quite small samples, weighing grams or tens of grams, the requirements of some geophysical and engineering measurements, the necessity of making all measurements in context on the same individual sample, and the necessity of preserving a large part of each individual sample untouched all act to increase individual sample size. The adequate representation of coarse grained or heterogeneous solid materials also increases sample size, as does the problem of dealing with minor and accessory mineral components.

2. The return of a full load of lunar surface material is considered to be the most important objective of the landing. Programs of accompanying active or passive instrumental experimentation should be limited by this primary objective. Inability to fulfill the sample packaging recommendations or inability to take adequate field notes during the sampling would be unfortunate, but should not discourage taking a full sample.

3. Sampling tools should be simple, multipurpose and low in weight. The use of a lunar x-ray diffractometer or x-ray fluorescent analyzer is not considered justifiable.

4. The question of the size of an adequate individual sample depends primarily on the nature of the material, the purposes in mind and the methods of study. The matter also is influenced by the number of kinds of material encountered at the sampling site, their relative abundance and their relative interest. The physical capability of the astronaut under the actual conditions encountered, and the sampling tools and the sample containers that are available are added factors. It is possible that the lunar materials may be so

coated by lunar varnish, analogous to desert varnish, and produced by radiation damage and chemical action, that the visual differences between materials may be obliterated. Most of these factors can be evaluated only on site, hence much depends on the training, resourcefulness and judgement of the astronauts.

## Section B

## Sample Containers

1. At least a representative part of the sample, and, if possible, all of it, should be packaged at the time the material is collected in sterile, vacuum-tight containers. The individual parts of the total sample should be packaged separately. Reasons for this include the elimination of contamination prior to terrestrial examination; the retention of materials that may prove volatile or otherwise unstable under non-lunar conditions; and the opportunity to evaluate interaction of the sample with terrestrial gases and water vapor.

2. Special packaging requirements may arise in other groups in the Scientific Program, such as in connection with bacteriological examination and magnetic shielding.

3. Proper labelling of the samples and correlation with written, voice and photographic field records is essential.

4. The samples when taken should be referred to a lunar coordinate system, including identification of top side.

5. Maintainence of the sample during return at temperatures not substantially higher than lunar may be important, especially with regard to temperature-sensitive matters such as thermoluminescence, degassing and organic materials.

6. Broad specifications for the sample containers include: adaptability as to size and shape of the sample; the non-contaminative nature of the construction material; strength; thermal stability; ease of use; lightness in weight.

## Section C

## Sample Accession

This section concerns the handling of the sample in the interval between recovery on Earth and the Preliminary Examination.

1. Immediately upon return to Earth, and during transit to MSC at Houston, the samples should be safeguarded, by a clearly defined authority, against contamination and against unauthorized examination and distribution.

2. Immediately upon return to Earth any part of the sample received in an open condition, that was not sealed in special containers as earlier recommended, must be put into dry, air tight containers to prevent further terrestrial contamination. The containers must be provided with identification. The entire history of any such material including the brief terrestrial span before packaging must be immediately ascertained and this information added to the main sample record.

3. Transport of the entire sample to MSC should be expeditious as possible, within limits imposed by absolute safety. This is required because the decay of certain cosmic-ray-induced radioisotopes begins immediately after the sample is below the terrestrial atmosphere, and measurements hence should be made as soon as possible.

4. All samples must be stored under simulated lunar conditions at MSC pending the preliminary examination.

## Section D

## Preliminary Examination

The preliminary examination is concerned with a gross evaluation and examination of the material, with regard to its mineralogical, biological and general physical nature, as a guide to following detailed studies.

1. The sample containers must be opened in a simulated lunar environment, and every precaution must be taken to obviate contamination, biological or otherwise. Provision must be made at this stage for the recovery of degassed material, gaseous decomposition products, finely dispersed solid material, etc., that may be present in the containers.

2. Every individual piece of the bulk sample must be provided with an identifying number (but not inscribed directly on it) and with a gross visual description. All pieces must be weighed and photographed. At this point also correlation must be made with the field notes. This will be the beginning of a permanent written record of each piece that will detail all subsequent handling and measurement and all storage or experimental environments. This cataloguing operation must be done before the samples are subdivided or measured in any way.

3. The actual scientific work done on the material at this stage would be:

(a) Bacteriological evaluation
(b) Evaluation of the possible prejuidicial interaction of the sample constituents with the terrestrial environment, such as hydration, deliquescence, disaggregation, adsorption of gas, etc.
(c) Measurement of any physical properties that are markedly time-dependent or that are markedly influenced by contamination or by handling.
(d) A gross preliminary description of the mineralogy, petrography and physical nature of the material as a guide to planning of following detailed geochemical, mineralogical and other studies.

During or following the preliminary evaluation part or all of the sample would be released to a controlled atmosphere or to the terrestrial atmosphere, but with protection against contamination, if this was found permissable or justifiable.

## Section E

## Detailed Mineralogical and Petrographical Examination

It must be recongnized that the entire Apollo Scientific Program will be critically scrutinized by scientists the world over. It is essential that the program be definitive in scope and faultless in execution. The development or improvement of methods and instrumentation appropriate to the task will be an important accompanying contribution to science. Provision should be made within the program for such work. The study of the lunar material also may bring about the recongnition of new terrestrial problems, or require the accompanying investigation of terrestrial materials. The relation of such work to the Apollo program requires consideration.

1. The nature of the mineralogical and petrographical studies can be finally decided only after the return and preliminary examination of actual samples of lunar material. In general, the mineralogical and petrographical studies would involve: (a) the identification and characterization, in chemical, physical and structural regards, of the individual mineral phases present; and (b) the description and interpretation, in hand with geochemists and others, of the phase assemblages observed.

2. The primary responsibility for sample preparation for all groups, especially when purely physical measurements are involved, should remain with the mineralogical and petrographical group.

3. The detailed mineralogical and petrographical studies would involve:

   (a) Quantitative chemical analysis by wet methods, x-ray fluorescence, optical spectrography, electronprobe, neutron activation or other techniques as appropriate. This work would be directed toward a knowledge of the bulk composition of the individual mineral phases present and of the solid aggregates observed. More specialized matters such as noble gas analysis, trace elements, isotope analysis, etc., would be primarily the concern of the geochemical group. All of the analytical work, wherever or however done, should be integrated with respect to individual samples and correlated with other types of measurements.

(b) X-ray and morphological crystallographical description of all individual mineral phases. Crystal structure determinations would be made where desirable, as in the description of new phases that may be encountered, or as needed in the interpretation of radiation damage or other effects.

(c) Description of the physical properties of the individual phases, including crystal optics, density, absorption and fluorescence over a wide spectrum of electromagnetic and particle radiations, and so forth. This work will be confined to what are essentially the conventional or common properties. More specialized matters such as surface chemistry and surface physics, radiation damage, fission track studies and thermoluminescence should be undertaken, presumably by specialists within the mineralogical or geochemical groups.

(d) A complete petrographic description of solid aggregates, including study of the accessory constituents, with interpretation of the assemblages observed.

(e) In the case of new phases or new phase assemblages that are encountered, and especially where the information would be of geochemical or geophysical interest, experimental studies would be undertaken of the phase transformations and phase equilibria as a function of temperature and pressure.

(f) It is evident that each individual sample will accumulate a history of observations and measurements, and will be subjected to various environmental conditions and opportunities for contamination. This information must be centrally recorded and passed on to each new investigator of the sample.

Section IV

# FIRST REPORT - GEOCHEMISTRY PLANNING TEAM

## A. INTRODUCTION

This is the first report of the Apollo geochemistry planning team. The group has so far held three meetings, the second in connection with the Manned Lunar Exploration Symposium at Houston in June. On that occasion the other science teams were also present, and we had an opportunity to review our recommendations and requirements along with those of other groups. An effective consensus seems to have resulted.

While this report goes beyond the brief statement issued after our April meeting, it will be obvious that it is not a finished product. The special skills and interests of committee members are reflected in the extended coverage of certain topics. Others may have been correspondingly short-changed. These reservations, however, do not apply to the main recommendations and conclusions of the report.

At the outset it seems useful to place geochemistry in the context of the scientific objectives of the Apollo program. The central questions about the moon have to do with its origin and history, and the light these can shed on the origin and history of the solar system. So far we have been limited by distance in attempting to solve these problems. Though a number of theories have strong partisans, the issues cannot apparently be resolved without a closer examination.

The moon may have originated at a distance from the earth and later been captured by it; it may have grown along with the earth as a "double planet" system; it may have been torn out of the earth after the latter's formation. In its later history the moon may have been and remained a cold rigid body, modified only by occasional meteoritic impact and minor local heating. Or it may have had an extensive history of melting, volcanism, and crustal evolution like the earth.

In gaining our present understanding of the earth and of meteorites, chemical and isotopic data have been of crucial importance. The same will surely be true in resolving these issues about the moon, and in the growth of our understanding thereafter.

With these objectives in view the geochemical portion of the Apollo science program will now be discussed. The next (and largest) section deals with sample return. We consider this to be the most important part of the program. The later sections will discuss active experiments, passive experiments, and in-flight experiments recommended for lunar orbital missions. Finally, there will be a summary of conclusions and recommendations.

## B. Sample Return

### I. General

Present plans for the early Apollo missions call for the return of up to eighty pounds of lunar surface matter (including containers) in a volume of 2.2 cubic feet. The return of this material will be a scientific event of the first magnitude. We expect the geochemical data obtained from these specimens to be far more significant than geochemical data obtained on the surface of the moon itself (with some special reservations discussed in the appropriate sections). It may be well to begin by listing some reasons for this:

1. In all areas of geochemistry laboratory equipment in the hands of experts surpasses (usually by a wide margin) the capability of field instrumentation, especially where the latter may be degraded by a hostile environment. This applies to precision, sensitivity, and reliability. Sampling is under much better control.
2. The proposed sample size is sufficient for a very large number and variety of experiments while allowing preservation of a major portion for the future.
3. Successive generations of experiments, each developing out of data and conclusions from earlier ones, are incomparably easier to carry out in the laboratory.

Time is not pressing, and both apparatus and conceptions can evolve as the program proceeds.

4. Results of one kind may suggest experiments of another. The entire scientific community will be drawn in. A single successful mission can lead to years of fruitful work, as well as to constructive modifications of the sampling program for later missions.

The sections that follow will deal with the stages of the sampling program in chronological order.

## B.2 Development of Sampling and Packaging Methods

Development of sampling and packaging methods is the first task of the program. This development must take into account our ignorance of surface conditions on the moon. The remarkable photographs taken by Ranger VII appear only to eliminate some of the more extreme possibilities. There is need to keep in mind two crucial and apparently contradictory notions. First, no effort should be spared to make sampling and packaging conform to the highest standards that now exist or can be developed. Second, any sample obtained under even halfway decent conditions will be extremely valuable. The astronauts should be given the tools and training to do the best possible job, in a limited time, but only considerations of personal safety should be allowed to interfere with the return of a substantial mass of sample.

The sample containers must conform to mission requirements. They should be made of a clean, sterile, and easily identified material, easily vacuum sealed. The materials should be non-magnetic if possible. The existence of a hard vacuum on the lunar surface makes gas containment a secondary objective for most surface materials. The hardest possible vacuum should be preserved in samples specially gathered for some experiments; in general a modest vacuum ($10^{-6}$ Torr) or inert atmosphere (probably $N_2$) will suffice. It is possible that for certain samples high pressure containers or refrigeration would be needed, and these should be available at least for use on later missions.

To ensure success and flexibility this development should proceed along more than one track.

Sampling tools present another problem. A variety of physical forms may be encountered, ranging from loose powder to dense rock. Standard geologist's tools may not be suitable, or their use may require special techniques. Contamination is a very serious problem for these unique samples. Electrostatic effects will be a nuisance, and perhaps a hazard. Here, too, is an area for immediate and diverse development.

Sampling strategy and procedures need to be studied theoretically and experimentally. While detailed advance instructions may be useless, a general sampling strategy must be developed. The development of such a scheme is in part a task for the present committee.

As a rough guide we suggest the following. A few large coherent samples should be taken of materials that appear to be representative. These will permit parallel and serial experiments on samples whose relative positions are known. Depth, orientation and position must be accurately recorded. At the same time a large number of small samples should be gathered to give some idea of the range of materials encountered, and especially in order to guide sampling on later missions. There should be room for a little of anything that "looks interesting". A method of labelling is needed which is positive and requires little or no attention from the astronaut. Some samples for special purposes will require special attention on the moon (e.g. high vacuum samples). In addition, if further materials of any sort can be put in odd corners of the spacecraft, it will be most useful.

Finally, special survey instruments are needed to assist in identifying suitable samples. Solar radiation and particles may well have darkened all rocks to a similar shade, and the conditions of illumination and observation will probably make the eye of less service than on earth. We need simple, light and rugged instruments to identify similarities and differences among rocks, and as an aid to identification. Such instruments might also benefit terrestrial field studies. Some possibilities for this will be described in section (C).

## B.3 Astronaut Training

The present astronaut training procedures seem to be meeting the goal of knowledge of the elements of geologic practice and theory, and experience in the problems of field work. We may hope that the impossible achievement of knowledge without bias has at least been kept in view. We venture to suggest that more contact with outside centers of planetary and meteoritic research, and with the clashing ideas held by leaders in these fields, would be useful. It would also be easy to arrange.

The new scientist-astronauts should have time and opportunity for continuing research, preferably at major research centers.

At the proper time the astronauts will obviously require detailed instruction in sampling and packaging procedures, and in the proposed sampling strategy.

## B.4 Sample Return and Unpackaging

This stage of the program was discussed extensively at Houston and again at our November meeting in Washington. It was agreed by our group and by senior members of a number of the teams, that a central storage and unpackaging facility of modest scale is required, and that this should be located at MSC in Houston. Facilities for cleaning, handling and manipulating samples in vacuum, and behind suitable biological barriers, should be available. The first group of reconnaissance measurements, to be discussed below, would be done there. This would also require some space and instrumental facilities.

It is clear that these facilities need not be monumental in scale. A new committee has now been formed to develop detailed requirements for this facility. This committee has members from the various teams including Gast and Arnold from this one. There will be continued interchange of ideas.

Procedures for unpackaging and handling should now be under development, as part of the packing development discussed above. Gas transfer is a special aspect of this problem.

Under this proposal MSC would assume the very serious responsibility for maintenance of records, and for preserving the samples. There will be heavy demands for "souvenirs" and a clear policy against this will be needed. The distribution of specimens should, of course, be carried out according to a policy agreed on in advance, and under the detailed guidance of a qualified and representative scientific committee (see below).

B.5 The Experimental Program

a. General

The aim of the whole effort discussed here is to maximize the advance in knowledge resulting from the Apollo program. For this purpose we must choose (or recruit) the best available people in each field, and this group of experimenters must prepare a coherent strategy. We cannot draw up final plans now, but the shape of the program seems clear. It is also possible to predict in some detail the types of measurement presently most likely to be useful. Later developments will be more likely to add to this list than remove items. We will discuss the stages, again in chronological order.

b. Choice of Experimenters

Once a type of experiment is given, it is not difficult for colleagues to agree on a short list of the leading practitioners of it. We give below a number of likely experiments, and we could easily enough put down such names for each item. The method of choice is subjective, but the lists drawn by different committees would not differ much. There is an immense difference, too, between these people and the average worker. A continuing effort must be made to draw them in, while at the same time encouraging others outside the circle to apply.

We must also ensure that experimenters selected for the program devote a proper share of effort to preparation for the samples, and to the samples themselves. To this end the committee urges that a program of "dry runs" be carried out by prospective experimenters, wherever this is possible. Such a program might consist of analyses of standard samples, such as those made available by the U. S. Geological Survey and the National Bureau of Standards. Interlaboratory comparisons of this sort have an important value for terrestrial geochemistry as well. They will undoubtedly lead to improvement of technique. Performance on these tests should be thought of as a more objective criterion for the final distribution of samples. We recommend that this program be a continuing responsibility of the appropriate teams and that funds be made available by NASA for its support.

c. Proposed Schedule of Experiments

After discussions with other teams, particularly the biologists, we now foresee three stages in the experimental program. The first stage will occupy the four week period of biological testing. This will include experiments in which time is of the essence, such as gamma ray measurements. It will also include such rough characterization of the material as can reasonably be carried out behind a stringent biological barrier. First stage experiments now identifiable are these:

1. The gamma ray spectrum of one or more massive samples must be measured. This contains important information concerning the cosmic ray and particle bombardment of the lunar surface, some of which will disappear with the decay of short-lived nuclides. The analysis of one or more samples should begin within hours of their arrival on earth. Measurements at appropriate intervals over a year or more can yield data on a large number of nuclides. These analyses can be carried out on samples in the original containers and are truly non-destructive. A rough measurement of the concentration of K and possibly also U and Th will be available quickly from this analysis; quite accurate values can be obtained after some time.

2. Sensitive structural experiments. Any structural parameters which would be altered by accumulation of a monolayer of inert gas must be studied before such a layer accumulates. In the present state of the art this takes less than a month, but perhaps future advances can remove this requirement. In any case such studies should be provided for in a

modest "hard vacuum" facility at Houston.

3. Gas experiments. The gas "in" the samples, defined as that resisting bakeout at a few hundred degrees Centigrade, can be studied at leisure. However, surface gas (if any) present "on" samples may have to be looked at quickly.

At the same time along with tests for biological hazards, small samples of loose material will be available for scientific examination. The main tools to be used behind the biological barrier, for this general characterization, will be:

1. Mineralogy (see report of that team).

2. One (or at most two) simple analytical instruments. The optical spectrograph seems most generally useful here, especially since only the sample-source system need be behind the barrier. It is possible that x-ray diffraction-fluorescence equipment would also be worth while, though at present we think not.

At the end of this first stage enough information would be available for distribution of samples for many purposes. For others, choice of sample size and type are strongly dependent on detailed characterization of the range of materials available. Here a second stage of more detailed analysis will be required. Some of this will be done at Houston, and some elsewhere. The third stage, of major experiments involving many experimenters, will not begin or terminate sharply. Generations of measurements will build on previous ones. However, throughout this process, there must be detailed planning and close contact between groups to insure wise use of material.

d. Later Experiments

Some later experiments of use for purposes of characterization follow. These would generally be carried out on the bench or in an inert atmosphere.

1. Micro- and semi microanalysis. Elements analyzed and sample sizes for silicates: Si, Al, Total Fe, Mg, Ca, Na, K, Ti. Required 6 mg. Accuracy 0.5% for major elements. To do $H_2O$, and FeO, and F requires 20 mg. additional. Other minerals: up to 25 mg. required, depending on composition.
2. X-ray fluorescence for major constituents from Mg up.
   (a) Non-destructive: Requires finely ground samples (300 mesh or less). Sample size - 10 mg. minimum. Accuracy 2-3% of the value determined, provided closely similar standards are available.

(b) Destructive: (fusion of sample and addition of an absorbing element). Sample size 50-100 mg., accuracy 1-2% of the amount present. Preliminary results indicate that 10 mg. can be analyzed, with some loss of accuracy.

3. Electron microprobe. For analysis of individual grains of minerals down to 10 microns in diameter. Accuracy about 5% for light elements (Mg and above), 2% for heavier elements.

4. Quantitative Spectrographic Analysis

(a) Regular procedure: Minimum sample 10 mg., but usually done in duplicate. Overall accuracy ±15%.

(b) Microspectrographic: Minimum sample 1 mg.

5. Neutron Activation Analysis. Instrumental neutron activation analysis is currently used for O, F, Na, Al, Si, Cr, Mn, Fe, Co, and Cu. Sample size may be up to one gram. Accuracy ±3% in favorable cases. Essentially a non-destructive method.

Other less certain possibilities for this stage include spark source mass spectrometry, the ion emission micro-probe (for light elements) and alpha scattering. With care the same samples may be used for several kinds of analyses.

e. Main Program

Finally we come to the main program itself. Here it is very hard to be definite. A serious case can be made that we should analyze for every possible stable and radioactive isotope of every possible element, in as many distinct specimens or phases as may be available in sufficient quantity. Economy of sample and time are the only obvious limitations. Rather than attempt a coherent account of particular experiments this section will contain comments taken in large part from material submitted by committee members.

1. Goals in Lunar Materials Analysis (Gast):

The analyses outlined in this program are not primarily an exercise in the analysis of unknown materials. They are aimed at answering as many fundamental questions regarding the moon as possible within the limitations imposed by sampling. It is clearly impossible to anticipate all of the ways in which isotopic and chemical data on isolated samples may lead to inferences on the structure and composition of the moon. It is, however, possible to suggest several lines of evidence which may be instructive. In general, the goal is that isotopic and chemical composition of a few samples may allow us to place the moon in a sort of planetary chemical context. At present, this context consists of two extensive sets of chemical and isotopic data 1) for terrestrial materials and 2) for meteoritic materials.

Several parameters which would be particularly illuminating are: 1) the abundance of K, Rb, U, Th, Pb and Sr, 2) the isotopic composition of lead and strontium, 3) the absolute and relative abundance of the rare earth elements, 4) the concentration and isotope composition of rare gases.

The isotopic composition of a particular lead or strontium sample is determined by the relative abundance of U and Pb or Rb and Sr in all of the chemical systems in which this particular sample has resided and the length of time spent on each system. In a differentiated "geologically active" body such as the earth, the averaging over different systems is significant. In "geologically passive" bodies such as the source of chondritic meteorites, there is virtually no averaging effect. In the first situation, a single specimen yields information on the relative abundance of Rb and Sr and U + Th and Pb for a much larger volume than the local environment of the specimen. In the second situation, the age of the entire body may be inferred from the isotope compositions.

This can be clarified by a more specific example. It has recently been suggested that the meso-siderites and basaltic achondrites originate from the moon. It has also been shown that the earth has a much lower abundance of Rb relative to Sr than chondrites, as well as a much higher abundance of K relative to U and Th than chondritic meteorites. Determination of the isotope composition of strontium as well as the K, Rb, U, Th content from the lunar materials should resolve this question rather quickly. If the moon is on the average earthlike or achondritic, $Sr^{87}/Sr^{86}$ ratios should not exceed 0.725 and more probably fall around 0.703, even if it is differentiated. If it is chondritic, the $Sr^{87}/Sr^{86}$ ratios should fall above 0.750.

The rare earth abundances may be particularly diagnostic in determining the extent to which the moon has been differentiated. It is significant that in spite of very significang differences in composition, the relative abundance of the rare earths in the basaltic achondrites and the chondrites is identical. Similarly, terrestrial rocks somewhat similar to the achondrites have chondritic relative rare-earth abundances. The nonchondritic meteorites and most terrestrial materials have relative rare earth abundances which indicate some fractionation. The relative abundance of rare earths in the lunar surface should distinguish differentiated material from undifferentiated material even if the initial moon is identical to basaltic achondrite.

The rare gas abundances in lunar materials, in particular He and Ar, will when coupled with U, Th and K content yield a gas retention age, which again will be an indication of whether or not rock forming events have taken place in the recent history of the moon. The abundance of other rare gases - Ne, Xe, Kr - in the rocks may be the most sensitive indicator of the extent to which solar wind accretion is important on the lunar surface.

Finally by way of proposing specific analyses, I will give an example of what I think could be learned from a 1-2 gram piece by mass spectrometry.

1. Sr isotope composition and conc, down to 0.5 ppm Sr.
2. Ca and Ba conc. and partial isotope compositions down to 0.5 ppm Ba.
3. K, Rb and Cs abundance, possibly $K^{40}/K^{39}$.
4. U and Th abundance down to 0.2 ppm U.
5. Lead content with partial isotope composition. $Pb^{206}$, $Pb^{207}$, and $Pb^{204}$. Quality of isotope composition depends on conc. if less than 5 ppm. $Pb^{206}/Pb^{207}$ ratio could be combined with activation determined $Pb^{206}/Pb^{204}$ ratio.

Possible additional determinations:

1. La, Eu, Nd, and Sm
2. Ag, Cd, Zn.

2. Stable Isotope Effects (Clayton)

Important chemical isotope effects are expected for hydrogen, carbon, nitrogen, oxygen, silicon and sulfur. If the lunar matter had a different history of proton bombardment in the young solar system, the concentrations of D, $C^{13}$, $N^{15}$, $O^{17}$ and the isotopes of lithium, beryllium and boron may differ from terrestiral values.

In order to get the most use of chemical isotope effects, measurements on separated phases are essential. Samples of the order of one millimole of the element in question are required for the conventional gas source mass spectrometric analysis. For these fairly abundant elements, contamination is not a very serious problem, so that it would be possible to use material which had previously been used for other measurements, such as measurements of physical properties. Since currently used techniques for oxygen extraction involve fluoxination of silicates, with $SiF_4$ as a by-product, it would be desirable to use this gas as the sample for silicon isotope analysis.

In summary, I would recommend that oxygen and silicon isotopes be measured immediately on about 50 milligrams of whole rock. Hydrogen, carbon, nitrogen and sulfur, probably present in lower concentrations, would require more sample, and may be deferred a while. If mineral separation proves feasible, isotope fractionation effects should be measured in the separated phases for oxygen and silicon and any other elements of this group in adequate concentration. The decision cn lithium, beryllium and boron can await the determination of their elemental concentrations.

3. U. S. Geological Survey Methods for Lunar Program (Fleischer)

Wet Chemical Methods

1. Conventional rock and mineral analysis.
2. Micro and semimicro analysis of rocks and minerals.
3. Minor or trace elements.

Spectrochemical Methods

1. Semi-Quantitative spectrochemical analysis by Powder D. C. Arc Method.
2. Quantitative Spectrochemical Analysis by Powder D. C. Arc Method.
3. Microspectrochemical Analysis of Minerals.
4. Spectrochemical Determination of Lead in Zircon for Lead-Alpha Age Measurements.
5. Quantitative Determination of Hf and Zr. D-C Arc Method, using the Direct Reading Spectrometer.
6. Rare Alkalis - D. C. Arc - $K_2CO_3$ buffer - solid sample (silicates)
7. Rotating Disc - H.V. spark-solution analyses.
8. Plasma arc - solution analyses.
9. Fusion pellet method, multisource excitation using the direct reading spectrometer.
10. Direct Reader - D. C. Powder.

Spectrochemical Methods - Denver Laboratories

(A) Techniques

(1) Six-step semiquantitative method.

Ref. Geol Survey Bull. 1084-1 and Branch Chief memo dated Aug. 24, 1961.

(2) Quantitative method

Ref. Geol. Survey Bull. 1084-G.

(3) Modified Harvey Carbon powder method.

Ref. Book by C. E. Harvey on Spectrochemical Procedures, Applies Research Labs., 1950.

Electron Microprobe and X-ray Fluorescence Analysis

(A) Qualitative

(B) Quantitative - X-ray fluorescence

(1) Non-destructive powder techniques

(2) Quantitative analysis with altering of the sample

(3) Soft X-ray analysis

(4) Electron probe

Fleischer's report gives detailed information on these methods: sample size, elements, precision, etc.

4. Phase separations

Our ability to make clean separations of mineral phases in terrestrial materials is still marginal in many instances. Present methods often use material lavishly in order to obtain small concentrates. Little progress has been made with fine-grained rocks. An effort in this area is needed over the next few years, if we are to use lunar materials effectively and economically. Again improved methods would be of great benefit for terrestrial geochemistry. This subject is intimately connected with the statistical sampling problem. We hope the mineralogy team will push this.

5. Emission Spectrography (Turekian)

The most general instrument to provide a reasonable semiquantitative estimate of the major and minor elements is the emission spectrograph. All other techniques either require more material or are more specific. The following scheme can be used for the most immediate information for the least amount of material. It is also insensitive to the type of silicate being analyzed. The quantity of material listed is the amount necessary for a triplicate determination:

1) Major elements: 10 mg of sample mixed with a large amount (e.g. equal to or greater than the sample) of strontium carbonate. Using the DC arc, reasonably satisfactory semi-quantitative results can be obtained for the major elements Ca, Mg, Si, Al, Fe (total), Na and K.

2) Minor elements: 20 mg of sample mixed in equal parts with "Spec-pure" calcium carbonate can be analyzed for a host of trace elements using as internal standard the

iron already in the sample and previously determined. All the trace elements Rb, Sr, and Ba, to the limit of their sensitivities in the DC arc, can be determined in this manner.

In a separate set of arcings Sr and Ba can be determined in the above mixture using calcium as an internal standard. As the calcium from the "Spec-pure" calcium carbonate swamps the calcium in the rock (for most rocks) the semiquantitative nature of the calcium determination has a minimum effect and the strontium and barium determinations can be quantitative (see Turekian, Gast, and Kulp, 1957; and Turekian and Carr, 1961).

Rubidium may be determined by mixing 10 mg of the sample with "Spec-pure" potassium chloride or potassium carbonate and using the DC arc, photographing only the alkali emission to diminish the cyanogen background which envelopes the rubidium lines.

A total of 40 mg will give results of fairly high quality for initial reconnaissance within two days.

6. Activation Analysis

This is the most widely used method for trace-element analysis in the meteorite field, and is also of growing importance in terrestrial geochemistry. Its use has resulted in a drastic lowering of abundance estimates for many elements, and a qualitative improvement in precision. Instrumental methods not involving wet chemistry can sometimes be used, so that samples are available for other purposes. Meinke has made available detailed information on this type of analysis.

7. Bombardment Effects (Arnold)

Cosmic rays produce new stable and radioactive nuclides in meteorites. The study of these has increased our knowledge of meteorites and provided the only available information on the history of cosmic radiation over time scales longer than that of $C^{14}$. Measurements on lunar samples will be most profitable. The great hope is that cosmic-ray-produced $K^{40}$ will be measurable in some K-poor phase, and that this can tell us something definite about the cosmic ray intensity on a billion-year time scale. Accurate long-time erosion rates may also be obtainable. The development of fossil cosmic-ray tracks is another possibility.

The gamma ray experiments described above would at best give information on perhaps one third of the radioactive bombardment products of interest, and on none of the stable ones. For the B and x-ray emitters meteorite samples on a kilogram scale have been usefully employed. Minimum sample size for a useful broad program on cosmic ray products is a few hundred grams. The measureable stable products will probably include the rare gases; others such as Sc, Ca isotopes, K isotopes, elements of the Li, Be, B group, will be accessible only if sufficiently pure targets are available.

Bombardment by solar particles and photons of all energies may have profoundly altered the exposed surface materials. A variety of measures of radiation effects have been used. The choice of methods will depend on the character and intensity of the bombardment.

8. Gas experiments. There is a very rich group of possible gas experiments in addition to the few discussed above. The rare gases, and organic fragments, provide exciting possibilities for analysis. The work of Reynolds, Nier, and their coworkers, among other groups, has been outstanding here. This field makes special demands for sophistication of technique and data analysis. The high vacuum samples described earlier would be largely devoted to such analyses. It is assumed that each of these would be transported unopened to the laboratory where it was to be analyzed, and treated there according to a sequential program.

C. Active Experiments

For the early Apollo missions, an active experiment must be of extraordinary importance to compete with observation and sample collection for the astronauts' very limited time. In the geochemical area we know of none which can do so, in its own right. At the same time, instruments which can furnish guidance for sample selection will be most useful.

The ideal instrument of this type would give an elementary (or mineral) analysis of surface material, without sample preparation, rapidly and with an accuracy of a few percent. No such gadget exists. At the lower limit of usefulness is a device which could indicate sizable differences in composition between two materials, without identifying them.

Any useful instrument must be portable - perhaps on a "Eugene's staff".

A magnetometer may be one useful device of this class. The presence of magnetite or free metal could easily be seen. Since there appears to be a serious possibility that one or more of these substances will be encountered, development of such a device appears worthy of support.

More general analytical instruments might include the nondispersive x-ray fluorescence spectrometer, gamma ray spectrometer, alpha scattering, neutron activation, x-ray diffraction and dispersive x-ray fluorescence. Studies in connection with the unmanned program suggest that only the first two can be considered for the present purpose, in the current state of the art.

Non-dispersive x-ray fluorescence requires a source of excitation, one (or perhaps two) proportional counter tubes, and provision for pulse height analysis. The source excites, the proportional counter detects, and the pulse height analysis displays characteristic radiation representative of sample composition.

With available band widths it would appear practical to telemeter proportional counter pulses in real time, and do all data reduction by computer on earth, relaying back the final results verbally.

A. D. Metzger at JPL and co-workers have obtained promising results with this method. It appears likely that rough quantitative analyses could be made in 30 seconds distinguishing Mg-Al-Si, S, K-Ca, and the Fe group. This would be really useful for sampling. Perhaps even individual elements can be measured. Further development may enhance this capability.

Gamma ray instruments are standard in terrestrial field work. On earth they respond mainly to K and U, Th, and their daughters. On the moon cosmic-ray effects may be prominent, if these radioactive elements are low in abundance. The count rate of a small crystal may be low, however, and thus this technique may be limited to qualitative distinctions.

Simple devices which test strength, density, or other physical parameters are also worth considering.

## D. Passive Experiments

This subject has received little discussion at our meetings. The general arguments against active experiments do not apply here, and it is clear that there are passive scientific experiments of major importance (e.g. the seismograph). We do not at present have any recommendations for passive experiments in the particular area of our charge. Passive experiments are most appropriate where properties are a function of time, or where data gathering is inherently slow.

The lunar atmosphere may present such a case. So may emanations from beneath the surface, though this is somewhat "far out" at the moment. In any case another team is considering gas measurements in situ.

## E. In-Flight Experiments

In-flight experiments are not now a part of the Apollo program as such. They come under proposed Manned Lunar Orbital Missions instead. However, our committee has considered them, and wishes to register here its strong interest in a number of them. A close lunar orbiter would allow useful geochemical mapping of the moon by means of

1. Gamma rays
2. X-rays
3. The vacuum U.V.
4. The optical region
5. Infrared
6. Radio waves
7. Neutrons
8. Protons

9. Alpha and Beta particles

10. Other electrons

## Summary and Recommendation

The following is an attempt to summarize the key points of this report, not necessarily in order of importance.

1. Sample return is the dominant portion of the Apollo science program, where geochemistry is concerned. A large mass must be brought back, under the best conditions of sampling and preservation if possible, but anyway brought back somehow.

2. Sample containers should be under development now. They should meet a variety of specifications, but not all need to be ideal in all respects. This remark applies particularly to vacuum.

3. Sampling tools also need development now.

4. The strategy of sampling needs further consideration. At present we recommend taking a few large representative samples of known orientation, along with a large number of small ones representing the range of materials encountered.

5. Survey instruments are needed to supplement the eye in characterizing possible samples.

6. The best workers in each geochemical field should be encouraged to participate in the laboratory program, along

with others whose names are not well known. A program of preparation, including "dry runs", will aid in planning proper sample distribution, and improve the general level of work done with the samples. This preparatory program ought to be funded specially by NASA.

7. The biological control to be maintained during the first four weeks will inhibit geochemical work. Early experiments should be confined to those (1) where information will be lost by waiting, or (2) which can yield preliminary data useful for planning later experiments, and are simple enough to carry out readily behind a biological barrier. These experiments are discussed in the text.

8. A major and well chosen portion of the sample must be set aside at once in proper custody as a reserve for the distant future. Within the remaining material, sample allotment should be in strong and proper hands. A policy against "souvenirs" will be necessary.

9. No passive experiments in the geochemical area are presently recommended.

10. While it is outside our present charge strictly speaking, the committee wishes to record its great interest in the geochemical results obtainable from a lunar orbiting mission.

75

N66-18670

# Section V

## Passive Lunar Seismic Experiment

Passive Seismology Planning Team


F. Press, Chairman
M. Ewing
G. H. Sutton
R. Kovach

A passive seismic experiment on the moon utilizes seismic waves from moonquakes, meteorite impacts, and other sources to study the sources themselves, as well as the internal constitution and state of the moon. Lunar seismicity, that is the statistics of moonquakes, is an index of strain accumulation and release. It relates ultimately to the thermal history and the current thermal regime of the moon. Seismicity is also an index of the origin of surface features, such as faulting, volcanism, and impacts. The correlation of lunar features with epicenters of seismic events will enable us to say something significant about the origin of the surface features. A single seismic system on the moon can give rough azimuths and distances, so that epicenters can be obtained with sufficient precision to make this correlation. Meteorite impacts would provide seismic sources the same way that underground explosions do. These impacts would be difficult to separate from lunar quakes, except that the first motion would always be compressional. It may well be that one of the best indicators of the cross section of meteors in space will be the seismic experiment. Roughly speaking, the seismic experiment is also a micrometeorite experiment with the entire surface of the moon serving as a sensor. Finally, seismic waves may be used to infer properties of the lunar interior. It is surprising how much can be accomplished with a single three-axis station. Modern methods of analysis of surface waves enable us to recover phase and group velocities of surface waves which have repeatedly circled the moon. Free oscillations of the moon, if they were recorded, make it possible for a single station to explore the lunar interior through to the center. The gravest mode of oscillation is approximately thirteen to fifteen minutes, which may well be within the range of the instrument. Distinct from surface waves, body waves, or seismic rays, could be used to reveal the presence or absence of a lunar core, velocity reversals in the moon, and mechanism of lunar tremors. The absorption of seismic waves indicates the anelastic properties of the moon. This can be obtained from the Q of the free oscillations, the absorption coefficient of propagating waves, or the decay of surface waves which repeatedly circle the moon. As a result of recent work, it is now possible to invert such data as Q versus period to obtain a Q versus depth curve. This may then be correlated with temperatures, materials, the presence of zones of partial melting, etc. The density-depth function in the moon can be recovered if the compressional and shear velocity structure is known. Thus the seismic experiment contributes to this important aspect of the lunar interior.

Much information and experience has been obtained in recent years in the design and fabrication of seismographs for use on the moon. In connection with the Ranger program a single-axis short period seismometer was designed and constructed. For the Surveyor program, a three-axis seismometer system was designed, constructed, and is now being readied as flight hardware. This system covers both intermediate, short and long periods. The prototype of a three-axis system for use on possible Surveyor follow-on programs has been completed. It also responds to short and long periods; its response is not as long as the Surveyor instrument, however, its weight is less. With this backlog of experience, the system which will emerge for Apollo will have had the benefit of many years of prior effort.

It is proposed that the Apollo's passive seismic system be composed of a three-axis seismograph, capable of responding to short and long periods. It should be designed to operate for at least six months in a continuous fashion. It would be placed on the moon by an astronaut, whose duties may be as simple as placing the equipment on the lunar surface, or as complex as adjusting the bandpass and gain of the instrument in the light of lunar seismic noise.

Since difficulties increase rapidly with seismometer pendulum period, it is suggested that the free period of these be made only as long as necessary to achieve the desired long period response when in combination with filter shaping. The possibility of providing several passbands with individually adjustable magnification controls and signal level indicators should be studied. The astronaut can set magnification to the maximum value compatible with noise in each band. The outputs could then be combined to record on a single channel. In addition to the three-axis system, we recommend the inclusion of a single short period vertical seismometer. This unit could have a size roughly one-quarter that of the Ranger seismometer. Its total weight would be of the order of 10°/o of the three-axis system. It would serve as a backup device should more complex long period apparatus fail. It would also serve to record short period body waves, thereby enabling us to decrease bandwidths required for the long period seismographs.

Suggested seismometer parameters:

Three-axis system: Seismometers free period: 3 - 10 sec.

Short period single axis seismometer: 1/2 - 1 sec.

Damping: (near) critical.

Transducers:

Displacement for signal for three axis system with damping and mass position feedback servo through velocity transducer; velocity transducer for single axis seismometer. (Type of displacement transducers to be selected by comparison of experience of the groups with various types.)

Frequency response:

D. C. - 2 cps, separately controlled in three bands for three-axis system. 0.5 - 5 cps for single axis.

Dynamic range and distortion:

Not less than 40 db range analog, with amplitude distortion not greater than 10°/o, phase distortion calibrated.

Magnification capability (minimum):

| | |
|---|---|
| Short-period band | - $10^6$ |
| Mid-period band | $10^5$ |
| Long-period band | $10^4$ |

Each band to be fitted with a magnification control and a threshold indicator.

Power consumption:

Power:

Approx. 1 watt continuous; 3 dc levels regulated under 28 volts.

Approx. 1 watt hour initial leveling (e.g. 1/4 amp., 12 volts for 20 minutes).

Approx. 1/50 watt hour each day for level adjustment (e.g. 1/4 am. 12 volts, for 20 sec).

Distance for power transmission: 10-20 ft.

Peaks. Pyro battery needed one time only.

Level accommodation:

Three-axis system: Servoed gimbal to accommodate 15° or less - automatic rough level probably not required since instrument will be positioned manually on a prepared site. Masses to be continuously servoed to zero by feedback of processed transducer 'error signal'; gross corrections by mechanical adjustment actuated by error signal.

One-axis system: 30°

Temperature and environment tolerance:

0 to + 70° C operating, -50° to + 125° C storage or enroute.

No vacuum tolerance required, instruments can be sealed in a case with an atmosphere, if necessary.

Radiation tolerance as dictated by future studies.

<u>Weight and volume</u>:

Using the already developed Lamont and Caltech models as a basis, it is estimated that such a seismometer package would weigh less than 25 lbs. and be between 600 and 1200 cu. in. in volume exclusive of heat screens, and power supply.

<u>Telemetry</u>:

Central multiplexer and AD converter for all experiments is desirable.

Range-3 axis system: greater than 40 db analog

1 axis seismometer: 40 db analog

Sample rate: 3 axis: 3 channels, 5 samples/sec, each sample 10 bits

1 axis: 2 channels, 10 samples/sec, each sample 7 bits

3 engineering channels at less than 1 bit/sec.

Bits/sec total system less than 300 bits/sec.

Time schedule:

With a flight date estimated at September, 1968, it is suggested that 18 months be allotted to development of the model instrument, and 18 months allowed the flight unit vendor for finalizing and testing. Allowing a buffer period of 3 months, this will deliver flight hardware one year in advance of the suggested flight date. Power supply data storage recorder, and heat screen design can parallel the seismometer package design to an extent that these will be ready for finalizing in the same period as the seismometer package.

This is a close schedule for such an experiment and would require close cooperation between our groups, and coordination with vendors of auxiliary equipment.

During the first two years, activities will be primarily design and construction of models and coordination with the space agency and supporting vendors, and a full staff will be required.

In the 18 months prior to delivery of the flight hardware, activities will be primarily surveillance of the manufacturers' activities and the costs will be less. These costs will be covered under a renewal of the contract at that time. Data handling and analysis funding will then be required.

84

## Section VI

## ACTIVE LUNAR SEISMIC EXPERIMENT

N66-18671

Active Seismology Planning Team

In Addition to the Passive Seismology Team

J. M. DeNoyer
G. Simmons

The purpose of this experiment is to ascertain elastic properties of the lunar surface and interior to a depth of about 500 feet. This information is necessary to properly interpret lunar surface features and near surface lunar stratigraphy. It may be that the original lunar surface is not buried to an extent not penetrable by the astronaut. In this case, this experiment may provide the only data from which to infer the nature of this original surface.

As presently conceived, the experiment utilizes mortars to deploy explosive charges and provide the seismic sources. In view of the hazard to the astronaut and to other experiments from flying particles, this experiment should be set up by the astronaut, but its performance deferred until he has departed and until all other experiments have completed their functions (six months after set up).

Data requirement

In order to complete a seismic refraction experiment on the moon, the instrumentation must be capable of providing the following information:

1. Distance from the seismic source to the receptor.

2. Instant of explosion or other seismic source (time break).

3. Precise timing of interval between (2) and any event in the subsequently received seismic signal.

4. Reception of the seismic signal without distortion which might obscure the character of the signal.

When data is transmitted at the time of performance of the experiment (no storage) item (3) can be recorded on earth in parallel with the lunar data during reception.

Instrumentation

The instrumentation would consist of the following:

1. A package of five projectile throwing mortars each of which is fitted with a range encoder operated by a range metering line towed by the projectile.

If the range metering line is of conducting material, it may also be used for projectile charge detonation and instant of explosion indication.

One technique suggested would be to include a capacitor aboard the projectile and after the projectile is launched, commence charging the capacitor through the metering line. A switch aboard can then discharge the capacitor through the detonator, either on a command or when the capacitor voltage has risen to a predetermined level. Discharge of the capacitor can be used as a time break impulse.

2. A program unit to sequence firing of the mortars at 2-5 minute intervals.

3. A geophone for reception of the seismic signal (if possible, it would be well to use two at 100 ft. spacing).

4. Amplifiers for geophone signals. These probably should have a gain-change or compression for larger amplitudes to prevent overload on ground-roll, etc. and yet leave smaller first-arrivals unaltered.

It might be well to provide a separate amplifier for application of the time break to the telemetry rather than risk coupling of noise into the seismic amplifier input by the long time break line. Probably the time break amplifier could be very basic since the time break signal will be fairly strong.

The program unit, amplifier and other associated electronics would presumably be housed with other similar equipment of the mission which requires controlled environment, and after a six-month period, power, telemetry, etc. will be transferred from other experiments to the seismic experiment which then is controlled by its own programmer.

The astronaut would be required only to emplace the geophones, and emplace and aim the mortar package. The mortar package might be 20 ft. from the mission telemetry system and connected by cable. If only one geophone is used, this can be near-by the telemetry package - if two are included, the second should be approximately 100 ft. distant. It would be well if these can be buried.

In performance of the experiment, the mortars will be fired singly, in sequence, at two to five minute intervals as determined by the programmer, which will also switch range encoder data. Projectiles will be thrown and exploded in a more or less uniformly spaced linear array over ranges of 200 - 2000 ft.

Early field tests indicate that the maximum charge required will be about 4 oz. of TNT equivalent. For the nearer shots the charges may be somewhat larger than indicated, for reliability reasons. The minimum will probably be of the order of 1 oz.

The data form will be a series of events displaced in time as follows:

1. An indication of projectile launch.

2. Range encoder data, which at present is a series of step signals each indicative of an increment of range.

3. Time-break, a fast rise time pulse or step indicative of the instant of explosion.

4. The seismic waves with frequencies probably in the range of 0.5 - 100 cps.

In order to achieve timing to a few milliseconds, the system must have fairly high frequency handling capability, perhaps 500 cps.

A dynamic range of 60 db is desirable; however, compression may be applied to the larger amplitudes. Then with a telemetry dynamic range of 40 db approximately 7,000 bits/sec will be required for the data channels.

<u>Specifications summary</u>:

Geophones (typical)

| | | |
|---|---|---|
| weight | - | 8 oz. each |
| volume | - | 8 cu. in. |
| natural frequency | - | 5 cps |
| damping | - | .6 of critical |
| sensitivity | - | .5 V/in/sec |
| temperature tolerance | - | lunar surface |

<u>Amplifiers</u>:

| | | |
|---|---|---|
| input noise | - | .1 max |
| gain | - | dependent on telemetry input requirement: (100 db will give an estimated 1/2 V output with charge and geophones suggested). |
| dynamic range | - | 60 db |
| pass band | - | 1/2 - 500 cps |

| | | |
|---|---|---|
| power | - | 3 levels at less than 28 volts, regulated, 2 watts for 20 minutes |
| dimensions (est.) | - | 1" X 2" X 6" |
| weight (est.) | - | 8 oz. |

**Programmer:**

| | | | |
|---|---|---|---|
| Time sequence | 0 sec | - | activate system |
| | 60 sec | - | launch and record (or transmit) |
| | 120 sec | - | ready next shot and power off (or recycle) |
| Power consumption | | - | 3 watts - 20 min. 28V DC |
| Dimensions (est.) | | - | 3" X 3" X 3" |
| Weight (est.) | | - | 1 lb. |

**Mortar package:**

Power

Case open squibs (3) 28 volts, 2 amp. few ms.

Range encorder (5) 28 volts, 50 ma, 20 min.

Launch squib (5) 28 volt, 2 amp, few ms.

Detonate power (5) equiv. to 28 2 amp, few ms.

Dimensions - approx. 4" X 8" X 18"

Weight - approx. 20 lb.

Telemetry requirements:

1 - data channel per geophone used - 7000 bits/sec for seismic data.

1 - engineering channel to indicate transfer of system to active experiment, mortar package case opening, projectile launch and sequence of advance.

If the bit rate is beyond the capability of the Apollo system telemetry consideration should be given to on-site recording and slow playback, before degradation of the experiment to accommodate the system.

70

N66-18672

Section VII

# LUNAR GRAVITY MEASUREMENTS

J. Weber and G. J. F. MacDonald

## ABSTRACT

18672

Precise measurements of the acceleration due to gravity on the lunar surface over a period of months may yield valuable information concerning the internal constitution of the moon.

The moon will interact with gravitational radiation. The lunar free oscillations may be observed to be excited by such radiation if the power spectrum is sufficiently intense over the frequencies of certain of the moon's normal modes. Simultaneous observation of the earth's normal mode excitation will make it very likely that the effects are due to gravitational waves.

Observations are planned using a lunar gravimeter having a weight less than 30 pounds, a volume less than one cubic foot, power consumption less than 5 watts continuously, and less than 15 watts with 30% duty cycle. This device will continuously monitor the lunar gravitational field, recording changes greater than about one part in $10^9$.

Author

## Lunar Tides and the Love Numbers h and k

The gravitational fields of the earth and sun are expected to cause tidal deformations of the moon. In the Newtonian approximation these forces can be expressed as the gradient of a potential U. The lunar surface is moved by an amount $\delta$ proportional to the potential

$$\delta = \frac{h\ U\ \text{surface}}{g} \tag{1}$$

Here g is the acceleration due to gravity and the constant of proportionality h is called a Love number.[1,2] There is an additional effect on the potential itself due to the redistribution of mass in consequence of the tidal deformation. We may write the change of potential as

$$\Delta U = kU \tag{2}$$

Here k is another kind of Love[1,2] number. k measures an amplification of the perturbing gravitational field due to the lunar deformation.

The orbital motion (free fall) transforms away the first derivatives of the external potential at the center of mass, leaving a quadrupole term as the major tidal producing potential. For the effect of the earth (or sun) on the moon U is therefore given approximately by

$$U_2 = \frac{-GMr^2P_2(\cos\theta)}{R^3} \tag{3}$$

Here G is the constant of gravitation ($G = 6.67 \times 10^{-8}$ cm$^3$ gm$^{-1}$ sec$^{-2}$, M is the mass of the earth (or sun), r and $\theta$ are spherical coordinates using the lunar center of mass as origin, R is the distance between centers of mass of the moon and the tide producing body. In correcting the potential for the redistribution of lunar mass due to tidal deformation we note than on the lunar surface we are "outside" of the induced tidal lunar quadrupole so for a lunar radius $r_o$,

$$\Delta U = \frac{k\ G\ M\ r_o^5\ P_2(\cos\theta)}{R^3 r^3} \tag{4}$$

The potential due to the lunar mass m itself is given for a sphere by

$$U_o = -\frac{Gm}{r} \tag{5}$$

3, 4, and 5 enable us to write the total potential. Differentiating this and correcting for the tidal displacement of the lunar surface gives the tidal induced change in acceleration due to gravity as

$$\Delta g = (1 + h - \tfrac{3}{2}k)\ \frac{\partial U_2}{\partial r} = \alpha \frac{\partial U_2}{\partial r} \tag{6}$$

During the monthly cycle the quantity $\frac{\partial U_2}{\partial r}$ will vary because of change in distance between the moon and perturbing bodies, and because of latitudinal and longitudinal libration. Calculations [3,4] show that the earth produces the major effect, which is a tide with peak to peak amplitude of roughly one milligal. The solar effect is about two percent of this. The "gravimetric" factor $\mathcal{G} = 1 + h - \frac{3}{2} k$ depends on the internal constitution of the moon. MacDonald [5,6] has considered a number of models. A lunar model assuming a reasonably homogeneous composition, made of silicate materials similar to those of the earth's mantle gives $\mathcal{G} = 1.0033$ while a uniform fluid model gives $\mathcal{G} = 1.25$. These are upper and lower limits. Urey, Elsasser and Rochester [7] have discussed fluid core models.

h and k may have real and imaginary parts, if internal dissipation significantly affects the lunar low frequency response. On the earth the averaged lag of the 12.4 hour lunar tide is $2.2^0$; the dissipation is due in part to shallow ocean friction and in part to dissipation within the solid earth. Independent determination of h and k cannot be made unless surface tilt is simultaneously measured. However the magnitude of $\mathcal{G}$ together with reasonable assumptions, will enable h and k to be inferred. A lunar gravimeter should be able to measure changes in lunar g (162 gals) of a part in one thousand of the tidal amplitude of one milligal---better than one microgal. Existing earth tide meters of the La Coste

Romberg, and Block Weiss type achieve more than an order of magnitude sensitivity greater than this.

## Gravitational Waves

In 1916, shortly after the formulation of the General Theory of Relativity, Einstein predicted the existence of gravitational waves. A gravitational wave can be thought of as a propagating gravitational field. Einstein's field equations are

$$R_{\mu\nu} - 1/2\, g_{\mu\nu} R = \frac{8\, G\, T}{c^4}{}_{\mu\nu} \tag{7}$$

In (7) $R_{\mu\nu}$ is the Ricci tensor, R is the curvature scalar, $g_{\mu\nu}$ is the metric tensor. The $g_{\mu\nu}$ are the field variables. $T_{\mu\nu}$ is the matter stress energy tensor, as before G is the constant of gravitation, c is the speed of light. The objects $R_{\mu\nu}$ contain the field variables raised to the fourth power. These equations are highly monlinear and in the absence of special symmetry contain thousands of terms, when written out entirely in terms of the $g_{\mu\nu}$. No exact solutions representing spherical waves without singularities have as yet been found. Einstein obtained weak field solutions by writing

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \tag{8}$$

Here $_{\mu\nu}$ is the lorentz metric, $h_{\mu\nu}$ is a first order quantity. The objects $\varphi_{\mu\nu}$ defined by

$$\varphi_{\mu\nu} = h_{\mu\nu} - \frac{1}{2}{}_{\mu\nu} h \tag{9}$$

with h the trace of $h_{\mu\nu}$ are convenient. To first order the $\varphi_{\mu\nu}$ satisfy

$$\Box \varphi_{\mu\nu} = - \frac{16\pi G}{c^4} T_{\mu\nu} \tag{10}$$

The set of equations (10) are formally the same as those of electrodynamics, the matter tensor taking the place of the Maxwell four current density. These equations admit a multipolar expansion with quadrupole radiation as the lowest order. For a mass quadrupole oscillator the radiated power is

$$P = \frac{GI^2\omega^6}{15\, c^5} \tag{11}$$

Here P is the radiated power, $\omega$ is the angular velocity, G and c are as defined earlier. A one meter rod which spins about an axis normal to its length radiates away about $10^{-37}$ watts if it is spun so fast that it is on the verge of breaking up due to the centrifrigal stresses. Known double stars would be expected to radiate and would have a radiative lifetime of perhaps $10^{12}$ years. For these reasons no serious attempts to detect gravitational radiation were begun until very recently.

Some years ago Weber suggested [9] that the free oscillations of an elastic body would interact with gravitational waves and proposed use of the earth[9] and moon[10] for detection. The absorption cross section was [9] given as

$$\sigma = \frac{15\pi G I \omega^2}{8c^3} \tag{12}$$

Here $\sigma$ is the cross section, I is the quadrupole moment of the detector, $\omega$ is the angular frequency, $\tau$ is the relaxation time. For the moon's low frequency modes $\sigma \approx 100$ square meters.

According to Einstein's theory only the normal modes of equadrupole symmetry would be excited by gravitional waves. However some other theories such as the Brans Dicke[11] theory predict mono pole radiations.[11] The free oscillations of the earth were identified after being excited during the great Chilian earthquake. After the earthquake subsided no residual excitation of the free oscillations was observed. Recent U.C.L.A. data has resulted in substantial reduction of the surface noise level, but no free oscillations have been observed at other than earthquake periods. The lunar surface should be free of meteorological and oceanic disturbances. The use of the moon as a huge mass quadrupole detector offers exciting possibilities. Correlation analysis or records obtained simultaneously on the earth and moon would permit the unambiguous detection of cosmic sources of gravitational radiation. In recent years very intense sources of gravitational radiation such as double neutron stars[12], closely spaced dwarfs[13] and quasistellar[14] radio sources have been proposed.

## INSTRUMENTATION

The observations of the lunar tides, search for free oscillations, and the use of the moon as a detector of gravitational waves can all be accomplished by telemetering back readings of lunar surface gravity made with a sensitive gravimeter.

Earth tide gravity meters of the La Coste Romberg type have performance which would make them suitable if drift were further reduced and certain anomalies of the servosystem were removed. Their present weight, power consumption and environmental temperature tolerance were not intended for lunar applications, but redesign to meet the needs of the lunar investigations appears feasible and is being actively carried out by us.

We anticipate that our completed instrument will weigh less than thirty pounds, and will occupy a volume less than one cubic foot. Automatic leveling will be provided. A continuous power consumption of less than 5 watts and an intermittent power consumption of less than 15 watts at 30% duty cycle will be required. The channed capacity required to telemeter back information on the setting of a coarse screw, the free servo system voltage, and the instrument temperature will not exceed one bit per second. A long lifetime is essential and we require at least two months continuous records.

The most difficult problem appears to be maintenance of a relatively low temperature. If the lunar surface is covered with dust the gravimeter could be buried, thus simplifying its temperature control. We feel that the astronaut will probably have more than enough to do and that asking him to erect a metal foil radiation shield is more reasonable than having him dig or drill a hole.

Simultaneous monitoring of the free oscillations of the earth will be carried on at installations at U.C.L.A. and the University of Maryland.

# REFERENCES


1. A. E. H. Love, Some Problems of Geodynamics, Cambridge Press, 1911.

2. Munk and MacDonald, The Rotation of the Earth, Cambridge Press, 1960.

3. Harrison, J. C., An Analysis of the Lunar Tides, J. Geoph. Res. 68 (14), 1963.

4. Sutton, Neidell, and Kovach, Theoretical Tides on a Rigid Spherical Moon, J. Geoph. Res. 68 (14), 1963.

5. MacDonald, G. J. F., Calculations on the Thermal History of the Earth, Journal of Geophy. 64, 1967-2000, 1959.

6. MacDonald, G. J. F., Interior of the Moon, Science, 133, 1045-1050, 1961a.

7. Urey, Elsasser, and Rochester, Ap. J. 129, 842-848, 1959.

8. See for example J. Weber, General Relativity and Gravitational Waves, Interscience Publishers, New York, London, 1961.

9. J. Weber, Phys. Rev. 117, 306, 1960, and reference 8.

10. J. Weber, Proceedings of the NASA Stanford Relativity Conference, June, 1961, and Proc. International School of Physics, Evidence for Gravitational Theories, XX Course p. 140, Academic Press, 1962.

11. R. H. Dicke, Proc. International School of Physics, Evidence for Gravitational Theories, XX Course, Academic Press, 1962.

12. F. J. Dyson, Gravity Research Foundation Essay, New Boston, New Hampshire, 1962.

13. R. L. Forward, Gravity Research Foundation Essay, New Boston, New Hampshire, 1962.

14. W. Fowler and F. Hoyle, Dallas Conference on Gravitational Collapse, 1963.

1 0 2/15

N66-18673

# Section VIII

# Magnetic Measurements In The Apollo Program

Lunar Magnetic Measurements Planning Team

Norman F. Ness, Chairman
James Balsley
Richard R. Doell
Victor Vacquier

Norman F. Ness
NASA-Goddard Space Flight Center
Greenbelt, Maryland

July 17, 1964

# MAGNETIC MEASUREMENTS IN THE APOLLO PROGRAM

Measurements of magnetic fields and related phenomena in the lunar environment form obvious subjects for investigation in the exploration of the Moon. The lunar magnetic field strength is estimated to be small on the basis of a field origin similar to that of the Earth's in which a dynamo system of electrical currents circulates in a fluid core. The average low density of the Moon precludes all reasonable possibility for such a mechanism. Any present day magnetic field which exists may be related to an ancient field at the time of origin of the Moon or it may be due to the result of the complex interaction between the Moon and the streaming solar plasma containing the interplanetary magnetic field. It has been suggested by Gold (1962) that the finite electrical conductivity of the Moon may provide a "trapping" mechanism for acquisition of an effective magnetic field.

Direct measurements by the second Soviet cosmic rocket Lunik II (Dolginov et al., 1960) indicated the nonexistence of a lunar magnetic field appreciably larger than the 100 gamma noise level of the experiment. The solar plasma flow will compress any lunar magnetic field to a distance at which the directed pressure of the plasma is balanced by the magnetic pressure.

Figure 1 illustrates schematically in the noon meridian plane the case of a streaming solar plasma impacting a dipolar planetary field (in the absence of an interplanetary magnetic field). Figure 2 presents the results of computations on the subsolar radius ($R_c$) of the magnetosphere cavity thus formed for various values of plasma flux and equatorial magnetic field strengths. It is seen that a lunar magnetic field could exist which would not have been detected by Lunik II if the field were compressed by the streaming solar plasma (Neugebauer, 1961). If such a field configuration exists, it is extremely important to determine its characteristics. In addition, the lunar surface characteristics will be dependent upon whether the solar plasma is capable of directly impacting the lunar surface or not.

The effect of the interplanetary magnetic field however, is to lead to a much more complex interaction between the Moon and the streaming solar plasma, regardless of the existence of any intrinsic lunar magnetic field. This is because the presence of the interplanetary field causes the plasma flow to be "supersonic" in the magnetohydrodynamic sense. Figure 3 illustrates the dependency of the simplest magnetoacoustic wave velocity, the Alfvén speed, on magnetic field and solar plasma values. These parameters have recently been measured by the Mariner II (Snyder and Neugebauer, 1962) and the IMP-I (Bridge et al., 1964) spacecrafts. In general the solar plasma velocity is approximately 600 km/sec with a density of five to ten p/cm$^3$ and a contained magnetic field of four to seven gammas (Ness et al., 1964). This indicates a "super Alfvénic" flow with a Mach number between five and ten. It leads to the formation of a bow shock wave of the collisionless type because of the very rarified plasma density. In the case of the Earth the IMP-I satellite (Ness et al., 1964) has provided a definitive mapping of both the cavity boundary and the shock wave location as well as the physical characteristics of these boundaries (see figure 4). Thus even in the absence of a lunar magnetic field a complex interaction between the streaming solar plasma and the lunar body are anticipated because of these considerations. Indeed experimental evidence for a lunar magnetohydrodynamic wake in the solar wind has recently been obtained by the IMP-I satellite (Ness et al., 1964) and is illustrated in Figure 5.

The most important aspects of the lunar magnetic field are its spatial and temporal characteristics. In order to adequately investigate the spatial properties of the lunar field and the interaction of the solar plasma with the Moon a mapping by circumlunar satellites is required. Investigation of transient properties can be begun by measurements at one point on the lunar surface. At the present time it is suggested that a magnetic observatory be established on the lunar surface to measure and monitor the vector properties of the lunar magnetic field. As the exploration of the Moon continues, it appears reasonable to anticipate the establishment of several such observing sites at separate locations on the lunar surface. These additional sites will allow cross correlation of results between the stations and possibly the determination of subsurface electrical characteristics of the Moon as they affect fluctuating magnetic fields. The present state of the art in magnetic field instrumentation for space applications is well advanced. A triaxial vector instrument with a dynamic range of several hundred gammas and a sensitivity of fractions of a gamma with appropriate analog to digital conversion subsystems is possible within the weight and power limitations of 3 kilograms and 5 watts respectively.

Such vector information, obtained at perhaps one minute intervals, would normally be transmitted back automatically to the Earth for subsequent recording and analysis. It is important in the establishment of these observatories that the orientation of the vector instruments be known to within a few degrees relative to a lunar set of coordinates so that cross correlations between components will be meaningful. Directional properties of transient variations associated with solar terrestrial storm phenomena can be compared with satellite and deep space probe measurements of interplanetary magnetic fields as well as terrestrial field variations.

The possibility of returning to the Earth physical samples of the lunar material may well be one of the most rewarding aspects of the magnetic measurement program since the ferromagnetic properties of lunar rocks create "magnetic memories" of past lunar magnetic fields. Experimental work in the general field of terrestrial paleo-magnetism has indicated that a very complex situation has existed although an increased ordering of properties of the ancient Earth's field is now being deduced (Cox and Doell, 1962).

The exact sampling procedures to be employed on the lunar surface are extremely important in the collection of such physical materials. Fresh samples of unweathered and physically stable materials are required in order to investigate by both nondestructive and semi-destructive means the magnetic properties and magnetic history of the lunar rocks. Shallow drilling to depths of less than a meter as is generally done on the surface of the Earth, may well be adequate. Within an areal extent of approximately 5 meters and on the assumption of a reasonably homogeneous material, no more than three to five samples of the material are required from any one location. As many distinct sample sites as possible should be established on each lunar mission. It is also important that the orientation of the samples obtained are determined with respect to a lunar set of coordinates to an accuracy of $\pm 5^{o}$ as well as the relative location of the sample sites.

Procedures for obtaining such specimen by the use of specially developed drilling equipment must be implemented. The possibility of using the LEM itself as the basic support structure for the drilling of sample cores must be considered. The potential removal of loose surficial material by the descent maneuver rocket's exhaust and logistic problems merit this approach. At the present time the requirements for a deep drilling capability (100 meters or greater) does not appear to be a primary requirement. Subsequent return of fresh samples or the difficulty in obtaining such samples and their subsequent analyses may indicate, however, the necessity for a modification of such sampling procedures. All samples returned are optimumly drill core specimen of approximately 1" diameter for the most efficient and direct utilization in the laboratory.

The nondestructive measurements to be made on rock samples include:

1) Remanent magnetic field
2) Coercive magnetic force spectrum
3. Isothermal remanent magnetism (IRM) induced at a number of separate field strengths
4) Determination of coercive force spectrum of IRM
5) Magnetic susceptibility and electrical conductivity
6) Anhysteretic remanent magnetic (ARM) properties
7) Determination of coercive force spectrum of ARM

The above measurements do not require the physical destruction or deterioration of the rock sample and the material may always be returned to its original magnetic state since the changes to the original sample are known.

The following procedures are potentially destructive in that they may or may not leave the material in a modified condition, although in all possibility only slightly so.

8) Saturation magnetic properties - thermoremanent magnetic measurements (TRM)
9) If the measurements in (8) indicate no significant chemical changes have resulted, then a repetition of the measurements listed above (1-7) are to be performed

It is important that those samples of material for which the remanent and intrinsic magnetic properties are determined, also be age dated by some means. With this information and the interpretation of the remanent magnetism, conclusions about the lunar history and origin can be deduced. In the return of the samples to the terrestrial laboratories it is important that the material not be exposed to fields stronger than 10 gauss nor exposed to temperature variations beyond a reasonable upper limit. More importantly, however, they should not be exposed to variations in temperature beyond a total range of $\pm$ 10°C. when exposed to fields as large as 10 gauss.

The possibility of directly measuring the electrical characteristics of the Moon in-situ is a subject for future consideration. At the present time one of the major problems for measurements of in-situ electrical properties appears to be the mechanism for affecting direct electrical contact with lunar material. Direct utilization of the LEM's support pads may be one possibility. Although various electromagnetic geophysical prospecting methods exist for determination of relative terrestrial electrical properties of the very near surface material it is impossible to propose at this time a simple and effective measurement procedure which will yield accurate results on the lunar surface. It is reasonably certain that appropriate procedures can be developed once the physical properties of the lunar material are known.

July 14, 1964 ----- Prepared by: Norman F. Ness, Chairman
James Balsley
Richard R. Doell
Victor Vacquier

## References


Bridge, H. S., A. Egidi, A. Lazarus, R. Lyons, Results of MIT Faraday Cup Plasma Measurements on IMP-I, COSPAR-Florence, Italy, 1964.

Cox, A. and R. Doell, Review of Paleomagnetism, Bull. Geol. Soc. of America, Volume 71-6, pp. 695-768, 1960.

Dolginov, S. H., E. G. Eroshenko, L. N. Zhugov, N. V. Pushkov and L. O. Tynrmina, Magnetic measurements on the second cosmic rocket, Artificial Earth Satellites-5, 16-23, 1960. (ARS Journal Suppl., 1640-1643, 1961).

Gold, T., The hydrogen atmosphere of the moon, 3rd Int. Space Sci. Symp., Wash., D. C., 1962.

Ness, N. F., C. S. Scearce and J. B. Seek, Initial Results of the IMP-I Magnetic Field Experiment, J. Geophys. Res., 69, to appear, 1964.

Snyder, C. W. and M. Neugebauer, Interplanetary solar wind measurements by Mariner II, Space Res., IV, 1964 (to be published).

## List of Figures

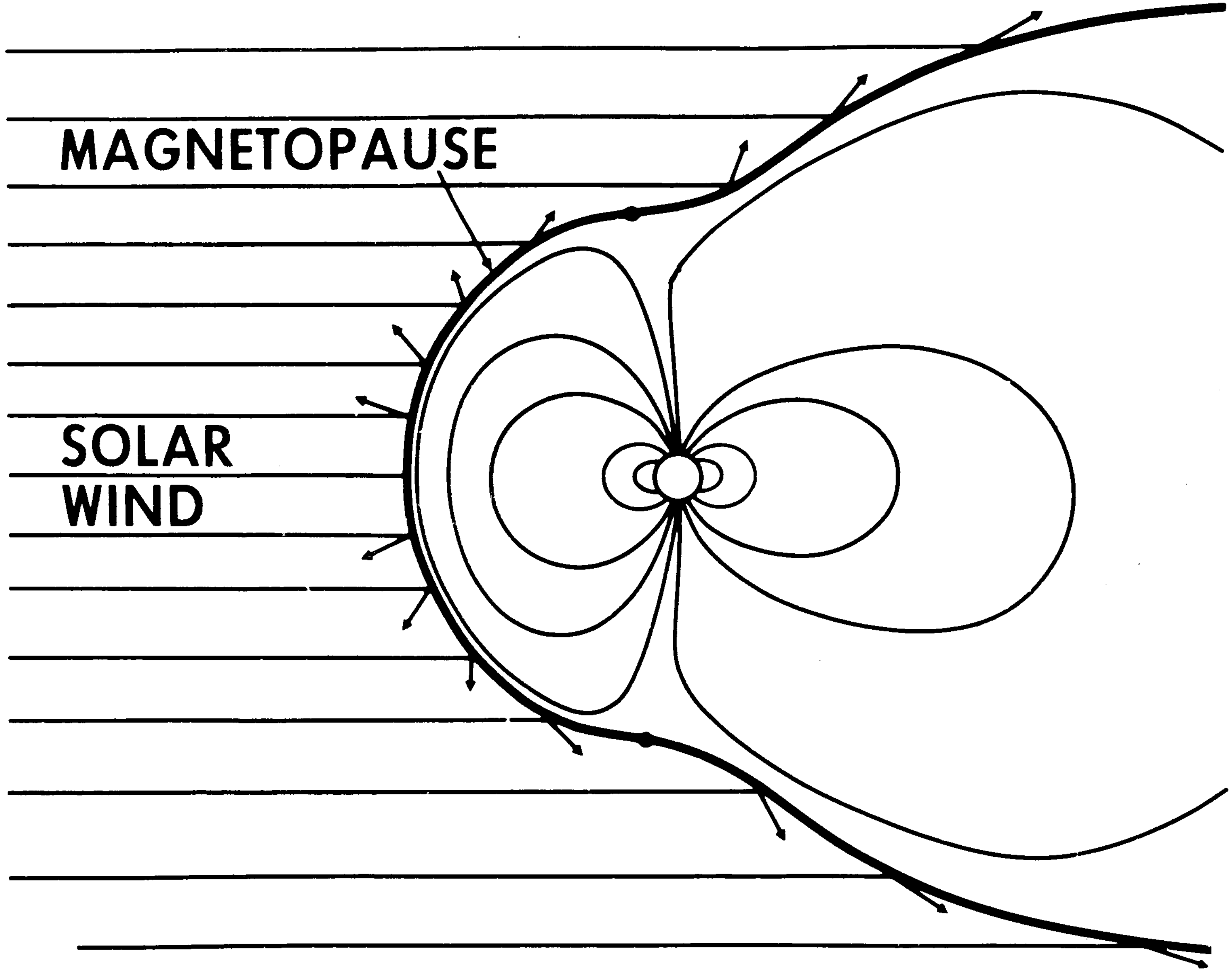



Figure 1

Schematic illustration of interaction of streaming solar plasma and planetary dipolar magnetic field (in the absence of any interplanetary magnetic field)

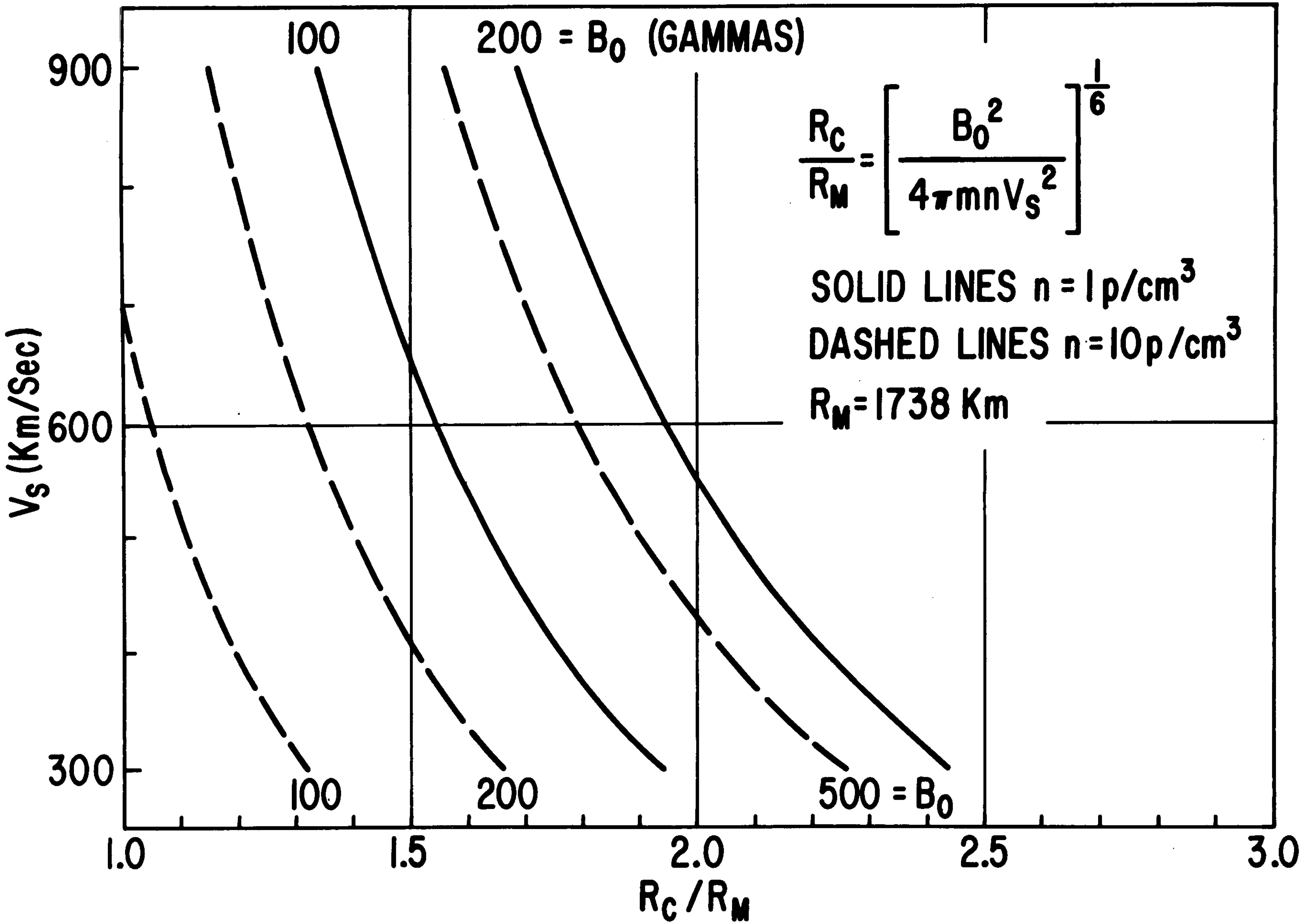



Figure 2

Theoretical stand off distance ($R_c$) in units of Lunar radii ($R_m$) for different solar wind fluxes and equatorial field strengths assuming the Moon possesses a dipolar field.

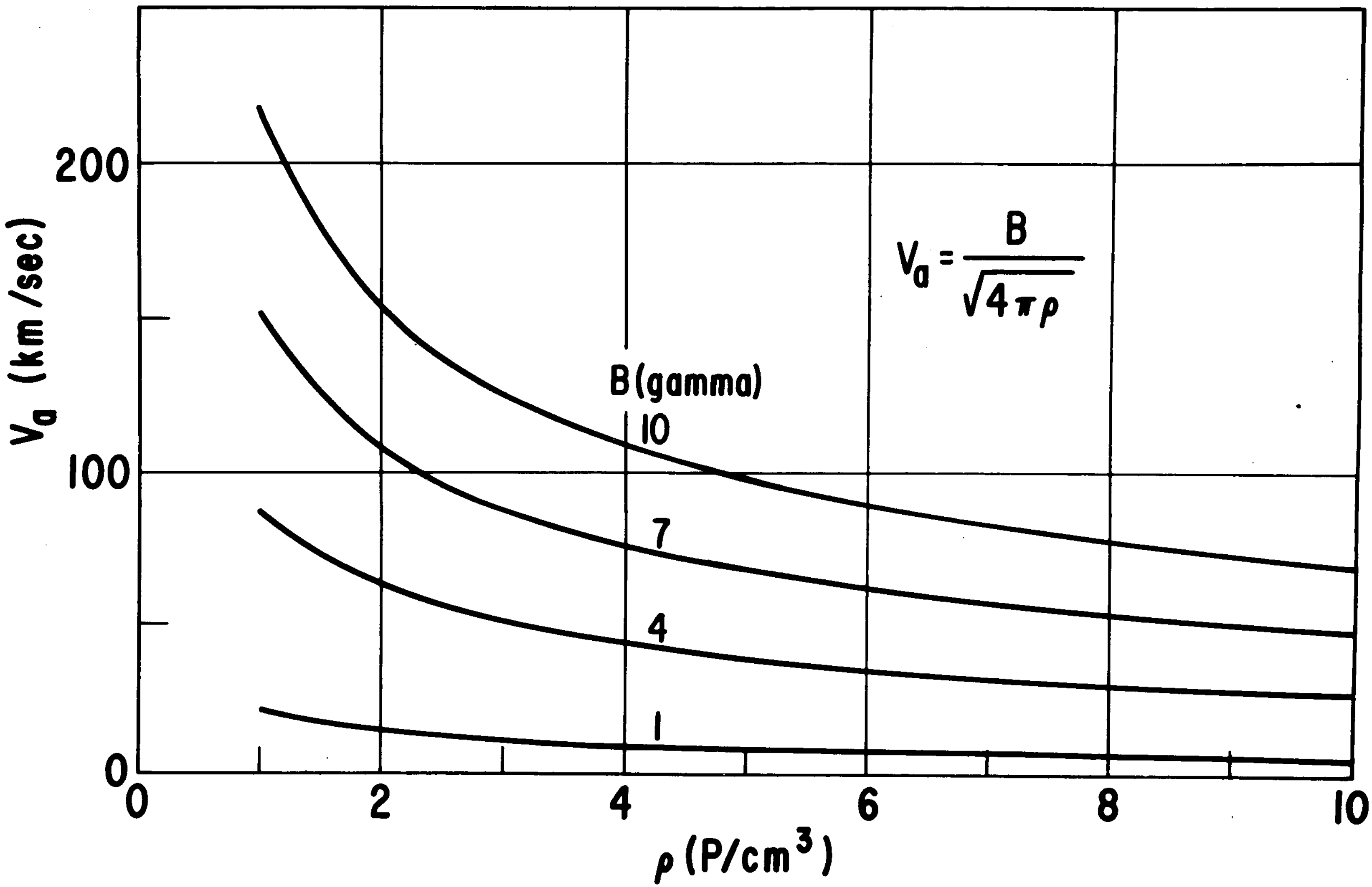



Figure 3

Alfvén velocity as function of solar wind plasma density and interplanetary magnetic field strength.

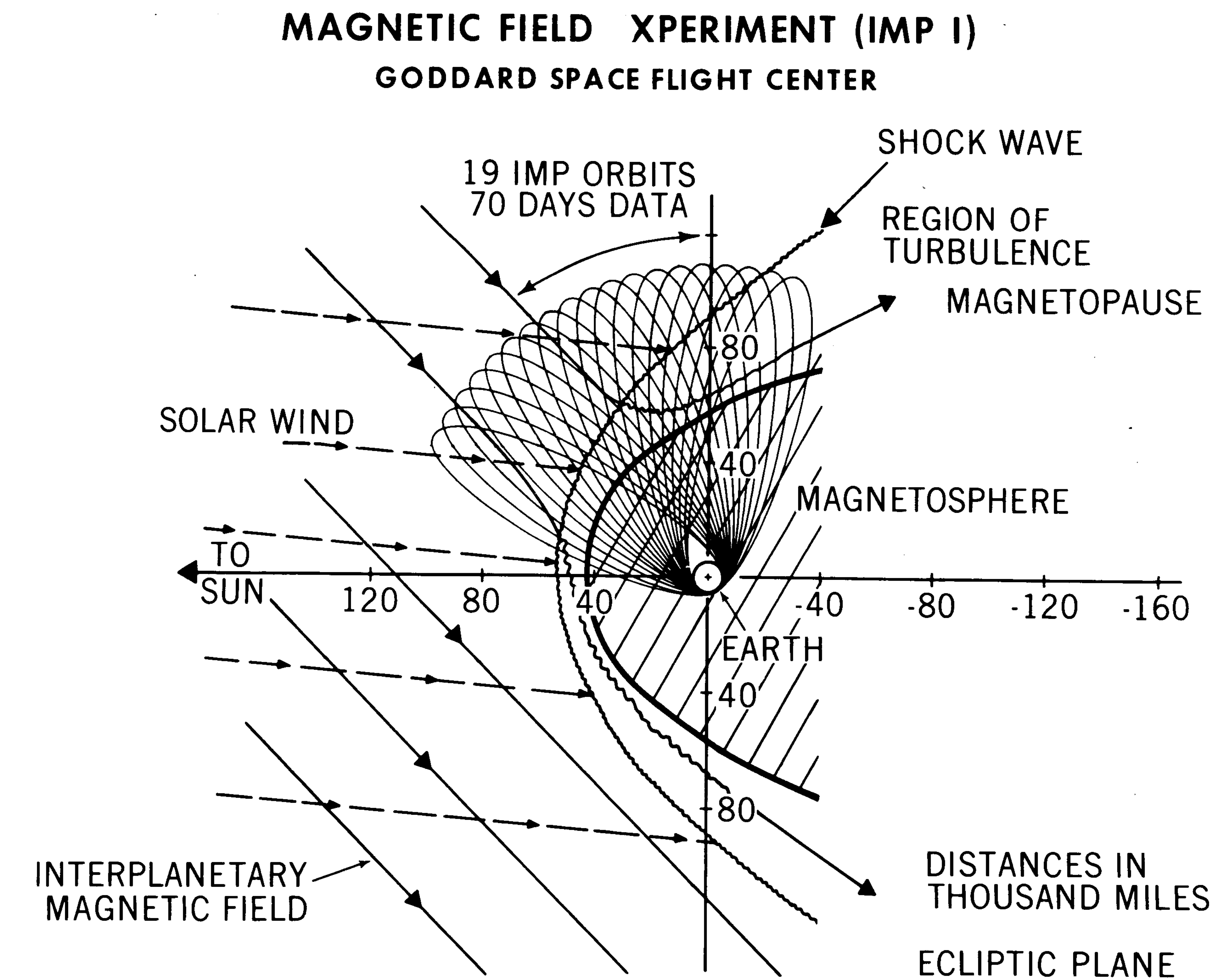



Figure 4. Summary of initial results of IMP-I magnetic field experiment mapping the interaction between the solar wind and the geomagnetic field. (after Ness et al., 1964)

MOON AND IMP (ORBIT 5) POSITIONS, DECEMBER 1963

VIEW ON ECLIPTIC PLANE

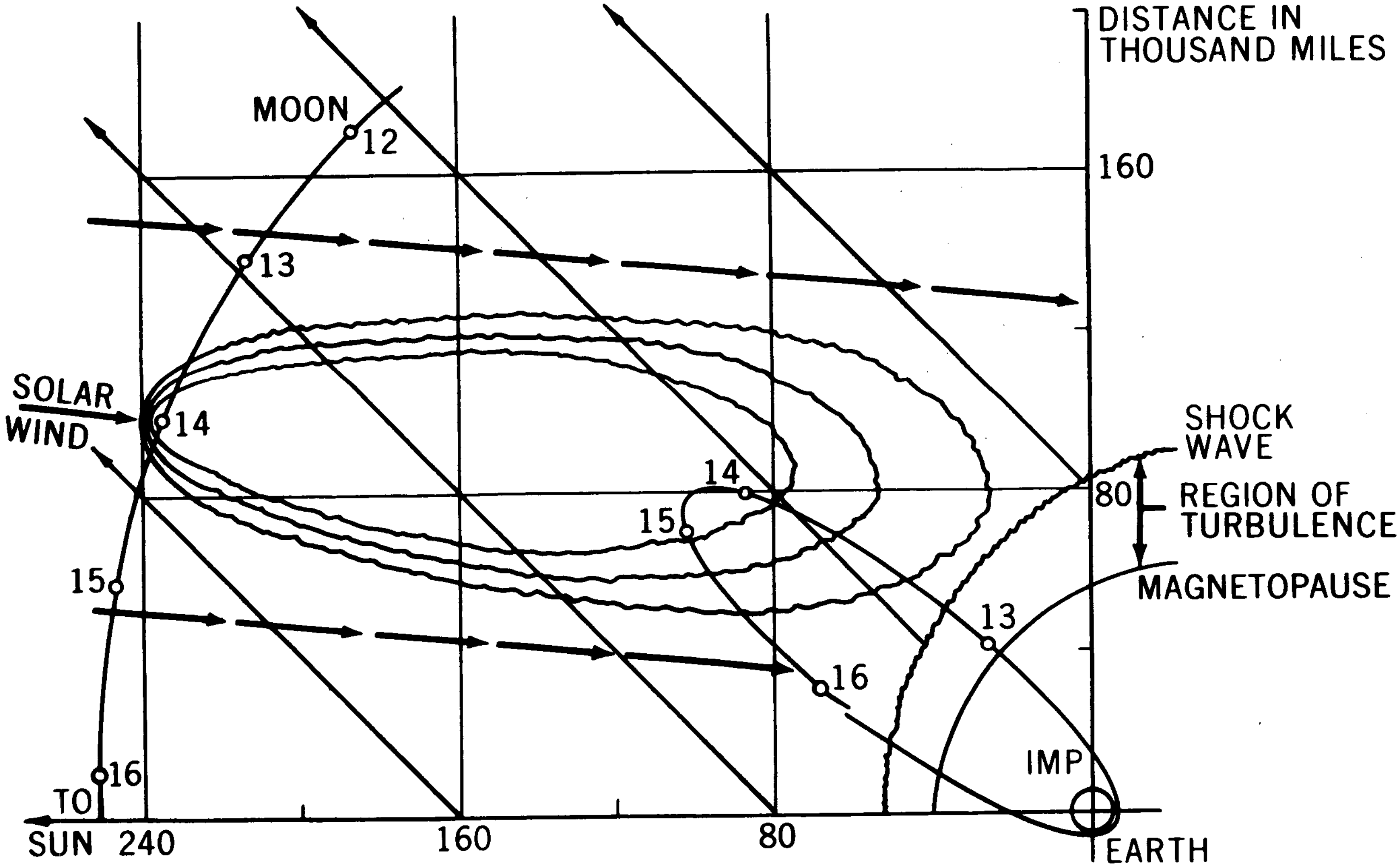



Figure 5

Detection of lunar magnetohydrodynamic wake by IMP-I (after Ness et al., 1964).

117

N66-18674

Section IX

# Preliminary Report on Lunar Heat Flow Measurement

Heat flow planning teams

S. P. Clark, Chairman, Yale University
A. H. Lachenbruch, U. S. Geological Survey
R. Von Herzen
M. G. Langseth

The internal thermal region of a planet is of fundamental importance in determining its development. On the earth, phenomena such as mountain-building, metamorphism, and igneous activity have their origin in deep-seated thermal processes. The moon is believed to be much less active than the earth as far as these processes are concerned, but some recent observations have suggested that it is not entirely dead. Even the total absence of thermal activity at the moon's surface would not mean that its thermal region was uninteresting. The causes of so important a difference between the earth and the moon merit intensive study.

The quantity, measurable at the surface, which has proven to give the most useful information about the internal thermal region of the earth is its heat flow. Heat flow is defined as the amount of thermal energy conducted to the surface and lost to interplanetary space, per unit area and unit time. This quantity is virtually unique among those accessible to geophysical observation in that it depends not only on the present constitution of a planet but also on past events extending back to its origin. Hence, observations of heat flow can set limits on conditions at the time of the origin of the solar system.

Observations of heat flow cannot be interpretated uniquely. There is uncertainty about the distribution of sources of heat, and the relatively long duration of the transient state in the case of heat conduction introduces additional uncertainty which is not present, for example, in the interpretation of gravity or magnetic data. The heat flow observed today originates partly in radioactive sources which have persisted up to the present, and partly in original heat and extinct radioactivity. There is no way to distinguish heat from these separate sources. Clearly knowledge of surface heat flow above does not permit us to set up a unique thermal history of a planet, but it does force us to discard large numbers of models which lead to a contradiction with observation. Experience with models of the earth suggests that the restrictions on speculation imposed by this single measurable quantity, the heat flow, are in fact severe.

As an illustration of the type of information we may expect thermal observations to provide, consider the variation of heat flow with position at the surface of the earth. Early observations of heat flow on land, coupled with determinations of the radioactivity of rocks, showed that a substantial fraction, perhaps half or more, of the measured flux originated in radioactive decay in the continental crust. It was anticipated that heat flow at sea would be substantially lower than on land because of the much thinner crust in the oceans. Measurements at sea have shown that this is emphatically not the case: the mean flux is nearly the same as in the continents. This unexpected result is not yet fully understood, but it is clear that differences in crustal heat production between continents and oceans are compensated by opposing differences in the mantle. This in turn shows that continental features persist, on the average, to considerable depths. It is intriguing to wonder whether heat flow observations on the lunar highlands and maria will also lead to unexpected and far-reaching conclusions. But the answer to such a question will inevitably have to follow the equally intriguing determination of the average lunar heat flow.

A primary reason for the scientific exploration of the moon is of course that it enables us to double our sample of the terrestrial planets. But in the case of heat flow there are special reasons why it is fortunate that the moon is our nearest neighbor. They are the result of its small radius. In the case of the earth, cooling from the surface has affected the temperatures only to a depth of about 700 km, provided conduction and radiation are the principal means of heat transfer. Furthermore heat generated by radioactive decay at depths greater than this makes only a minor contribution to the surface heat flow. Hence the earth's surface is thermally insulated from material deeper than roughly 700 km: i.e. about 70% of the earth cannot be observed thermally. If the thermal properties of the moon are similar to those of the earth, and if the two bodies are of the same age, we would expect the moon's surface to be thermally disconnected from only about 20% of the volume of the planet. A measurement of heat flow on the moon goes much further towards determining the internal thermal region than does a similar measurement on the earth.

Hence because of the small lunar radius, a measurement of lunar heat flow will permit upper and lower limits to the content of radioactive elements to be set. The thermal measurements detect elements which are present in minor or trace amounts, and thus complement other techniques, such as seismology, which are sensitive only to major constituents. A combination of geophysical techniques, including thermal measurement, can give important clues to the bulk composition of the moon. Is it chondritic, does it differ from the chondrites in ways that we suspect the earth may differ, or does it have chemical features which are unlike either the earth or the chondrites? Answers to these and related questions can be found from a carefully planned program of lunar exploration. Determination of the lunar heat flow is an essential part of that program.

## Proposed Methods of Measurements

Our lack of knowledge of the physical nature of the moon's surface makes it very difficult to select the best measurements to determine the heat flux from the interior of the moon, and the thermal properties of the surface material. Astronomical observations of the radiation from the moon provide us with estimates of the surface temperatures and thermal properties averaged over very large areas of the moon. Infrared measurements of the radiation from the surface have shown that the temperature fluctuates from 120°K to nearly 400°K during a 28-day lunation. These large surface fluctuations are transferred downward by both radiative and conductive heat transmission very near the surface and by conduction alone at depth greater than several centimeters. The variations will be superimposed upon the heat flow from the interior. Temperature gradient measurements must, therefore, be made at depth where the variations are small enough so that they may be removed from the temperature observations by measurements over several lunations and the application of linear heat-transfer theory. Observations of the cooling of the moon's surface during an eclipse or after the passage of the terminator indicate that these fluctuations do not penetrate very deep. This implies that the surface material of the moon is an extremely poor conductor of heat and has a very low heat capacity. It is conjectured from several lines of evidence that the surface material is largely very fine rock dust.

Calculations have been made of the subsurface temperature fluctuations caused by the incident solar radiation, where one cm of fine dust with a conductivity of $.3 \times 10^{-6}$ cgs overlies rock with a conductivity of $5.4 \times 10^{-3}$ cgs. The maximum and minimum temperatures as a function of depth are shown in Fig. 1.

Another factor affecting the interpretation of heat flux at the surface is the large distortion in the near surface steady-state temperature field that will occur if windows in the dust cover exist or if the cover is not of uniform thickness. Some interpretations of the moon's cooling rate during an eclipse suggest up to 8% bare exposures. The disturbance in subsurface termperature gradients resulting from the difference in mean surface temperature between exposed rock and dust is appreciable to depths of the order of the diameter of the exposure. Hence, if exposures exist, it would be impossible to determine the true flux of heat from the moon's interior without penetrating to greater depths than the diameter of the exposure. The small percentage of exposure postulated at the smooth appearance of much of the moon's surface, however, suggests that large areas of rather uniform dust cover may exist.

Another experimental difficulty results from the fact that the linearized theory of heat conduction cannot be expected to hold rigorously on the moon. Not only does the thermal conductivity vary with temperature, but also mean lunar conditions are well below the Debye temperatures of plausible lunar materials. This implies a temperature-dependent specific heat. In the case of a steady periodic perturbation of temperature, the linear theory predicts that the mean temperature averaged over one period is equal to the unperturbed value. No such simple result is true for the non-linear case, and the unperturbed temperature cannot be obtained without knowledge of the thermal properties of the material as functions of temperature.

In view of the uncertainties outlined above, it is proposed that three simple thermal experiments be emplaced on the surface of the moon by an astronaut. The object of these experiments will be to learn as much as possible about the surface heat flux, the surface temperature fluctuations and their propagation into the subsurface, and the thermal properties of lunar surface materials at several locations on the moon's surface. The experiments proposed are: 1) Measure the temperature and conductivity at three points in a drilled hole 3 to 5 m below the moon's surface. 2) Measure the temperature as a function of depth and time in the penetrable lunar surface material in an undisturbed area of the moon's surface. 3) Measure the temperature as a function of depth and time in the surface material of the moon beneath an area disturbed by an insulating blanket and also measure the heat flux through the blanket as a function of time. Measurements 2) and 3) will each be carried out at several locations on the moon's surface.

I. Drill hole measurements. If a hole is drilled in hard rock, temperature measurements will be made with a probe which can be inserted into the hole after it is drilled. A two-meter probe is planned with three temperature-sensing elements evenly spaced along its length. These elements must have high precision for temperature gradients as low as a few thousandths $^{\circ}C/m$ may represent the total heat flux from the interior. We must measure this gradient to an accuracy of about $0.001^{\circ}C/m$. Thermal elements consisting of small quartz oscillators appear to be best suited to this application.

*In situ* measurements of the thermal conductivity can be made by the transient method using the same probe. A known amount of heat is introduced near one of the sensors, and the conductivity and diffusivity of the rock are determined from the rates of heating and cooling. The amount of heat introduced is small so that the ambient temperature values of these quantities are found.

II. Measurement of temperatures as a function of depth and time in the penetrable lunar surface material. For this experiment strings of thermal sensors on a probe, spaced roughly five cm apart, will be driven by hand into the penetrable lunar surface material. It is planned to make the probes 50 cm long with 11 sensors per probe. The probes will be made so that the sensors will be left in the hole after insertion and the probe retracted. Should it be impossible to penetrate the full 50 cm, the elements remaining out of the hole will be laid along the surface. These sensor strings will be placed in four locations on the lunar surface.

From these temperature measurements it will be possible to determine the damping of the surface temperature fluctuation, the radiative component of heat transfer in the upper material, and the material's effective diffusivity. These measurements will not only be of value in interpreting the heat flow results, but will greatly aid in the analysis of microwave and infrared measurements of lunar surface radiation made from Earth or from a spacecraft.

III. The measurement of temperature as a function of depth and time in the surface material of the moon beneath an area disturbed by an insulating blanket. A string of temperature elements as described above will also be used to measure temperature beneath a circular blanket of poorly conducting material (K = $10^{-7}$ cal/cm sec°C or about 1/10 the estimated conductivity for lunar dust). The blankets will be 1/2 m in diameter and one or two cm thick. Materials with conductivities of about $10^{-7}$ cgs are already being made for the storage of cryogenic fluids. Two strings of temperature sensors will be driven vertically into the lunar surface beneath the blanket, one at the center of the blanket and the other halfway between the center and the edge. Temperature elements will also be placed inside the blanket to measure the gradient and hence the heat flux, since the thermal properties of the blanket material will be well known. The arrangement proposed is shown in a sketch in Fig. 2. When the blanket is emplaced on the surface, it will cause a large disturbance of the flux. Measurements of the flux through the blanket and the temperature at several points beneath the blanket as a function of time allow the determination of the conductivity of the surface material. This combined with diffusivity measurements defines thermal properties of the surface material completely. If the surface of the moon proves to be covered by a uniform dust layer, then it is possible to determine steady-state flux from the moon's interior by this technique. It is proposed to put this experiment at several different locations on the moon's surface so that lateral variations of heat flux will be detected if present.

All the above experiments will be emplaced on the moon and left to transmit temperatures of the various sensors back to Earth for at least one year. It would be extremely valuable to obtain measurements periodically two, three, and five years after the experiment is started. This long-term sampling appears completely feasible with the power supply now planned for the Apollo passive experiments.

During the first year, the temperature at all elements will be sampled as often as once every three hours. This fast repetition rate is not necessary during a large part of the experiment, but will be extremely useful during periods of rapid surface temperature variation such as the passage of terminator or a lunar eclipse.

Research Proposal

It is convenient to classfy lines of further research in one of the following categories: hardware development, mathematical studies of feasibility or expected accuracy, and experiments to be conducted on lunar missions preceding Apollo. Included in the second category would be problems of data reduction. It is anticipated that this work will be done by the scientific team and by personnel of the Manned Spacecraft Center.

A. Hardware development.

1. Temperature sensors - The large surface fluctuations and their rapid attention with depth require that temperature elements of different sensitivity be used at different depths below the surface. At the surface, low sensitivity elements such as platinum or copper wire resistance thermometers are suitable; at greater depth thermistors can be used; at still greater depths very precise elements such as oscillating quartz crystals are required. The selection, calibration, and testing of the thermal elements will be done by the scientific team.

2. Selection of blanket material and measurement of its properties will be done by the scientific team.

3. Detection circuits for the resistence thermometers and thermistors consist of self-nulling bridge networks of the Carey-Foster type. Each sensor will be placed in the network sequentially by a precision selector switch. The output of such a detecting unit can be analog or digital. Detection of the crystal thermometer frequency can be direct if FM telemetering is used, or if analog or digital telemetering is used, a discriminator circuit is required. The development of this equipment will be done largely by the Manned Spacecraft Center personnel in close cooperation with the scientific team.

4. The required telemetry for all passive experiments is being provided by Houston personnel.

B. Mathematical studies.

A principal interest will be various cases of non-linear heat flow in heterogeneous media. Few exact solutions are available and recourse must be had to numerical and analog methods in almost all cases. Access to digital and analog computers is required; it can be provided by members of the scientific team. The purpose of the studies will be to determine the minimum depth of hole that will be usable if a deep-hole method is possible and the accuracy and errors to be expected in the other experiments. Procedures of data reduction will emerge as natural consequences of these studies.

C. <u>Experiments for lunar missions preceding Apollo</u>.

Measurements of infrared and microwave radiation from the moon's surface with a resolution of a few m to one km will be extremely valuable to determine the degree of heterogeneity of the thermal properties of the lunar surface. Such measurements may be made by visible and infrared photography at relatively short range and by scans with infrared and microwave detectors near terminator and on the dark side of the moon. These could be done from a close-in lunar orbiter. It would also be extremely useful to have the surface temperature experiment reinstated on the Surveyor flights. Such data will also be of great value to preliminary geological surveys of the moon.

## VERY ROUGH BUDGET

Estimates in thousands of dollars are given in parenthese following the items.

1. Computer time. (10)
2. Selection of blanket material. Includes small vacuum facility and associated instrumentation for determination of thermal properties. (10)
3. Selection and calibration of temperature sensors. (20)
4. Devices for emplacement of sensors in hole and measurement of thermal conductivity. (10)
5. Travel. (5 per year)
6. Salaries. Part-time salaries for members of the scientific team and salaries of technical personnel. (30 per year)

Figure 1 Maximum and minimum lunar temperatures as a function of depth.

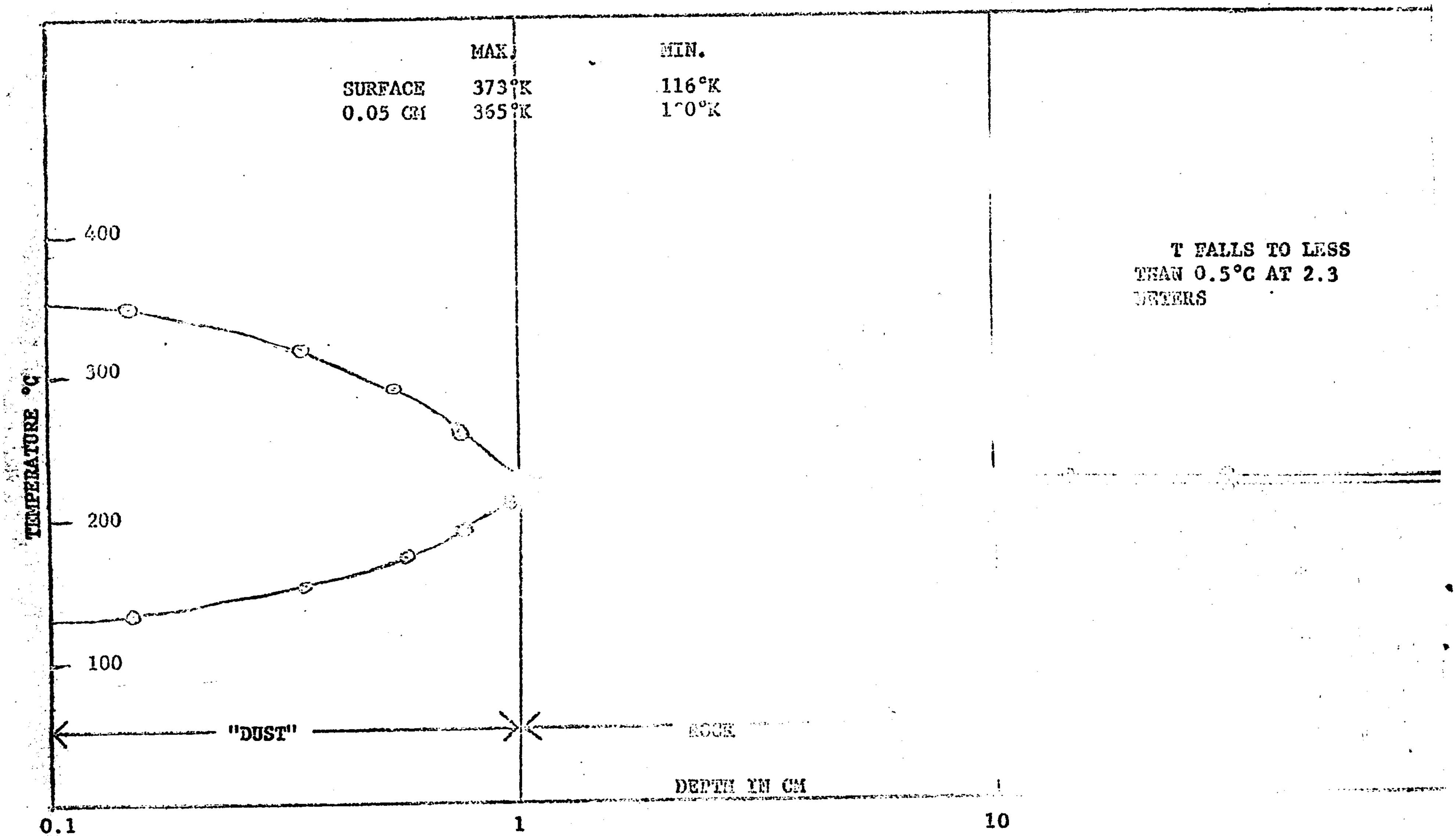



Fig. 1

Figure 2 Diagram showing measurement of temperature as a function of depth using an insulating blanket.

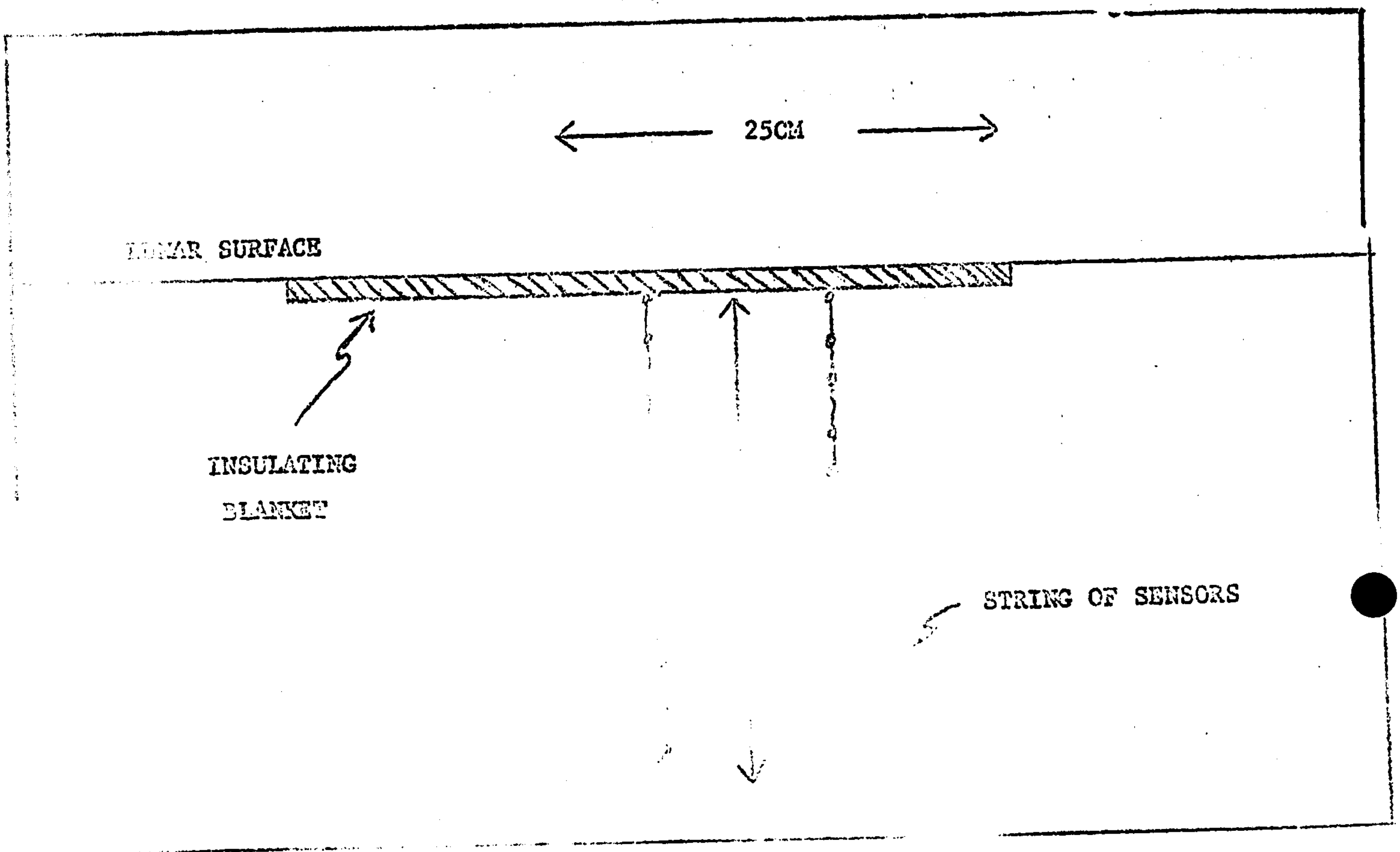



Fig. 2

N66-18675

13/15

Section X

# REPORT OF THE BIOSCIENCES PLANNING TEAM

The Biosciences Panel of the Apollo Sciences Team is herewith transmitting the results of its several meetings. The first of these meetings was held at NASA Headquarters in Washington, D. C., on June 1, 1964. Several other meetings of the Panel were also held on the occasion of the Manned Lunar Exploration Symposium at Houston, Texas, June 15-17, 1964. During that Symposium, Panel members also met with members of other Apollo scientific panels, in particular with the Geochemistry and Minerology-Petrography Panels. Discussions were also held with members of the Staff of the Manned Space Center.

The main concerns of the Biosciences Panel were: minimization of biological contamination of the moon and of possible back contamination of the Earth, astronaut training, sample collection, laboratory facilities at the Manned Space Center for the initial examination of lunar samples, the search for the existence of viable organisms on the moon, and the search for lunar organic compounds. These concerns are outlined in the Table of Contents on the next page.

All documents referred to in this report that have to do with biological filters and laboratory enclosures have already been sent to the MSC Staff in Houston (Dr. Elliott Harris of the Crew Systems Division).

# TABLE OF CONTENTS

## MINIMIZATION OF BIOLOGICAL CONTAMINATION OF THE MOON

There has long been general agreement that any introduction of microorganisms from the Earth onto the moon should be avoided as far as possible. Such an introduction will make more difficult, both now and in the future, investigations into whether the lunar environment does now, or ever did, harbor viable organisms. Consequently, this first section of the Panel's report summarizes its recommendations designed to minimize biological contamination of the moon.

### 1. The LEM

We believe that the outside of the lunar excursion module presents no particular problem. Some bacteria on the outside will undoubtedly survive the trip to the moon. However, because there is no lunar atmosphere, there would be no mechanisms to transport bacteria away from the vehicle during the LEM's sojour on the moon.

The principal source of Earth bacteria would be the LEM's atmosphere. We strongly advise that, on arrival on the moon, the atmosphere within the LEM should be vented through an ultra high efficiency biological filter (see "Air Filtration of Microbial Particles", Public Health Service Publication No. 956, June 1962). These filters have an internal flow resistance of only 2 mm Hg (1 inch of water), a particle (1-5 microns) retention greater than 99.99%, and a capacity of about 400 $ft^3$ per minute per $ft^2$ of filter area. Since the LEM has a volume of about 220 $ft^3$, an ultra high efficiency biological filter should allow the complete venting of the LEM in a few minutes, at most. Just how many minutes this would be depends, of course, on the size of the filter that could be placed in the LEM's vent(s). It is our understanding that members of the Microbiology, Biochemistry, and Hygiene Section at MSC are now determining what is the largest area of biological filter that could be installed on the LEM.

The suggested filter should prevent the escape from the LEM of any viable microorganisms and particulate chemical contaminants (the latter of great importance to the organic geochemists). When the LEM is opened after vacuum has been reached there will be no fluid medium to convey contamination to the lunar surface. Bacteria remaining inside the LEM should stay there, except for those carried by the astronauts themselves, on their space suits, and on their equipment. These problems are considered below. However, the Biosciences Panel would like to emphasize here that it feels that the major source of biological contamination from the Earth would come from the LEM's atmosphere, and that this contamination could be efficiently controlled through the installation of the recommended filters.

Another possibly serious source of biological contamination of the moon would be the bacteria present in the solid retrorocket fuel. It is quite likely that a significant fraction of the bacteria present in the hydrazine and dimethylhydrazine would survive the burning of the fuel. One can imagine small pieces of the organic material being blown out the rocket nozzle and escaping combustion. Consequently, a bacterial examination should be made of the fuel. Furthermore, a measurement should be made of the fraction of the bacteria that survive the fuel ignition. This measurement could be made at the same time as the search for organic impurities that is referred to on p. 16 of this report.

2. Astronauts' Suits

If the LEM is vented through a biological filter, the next major source of contamination would be the leakage through the astronauts' suits. The atmosphere within the suits will, of course, contain microorganisms and probably chemical aerosol contaminants, e.g., dried sputum. We have been informed that the current model of the space suit leaks about 200 cc of air per minute, and that it is unlikely that much can be done to reduce this rate of leakage. What is not known, however, is how much bacterial leakage would also emerge from the space suit. We recommend that the amount of this leakage be determined. This can be done using harmless bacteria and following the procedures given in the "Air Filtration . . ." monograph referred to above. Dr. Charles R. Phillips, Chief, Physical Defense Division, U. S. Army Biological Laboratories, Fort Detrick, Md., and a member of this Panel, has offered his advice to the MSC Staff on biological-leakage test procedures for the space suits.

Although we believe that the rate of bacterial leakage from the space suits should be known, we do not think that this leakage will present any serious problem. Such contamination as is occasioned by such leakage cannot travel very far from the spot where the astronaut is standing because of the lack of atmosphere to supply a transport medium. In addition, we understand that the astronauts will don protective aluminized-fabric overgarments over their space suits. If these overgarments are kept clean and sterile, introduction of bacterial contamination onto the moon should be that much further reduced. We recommend that, before the astronauts leave the LEM, the outer surfaces of the overgarments (or of the space suits themselves if overgarments are not used) be disinfected with a damp cloth or sponge containing a bactericide such as hypochlorite. This particular bactericide would probably interfere with contemplated measurements (by the geochemists) of chlorine isotope-ratios; if so, doubtless another satisfactory disinfectant can be found. A second suggestion for disinfecting is to use the considerable ultraviolet light in the lunar sunshine.

The problem of the outgassing of the suits is considered on p. 17.

3. Scientific and General Equipment

The scientific instruments and general equipment used on the lunar surface will be stored on the LEM in equipment bays. All such equipment should be biologically decontaminated when the bays are finally closed before the launching from the Earth. We suggest that ethylene oxide be used for this purpose. This compound is an effective disinfectant and is the least liable either to cause damage to any instruments or to leave any residue that would be objectionable in the search for organic compounds on the moon.

## MINIMIZATION OF POSSIBLE BACK CONTAMINATION TO EARTH

We consider very small the probability that any viable microorganisms will be found on the moon--and smaller still the chance that, if they do exist, they will be dangerous. One factor that tends to support this feeling is that the Earth apparently has been steadily receiving lunar material (possibly the tektites) resulting from the impact of meteorites on the moon. However, the problem with which we would be faced if lunar organisms pathogenic to animal or plant life were brought back and escaped could be so catastrophic that it cannot be ignored, even though its probability be considered very low. The following sections outline this Panel's recommendations for minimizing back contamination to the Earth.

1. The Returning Command Module and Equipment

The exterior of the Command Model (CM) ought to be essentially free of organisms and should require no treatment. However, all the equipment and sample packages--in fact, everything that comes out of the CM--should be considered as possible vehicles for lunar pathogens. Neglecting, for the moment, the problem of the astronauts themselves (see section below) we feel that it would be advisable at least to wipe off, perhaps with dilute hypochlorite solution, all the outside surfaces of objects as they are being removed from the CM. After all objects of value are removed, the interior of the module could be decontaminated with one of the standard vapor-phase bactericides such as ethylene oxide, B-propiolactone, or peracetic acid.

## 2. Considerations of Quarantine

The most likely source of lunar pathogens, if indeed any exist, would be the astronauts themselves. Lunar organisms, even if not inherently pathogenic, could, acting in conjunction with terrestrial organisms in the nose and throat of an astronaut, produce disease. Since such a symbiotic relationship would depend on the organisms normally found in the respiratory flora of different persons, one could equally conceive that, while the astronauts themselves might not possess the proper combination for activation of lunar organisms, they could in theory transmit such organisms to other persons whose nasal flora did contain suitable symbiotics. Under such circumstances, one would have to consider that any illness occurring within the astronauts within a few weeks after return--or among persons in association with the astronauts--would have to be thought of as potentially significant and therefore subject to strict isolation.

There is also the question of scientists whose studies may necessitate some direct contact with the lunar samples soon after the samples are brought to Houston. It is this Panel's hope and expectation that no such contact will be necessary. The scientific work that needs to be done quickly, before such time (2-3 weeks) as we can be reasonably sure that no pathogens are present, can all be done, we believe, behind biological barriers. (Reports on the specifications, commercial availability, and constructional details of such barriers have already been sent to Dr. Elliott Harris at the MSC.) The other scientific panels have already indicated to us that the studies that need to be done immediately on arrival of the lunar samples at Houston (e.g., x-ray spectroscopy of the radioactive isotopes, mass spectrometry of volatile material) can indeed be done behind the biological barriers. However, if it develops that some early study should be done that cannot use the bacteriological cabinets, and that a scientist will be exposed, then quarantine of that scientist should be considered.

The whole question of the possible return of lunar pathogens is really a public health matter, and, for that reason, the Biosciences Panel feels that further expert advice and opinion should be sought. It is our feeling that it is our responsibility to state that a problem exists, but not necessarily to make recommendations as to how it can be circumvented. Further, we understand that the Space Science Board of the National Academy of Science-National Research Council is convening, at NASA's request, a conference on this subject at Washington on July 29-30 of this year. We hope that this conference will be able to make firm recommendations on the public health aspects of possible lunar pathogens.

3. Astronaut Training

The astronauts are already receiving extensive training in geology and other earth sciences. This should be extended to include microbiological training as well. This training could be given by the microbiologist who is joining the MSC Staff, Dr. Elmo Dooley. The instruction should emphasize methods of collecting and handling samples under aseptic conditions, and should demonstrate how easily sterile material can become contaminated with a person's own microbiological flora. The astronauts should be shown the common laboratory demonstration of bacterial transfer, such as that effected by placing one's finger on, or coughing over, an open petri dish. They should also practice handling and transferring sterile material, and demonstrate that they can do this without contamination.

## SAMPLE COLLECTION AND PACKAGING

### 1. Samples for Microbiological Examination

Lunar microorganisms, if they are to be found at all, are most likely to occur in finely divided material collected either at some depth below the surface, or on the surface at sites where no direct exposure to the Sun's rays ever occurs. Samples should be small (a few grams each are sufficient), separately packaged, and accompanied by a description of the type of locale from which they were taken. The more individual samples that are collected, the greater will be the chance of finding any organisms. The sampling equipment and containers (see sections 3 and 4 below) should be clean and sterile. Efforts should be made to keep the samples cool (preferably below 35° C) all the time from collection to delivery to the MSC laboratories.

### 2. Samples for Organic-compound Search and Identification

The organic chemists, unlike the microbiologists, will need large samples. They will be searching for organic compounds that will exist in, probably, no more than the parts-per-million range, or even parts-per-billion. Thus, samples for the organic chemists should be at least 500-1000 grams in size. It is also obvious that the more such 1-kg. samples the organic chemists had, from different locales, the greater would be their chances of finding lunar organic compounds. It may be that more than one 1-kg. sample could be provided to the organic chemists by their sharing at least one sample with the petrographers. Assuming that a sample of lunar material is already a powder, and thus doesn't need further grinding or crushing, the organic chemists will wish only to do a series of organic solvent and aqueous extractions. The great mass of remaining (and essentially unchanged) minerals can then be used by the petrographers for their examinations. Dr. C. Frondel of the Minerology-Petrography Panel indicated at the Houston meeting that such a procedure would be acceptalbe for at least part of the material for which that Panel is planning experiments. Arrangements for multiple-use of the lunar samples is highly desirable. It should be quite feasible for the organic chemists to do their extractions and then give the material to other scientists for whose work the simple extractions would not interfere.

Like the biologists, the organic chemists would prefer sub-surface samples. Samples taken from the lunar surface, even from sun-shaded locales, will be of far less interest. The further one goes below the lunar surface (assuming the dust-layer model) the older the material should be and the more protected from cosmic ray effects. The organic chemists would, also like the biologists, prefer to have their samples packaged separately and accompanied by a description of the locale (appearance of the surface material, how far below surface the sample was taken, relation to position of the LEM).

3. <u>Sampling Devices</u>

The best way to collect samples may not be known until the "Surveyor" missions have provided us with a good knowledge of the character of the lunar surface where Apollo landing(s) will be made. However, it seems best at this time to make tentative plans for sample taking from both a surface that is (a) thick dust or finely divided material and (b) solid rock. In the case of (a), the device shown by Dr. Shoemaker of the Geology Panel, at the Houston Symposium, the highly-modified "Jacob's staff", should be suitable to enable the astronauts to reach down and take samples from as deep a position as possible in the "dust" layer. However, this device needs alteration to permit the gathering of small (1-10 gram) as well as large (1 kg.) samples. Of course, the sample scoop must be completely sterile and completely free of organic compounds.

If case (b) holds and the LEM sits down on solid rock, some kind of a drill or "coring" device will be necessary. It is our understanding that NASA now has such a device under development, but that it is expected to be too heavy to go on the first Apollo manned lunar landing. If that is true, and if the first landing will be on solid rock, we can only recommend that the astronauts be provided with some sort of pick-and-shovel combination that may enable them to chip off a few inches of the upper surface and bring back at least a few chunks of the underlying material. Again, any such devices used on the moon must be clean and sterile.

4. <u>Sample Containers</u>

This is a subject that is of very great interest to all the scientific panels, but it is also one on which considerable agreement was reached at the Houston meeting. In common with the other panels, the Biosciences Panel strongly recommends that the sample packages be made of metal (aluminum appears to be a very good choice), that they be gas-tight, and that their sealing be accomplished on the simple repressurizing of the LEM. We recommend that the aluminum containers be equipped with indium-wire or gold-wire seals. Such seals are in use in the laboratories of A. Tousimis (George Washington University) and J. R. Cuthill (National Bureau of Standards). Since the sample storage compartment in the LEM will be a rectangular parallelepiped, the individual aluminum containers should be of the same, or cubic, shape. The container "boxes" would have the indium-wire around the top edges with, of course, detached tops. After the astronaut had placed a sample in the "box", the top would then be laid on the indium strip. On return to the LEM and repressurization of the module, the aluminum-indium would form a tight seal. Again we repeat the obvious: the containers must be clean and sterile.

It would be of considerable value if, after the aluminum containers were placed in the LEM's storage compartment, the compartment could be pressurized up to 1 atmosphere with a cylinder of carefully-purified nitrogen. In this way no oxygen, water, bacteria, etc. could reach the samples even if one or more sample containers had, or developed, a leak. The 2-cubic foot sample storage compartment could, of course, be pressurized to 1 atmosphere with a very small, "lecture-sized" cylinder of gas.

One of the samples should be placed in a sealed metal container that will permit mass spectrometric examination of any volatile material that might diffuse out during transit. Dr. P. Gast of the Geochemistry Panel is in charge of the arrangements for the initial mass spectrometric examination in Houston, and our Panel (Dr. K. Biemann) will collaborate with him so a search can be made for both organic and inorganic volatile compounds. At any rate, the sample container whose content is to be analyzed should be opened directly into the mass spectrometer while the spectrum is continuously scanned. For this, some way of connecting the sample-container and spectrometer has to be designed. This could be either a flange permanently attached to the sample-container (which would, however, increase its weight and require the astronaut to decide which particular sample to place in the flanged container) or in the incorporation of a large vacuum lock in the design of the spectrometer. The sample-container could then be put into this lock, lock pumped down, lock opened to the spectrometer, and the sample-container punctured (using a bellows-operated steel pin) after the background spectrum became negligible. Devices of this kind should present no engineering problem.

5. **Seismology Charges and Retrorocket Fuel**

Some of the planned seismology experiments will require the setting off of small explosive charges on the moon. Such charges would make very insecure the organic chemists' search for lunar organic compounds. The solution here is simple: the astronauts should be instructed to set off the charges only after the samples for the organic chemists have been collected and safely stored in the LEM.

Much more serious is the problem of the LEM's retrorocket fuel. On its lunar landing, the LEM's motors will burn about 4000 lbs. of a $N_2O_4$-hydrazine-unsymmetrical dimethylhydrazine mixture. For the organic chemists and their search for traces of lunar organic compounds, this is a serious situation. It emphasizes the necessity of sub-surface samples. It also means that the astronauts should take, for the organic chemists, samples as far away from the landing site as possible. In addition, if, on landing, the LEM approaches the lunar surface tangentially (as opposed to straight down), the samples should be collected away from the LEM in the direction opposite to the approach path.

Regarding the retrorocket fuel, we strongly recommend that a study be made both of the trace organic impurities in the fuel and of the combustion products formed when the $N_2O_4$-dimethylhydrazine mixture is burned in vacuum. It would be particularly valuable if such studies could be made in the presence of the kinds of minerals expected on the lunar surface. The organic chemists will need to know more than the obvious, volatile combustion products ($CO_2$, $CO$, $H_2O$, $N_2$, $H_2$, $NO$, etc.). They will need to know what higher molecular-weight organic compounds are present or formed, including those that are formed in minute percentage yields (down to at least 0.01%). Since gas chromatography will be one of the organic chemists' chief tools in searching for lunar organic compounds, it should be used in the search for the organic products of the dimethylhydrazine oxidation. In addition, at the time of launching of the Apollo spacecraft, a sample (a few pounds) of both the $N_2O_4$ and the dimethylhydrazine used for the LEM should be saved. Then, when the lunar samples are back on Earth, if the organic chemists find evidence for a compound (e.g., in the mass spectrum or GLC trace) as yet unreported as a $N_2O_4$-dimethylhydrazine product, they still may have the chance of ruling out the rocket fuel as the source of the compound.

From the organic chemists' viewpoint, one excellent way around the retrorocket fuel problem would be to use perdeutero dimethylydrazine (with all hydrogen atoms replaced by deuterium). We believe, however, that other scientific groups that are interested in lunar isotopic ratios would object to this. This idea might be kept in mind for a later Apollo manned landing if (a) no further isotopic ratios (H/D ratios, at least) were to be determined and (b) the organic analysis failed to settle clearly whether a particular compound was lunar-indigenous or came from the retrorocket fuel burning.

6. Outgassing of the Space Suits

Another matter of concern to the organic chemists is the possible outgassing of the astronauts' suits during the sample-collecting trips from the LEM. This might lead to troublesome chemical contamination of the samples. It is, therefore, our recommendation that a thorough study be made of the volatile compounds that escape from the space-suit materials under the lunar temperature and pressure conditions. It is particularly important that gas chromatographic and mass spectrophotometric records be made of such volatile compounds. Furthermore, such records should be gotten in consultation with, or under the supervision of, the scientists who will be examining the returned lunar samples for volatile organic compounds.

If studies of the outgassing of the suits indicated severe organic-compound contamination, we would hope that the possibility would be considered of substituting material of extremely low vapor pressure (metals, metal bellows) in the construction of the space suits. We realize, of course, that the technical problem here may be quite insurmountable, and we raise this point only with respect to what the organic chemists might consider to be "ideal" sample collecting conditions.

7. Summary of Sampling Recommendations

It is perhaps worthwhile to summarize here the Biosciences Panel's recommendations regarding sample types, collection, packaging and transport. In response to the suggestion made by Dr. Verne C. Fryklund, Program Manager for the Apollo Science Program, we will designate our recommendations as ideal (I), acceptable (A), and minimum (M).

a. Number and amounts of samples:

(I) Many 1-gram samples of finely divided material collected from different locations (all from sub-surface and permanently shaded spots) plus several sub-surface 500 g-1 kg. samples. (A) Several 1-gram samples and one or two larger samples, collected as above. (M) Anything in any form the astronauts can bring back.

b. Sample collection:

(I and A) Sample material should be collected only with instruments that are sterile and completely free of detectable organic compounds. The locale from whence the sample was taken should be recorded on the container. (M) Samples picked up in any fashion the astronauts can devise.

c. Sample containers:

(I) Hermetically-sealed, metal, clean-and-sterile containers; containers placed in inert gas-pressurized storage compartment on the LEM. (A) Samples placed in individual, clean, and sterile plastic containers (preferably Teflon). (M) Samples placed in anything the astronauts can find available.

d. Sample transport:

(I and A) The samples should be kept cool (preferably not above 35° C) after collections. (M) Anything the astronauts bring back, regardless of what it is subjected to on the return trip, will be scientifically valuable.

## THE HOUSTON LABORATORIES

The Biosciences Panel's concern with the facilities at MSC at the time of the return of the lunar samples has been to assure that the initial investigations carried on there can be done under conditions of good biological control. Most of all we wish to make sure that the search for possible lunar organisms may be carried on under conditions where contamination by terrestrial organisms is highly unlikely. Our second consideration is to minimize any exposure of investigators at MSC to possible lunar pathogens. Both of these objectives may be achieved through the use of the sort of "biological barriers" that are now being used at the U. S. Army's Biological Laboratores at Fort Detrick, Md. Information which will enable the MSC Staff to begin planning the erection of these barriers at the Houston installation has already been sent from Dr. Charles Phillips of this Panel to Dr. Elliott Harris at MSC. We recommend that sample containers not be opened until they are within the complete isolation unit at MSC, and after their outer surfaces have been thoroughly cleaned and sterilized. Here both the _in vitro_ and _in vivo_ biological tests should be done, as well as the scientific investigations ($\gamma$-ray spectroscopy and mass spectrometry) that cannot wait for the results of the tests for pathogens. As far as we are aware, no initial investigation at MSC is being planned by any scientific panel that could not be carried out inside the bacteriological barriers.

We will repeat here what we said in an earlier report, namely, that the MSC sterile-laboratory facilities be in charge of an experienced microbiologist who would supervise the initial handling of the lunar samples. His judgments should be backed up by an outside advisory panel of microbiologists.

Finally, when the samples arrive at MSC there should be a clear authority set up that will designate which samples may be alloted to designated investigators. There should be no confusion at that time regarding the handling and disposal of samples.

The Biosciences Panel has spent a considerable fraction of its time in planning the types of investigations that it believes should be undertaken on the lunar samples. These investigations are of two broad types: (1) the search for the existence of viable organisms on the moon and (2) the search for lunar organic compounds. In some respects, these two searches overlap each other, and this should be kept in mind in reading the suggestions that follow. Furthermore, this panel feels that it can only suggest, or outline, the sort of experiments that should be done on the lunar samples. Between now and the time the samples are available, equipment and techniques will change. Equipment that today seems best for certain analysis will be quite obsolete by the end of the decade. The same considerations apply to investigators and laboratories. The best laboratories for the accomplishment of certain tasks today may not be the best by 1970. Consequently, final selections of research groups to carry out specific investigations should be left for the future.

1. Search for Viable Lunar Organisms

There is really no one on our present panel to plan in detail the exact media and techniques to be used in the biological tests for viable lunar microorganisms. The Panel expects to expand its membership to include microbiologists to plan this search. In any event, it appears that these details can be planned later. The simple culture media, microscopes, etc. can be accommodated easily behind known, and even commercially-available, bacteriological enclosures. Consequently, there should be no difficulty in arranging for this work to be carried out at the MSC.

Another method that we recommend for the search for lunar organisms, whether viable or not, is the use of the electron probe X-ray microanalyzer. This method is not destructive and thus will permit re-use of a sample for other analytical procedures. There would be no hurry about the use of this technique, and the work need not be done in Houston. However, the biological entities in the lunar samples. Already, electron probe microanalyzers have succeeded in locating bacteria when both biological and optical methods have failed (A. Tousimis, Proceedings of the International Conference on X-Ray Optics and X-Ray Microanalysis, Academic Press, New York, 1963, p. 539).

## 2. The Search for Lunar Organic Compounds

a. Mass spectrometry. There is only one technique in this area of interest that should be applied at MSC rather quickly after the lunar samples are brought there, i.e., while the search for pathogens is still active. This is an investigation the results of which would be of interest both to the geochemists and to the organic chemists, namely, the mass spectroscopic investigation of the nature of any volatile compounds appearing from the lunar samples. Dr. P. Gast of the Geochemistry Panel is in charge of arranging for these measurements, and the Biosciences Panel (through Dr. K. Biemann) will keep in touch with him. The geochemistry requirement would be a simple high-sensitivity mass spectrometer that permits scanning the spectrum up to xenon, i.e., to mass 140 or thereabouts--a suitable example is A. O. Nier's 2-inch radius, double-focusing instrument at the University of Minnesota. No accurate isotope ratio measurements are planned by the geochemists for the preliminary examinations at the MSC. Such a spectrometer would fit the organic chemists' requirements well, except that we might wish to extend the mass range a little, such as up to mass 200. For this purpose we will look into the possibility of using an "Omegatron", which is a synchrotron-type instrument at present widely used in the analysis of residual gases in vacuum tubes. Whatever mass spectrometer is acquired for these experiments should not be used beforehand for anything else (it should have the lowest possible background) except for testing and model experiments. As was mentioned earlier in this report under "Sample Containers", the sample container should be one that can be opened directly into the mass spectrometer.

The mass spectrometer will also play an important role in the general search for any organic compound, non-volatile as well as volatile, that may be found in the lunar samples. It has already played an important part in the analysis of life-implicated organic compounds from pre-Cambrian rocks (G. Eglinton, et. al., Science 145, 000 (1964); W. G. Meinschein, E. S. Barghoorn, and J. W. Schopf, Science 145, 000 (1964); both these papers are scheduled to appear in July or August).

b. Chromatography and spectrophotometry. There is already a considerable literature on the analysis of carbonaceous chondrites (meteorites) by a variety of chromatographic and spectrophotometric techniques (see, for example, "Organic Constituents of the Carbonaceous Chondrites", M. H. Briggs and G. Mamikunian, Space Sci. Rev. 1, 647 (1963). After thorough extraction with both water and organic solvents, the organic chemists have applied chromatography in a variety of forms (column, paper, thin-layer, gas, and ion-exchange) to separate out various fractions and compounds. Absorption spectrophotometry has then played a major role in the identification of organic compounds. In this way the organic chemists have tentatively identified, from carbonaceous chondrites, such classes of organic compounds as porphyrins, amino acids, and fatty acids. Their efforts have been marred only by the very great difficulty of ruling out terrestrial contamination as the source of these compounds. In the case of the lunar samples, the same well-established methods can be applied, and, if the sample collecting and packaging are properly done, terrestrial contamination will no longer plague the organic chemist. These investigations will reveal not only whether there are lunar organic compounds, but also whether such compounds are of the sorts associated with living organisms on Earth (amino acids, carbohydrates, fatty acids, purines and pyrimidines, porphyrins). They will also tell us whether there is optical rotatory power in either mixtures or purified fractions of lunar organic compounds.

c. Electron probe and secondary ion emission analysis. The use of the electron probe was already mentioned as a tool in the search for possible lunar organisms. It may also prove of value in the search for localized concentrations of low atomic weight elements indicative of organic compounds. The electron probe may also be greatly complimented by the new method of secondary ion emission analysis (R. Castaing and G. Slodzian, Proceedings of the European Regional Conference on Electron Microscopy, (Delft, 1960), Vol. 1, N. V. Drukkerij Trio, The Hague, The Netherlands, 1961, p. 169). This is also an in situ method of analysis of even higher resolution than the electron probe, which is limited to the analysis of the outer approximately 20 atomic-diameters of a sample. Secondary ion emission analysis permits the detection of considerably less material (down to $10^{-16}$ grams) than the electron probe will detect. It is also more sensitive for low atomic number elements (hydrogen included) and capable not only of elemental, but also of isotopic analysis.

d. Other physical methods. The moon samples should also be subjected to complete structural analysis. These should include electron microscopy, electron diffraction, and X-ray diffraction. The resolution of the electron microscope is 2-3 Å in diameter should be available. Electron microscope staining and radiographic procedures are advancing very rapidly. Currently, it is possible to localize enzyme molecules in ultrathin tissue sections and to make them visible on unit membrane structures of mitochondria and other cellular organelles (H. Fernandez-Moran, J. Intl. Soc. Cell Biol. 1, 411 (1962). Electron and X-ray diffraction procedures on micro sections of lunar samples may give useful crystallographic data on any organic compounds that may be present. Diffraction patterns (Kossel line analysis) of micron-size inclusions can be obtained using electron probes of one micron down to 0.1 micron (1000 Å) in diameter. Diffraction patterns of single collagen fibrils (600 Å in size) have been obtained (H. Mahl and W. Weitsch, J. Intl. Soc. Cell Biol. 1, 143 (1962).

Both ultracentrifugation and microelectrophoretic procedures can be used effectively to isolate particles on the basis of their size, shape, density, and charge. These well known techniques will be of major importance in the search for lunar organic compounds.

Biosciences Panel:

| | |
|---|---|
| M. Calvin, Chairman | Univ. Calif., Berkeley |
| Gaylord W. Anderson | Univ. Minnesota |
| Klaus Biemann | M.I.T. |
| Loren Carlson | Univ. Kentucky |
| A. J. Haagen-Smit | Cal. Tech. |
| Richard M. Lemmon | Univ. Calif., Berkeley |
| Charles R. Phillips | Fort Detrick |
| A. Tousimis | George Washington Univ. |

157

N66-18676

# Section XI

## Mission Profiles

### Introduction

The purpose of the study of planned activities of the astronauts on mission profiles, after landing on the moon is to define how a science program is to be carried out with seven Apollo flights to the moon. In defining a science program it is not sufficient to list the measurements, and required instruments; one must also make a rough assessment of what actually can be accomplished under the known or conjectured operating constraints.

A work statement was prepared that included objectives, constraints, and guidelines as we knew, or thought we could anticipate, them that could be in turn used to determine what could be done on seven missions. We also included several alternate or contingency missions. The mission profiles given in the appendix, were prepared as a paper exercise by a team of geologists, geochemists, and geophysicists from the U. S. Geological Survey; a four hour mission studied by the Manned Space Science Division is also included in the appendix.

The next step in the process will be to simulate the activities in real time: first unsuited and finally suited after confinement in a LEM mockup for the time needed to fly to the moon. The results of time vs task studies obtained by simulation will be used for the final definition of the Apollo Lunar Science Program.

Workstatement for Apollo Science Program

Mission Profile Study

(Prepared by Staff of Manned Space Science Division)

The following section is the workstatement for a mission profile study. The constraints, as listed, are tentative and in some instances arbitrary. For example, there has been no decision that Apollo Mission I will have a surface staytime of 6-8 hours.

I. PURPOSE:

The purpose of this study is to eliminate major flaws in the planning for the Apollo Science Program.

II. OBJECTIVES:

The specific objective is to prepare sample mission profiles for the science portion of the Apollo project. Profiles for all the nominal, alternate, and limited missions will be prepared on the assumption that the mission has been preceded only by the mission or missions indicated by the path shown in Figure
For example, the profile for Apollo Mission III will be prepared two ways. First, Mission I was nominal,

then Mission II was limited (L2), then Mission III was nominal. The profile for Mission III by way of II L2 may differ significantly from Mission III by way of N4.

III. <u>MISSION OBJECTIVES</u>:

To learn as much as possible about the origin, history, and constitution of the moon. More exactly, it is desired to determine the geological, geophysical, and geochemical parameters of the landing sites; to investigate the physical and chemical properties of the atmosphere; and to recover samples for study on earth. In addition, radiation monitoring for crew safety is to be included and given priority over all other measurements. Other possible hazards might be considered.

First priority will be given to operations necessary for mission safety. Second priority will be given to those necessary for the safety or success of future missions. Examples of operations in these categories include measurement of the engineering properties of the surface, and monitoring of radiation and micrometeoroid flux.

Further priorities will be assigned to investigations and experiments, to the extent that they:

1. are of basic and permanent scientific value,
2. can be done only on the surface of the moon,
3. can be done only by a man,
4. are valuable for future scientific or operational purposes.

IV. GENERAL CONSTRAINTS (Missions I - VII)

A. Space Suit Factors

1. The maximum endurance time of the Apollo suit with PLSS is 4 hours, of which the last hour is contingency time. Normal operating time will be not over 3 hours.
2. The maximum walking distance of an astronaut on the lunar surface, assuming level, firm terrain, is about 2.4 miles. This is an absolute maximum figure based on PLSS endurance and metabolic load. The maximum distance from the LEM permissible during any mission will probably be about 1/2 mile.
3. Body movements in a pressurized suit are restricted. Squatting and kneeling take several times the unsuited time and effort. Lifting arms above shoulder height is difficult. Putting a hand in front of the face requires a definite effort.
4. Hand movements are restricted by the glove. Gripping objects on the order of 1 1/2 inches in

diameter for long periods will be difficult.

5. Looking down between one's feet will be difficult. The faceplate will prevent any object from being brought closer to the eye than 2 1/2 inches.

B. LEM Factors

1. The maximum separated endurance time of the LEM is 48 hours. The maximum surface stay time is 24 hours.
2. 250 pounds of scientific equipment (including power supply, telmetry, etc.) can be carried to the moon. 40 pounds of this can be carried inside the CSM, and must occupy not over one cubic foot. The rest of the equipment must be carried on the outside of the LEM descent stage. 80 pounds of scientific payload (samples, film, tapes, and containers) can be brought back to Earth, and must fit within two cubic feet.
3. Nominal turn-around time for the LEM is about one hour.
4. Four PLSS recharges are available for lunar surface operations. Only one can be recharged at a time.

V. PARTICULAR CONSTRAINTS (Mission I)

A. Total outside surface time will be 4 hours, total stay-time 6-8 hours.

B. Only one man will be outside at a time, except for emergencies. Both men, however, will get out.

C. The man on the surface will stay within view of the LEM at all times, except for the walk-around inspection of the landing gear.

D. The maximum walking distance from the LEM will be about one-half mile.

E. For planning purposes, the following performance figures will be used for a man on the lunar surface in the Apollo suit:

1. Maximum sustained walking speed, level ground - 70 feet/minute.
2. Walking speed, level ground, straight-line traverse, with occasional rock sampling - 20 to 25 feet/minute.
3. Maximum grade climbable for short distances - 30°.
4. Strides will be 8 to 10 inches long.

F. A scientist-astronaut will not go on the first mission.

G. Ordnance (i.e., explosives for seismic shooting, etc.) will not be carried on the first mission.

VI. PARTICULAR CONSTRAINTS (Missions II and III)

A. The maximum stay-time of the LEM for Apollo Missions II and III is 8 hours.

B. The rate at which the astronauts will walk and slopes that they can climb will be determined from N1.

C. through E same as in V.

F. A scientist-astronaut may not be present on Apollo Mission II; a scientist-astronaut may be present on Apollo Mission III, and later.

G. Ordnance may be considered for Apollo Mission II or later.

VII. PARTICULAR CONSTRAINTS (Missions IV - VII)

A. Maximum stay-time for Apollo Missions IV - VII is 24 hours. The OUTSIDE time is 9 man-hours, i.e. first man out for a three-hour period, second man out for three-hour period, then first man out for a second three-hour period.

B. Operation with two men outside may be scheduled for Mission IV. Two men would be outside for a period of three hours, i.e. 6 man-hours. This operation would require some changes in PLSS charge rate.

VIII. GUIDELINES:

A. The Apollo science program guidelines of October 8, 1963, apply to all missions, until further notice.

B. The fields of investigations will be: geology, geophysics, geochemistry, biology, and the lunar atmosphere.

C. The sub-divisions of the fields of investigation are:

Geology

1. Field geology
2. Mineralogy and petrography (to be done on returned samples).

Geochemistry (most, if not all, geochemical activities will be done on returned samples. Analytical chemistry on the moon can be considered.)

Geophysics

1. Passive seismology
2. Active, deep seismology
3. Engineering seismology
4. Magnetic measurements
5. Heat measurements
6. Gravity measurements

Atmosphere - measurement of physical and chemical properties.

Biology - analysis of returned samples.

D. Assumed equipment or instrumentation

1. Complete photogeologic coverage of nominal site at scale of 1:10,000
2. Normal geologic hand tools or their equivalent; cameras, sample containers, etc.
3. Appropriate geophysical instruments
4. Radio link with LEM and earth and hand held TV to distance of 50' from the LEM

IX. NOMINAL AND CONTINGENCY MISSIONS:

Detailed operational sequences for Apollo Missions must include sequences for nominal missions, limited missions, and alternate missions. An alternate mission is defined as one in which the LEM does not descend to the surface, or the astronaut does not emerge after descent. A number of other alternate missions can be imagined. This study will include only the possibilities shown in Table 1. Limited missions are defined as those missions where the astronaut does descend from the LEM for periods of time almost up to that of the nominal planned mission. This study will include three possible limited missions as shown in Table 1.

Nominal missions land on the selected site and remain for the planned duration. After the first Apollo mission several types of nominal missions can be recognized depending on the position of a new site as compared with an old site. This study will include the nominal missions described in Table 1.

TABLE 1 Mission Definitions

A. Alternate Missions

A1. Command and Service Module (CSM) does not go into lunar orbit. (Circumlunar or long cis-lunar or long cislunar trajectories are the only such missions worth study at this time.)

A2. CSM goes into lunar orbit but LEM does not descend.

A3. LEM descends but does not land.

A4. LEM lands but an astronaut does not get out.

B. Limited Missions

L1. LEM descends and an astronaut gets out for no more than one hour.

L2. Crew spends more than 1 hour and less than 4 hours on surface.

L3. LEM lands on a non-nominal area (no large scale map available).

a. One astronaut spends no more than 2 hours outside time.

b. Stay is for the nominal period of time.

C. Nominal Mission

N1. Nominal mission to first landing site.

N2. Nominal mission to preceding landing area, original landing site in view.

N3. Nominal mission to preceding landing area, landing site not in view.

N4. Nominal mission to a new area.

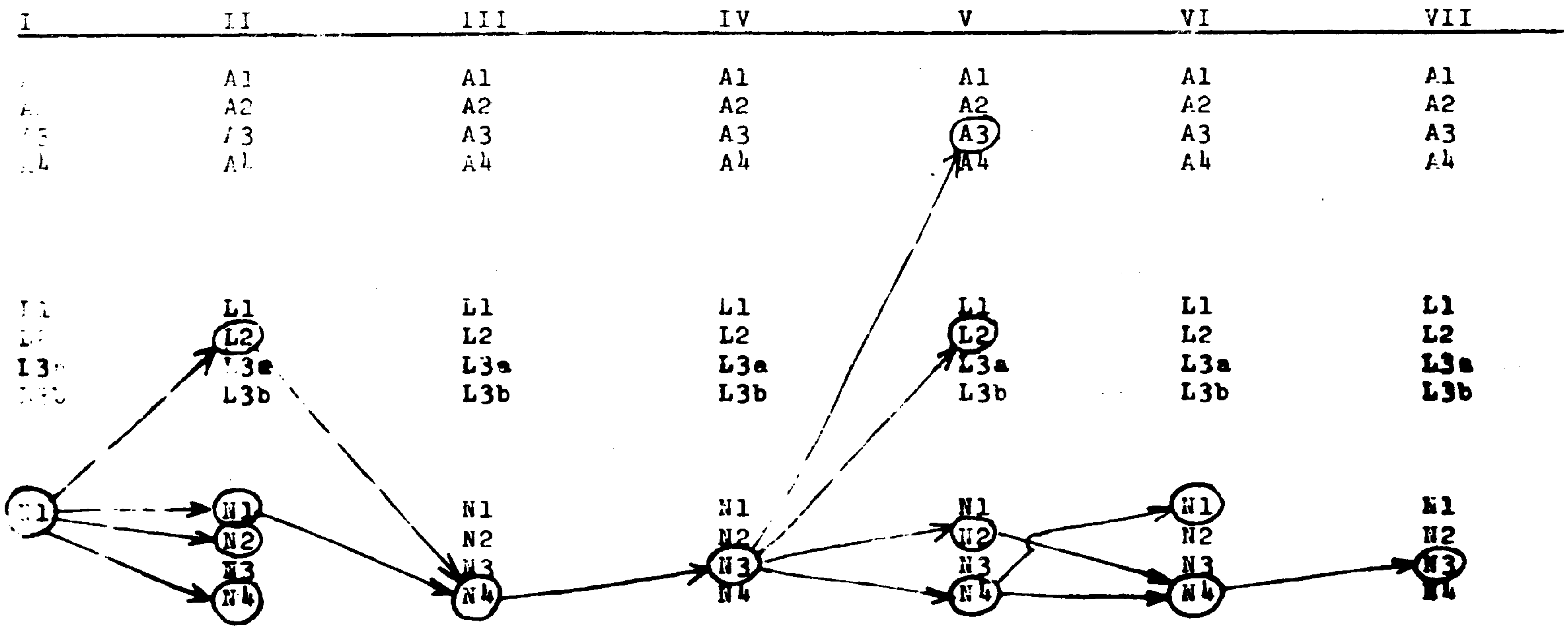
Apollo Mission I will have certain operational possibilities that will include those of Table 1, except N2, N3, and N4. Apollo Mission II will have all the possibilities listed in Table 1 and each of these possibilities can be achieved by being preceded by any one of the Mission I possibilities.

It is obvious that if we wish to prepare a realistic Apollo science program we must consider not only nominal missions but a number of possible contingencies. At this time, however, we must make a limited selection for detailed study from the very large number of possible paths. The examples to be studied are shown in Figure . The linked missions will be studied as examples of possible Apollo science programs.

FIGURE 1

SOME POSSIBLE APOLLO SCIENCE MISSIONS

THOSE MISSIONS STUDIED ARE CIRCLED



N66-18677

# Section XII

## PRELIMINARY STUDY OF

## 4 HOUR LUNAR NORMAL AND ALTERNATE MISSIONS

by D. Beattie, E. Davin, and P. Lowman

Manned Space Science Division, NASA Headquarters

### Introduction

This report presents preliminary results of a study of scientific investigations which can be carried out during the first of seven Apollo landings (the approved program). It has three specific purposes:

1. To outline nominal, limited, and short alternate mission science programs;
2. To find flaws in current plans, such as the report of the Ad Hoc committee ("Sonnett Report"); and
3. To define areas in which more information is needed for meaningful planning.

The study covers only a first mission with four hours available for surface operations exclusive of vehicle checkout and several limited and alternate missions. The following major assumptions were made, based on various sources.

1. The major objective on the missions will be the safe return of the crew.
2. Subject to crew safety, scientific/engineering operations will receive top priority. Of these operations, sample return is most important.

3. Scientific operations will be planned so that abrupt, unplanned termination of the mission will not cause a corresponding loss of scientific data; i.e., the operations will be compartmented with respect to scheduling as much as possible.

4. The best guarantee that an experiment will be performed is its simplicity and ease of performance, and minimum equipment.

Other assumptions are given in the work statement.

The most valuable scientific operation will be the geological traverses, because they can be done only on the moon and done best by a man. Therefore, the geological traverses will be considered the prime operational sink; i.e., any excess time can best be used in longer, more detailed, or additional traverses.

Schedule of Investigations and Missions

The following table presents a possible distribution of scientific investigations among the assumed seven Apollo missions. It is based on the Ad Hoc Committee report and preliminary results from the Apollo Science Program study teams.

**TABLE 1. Investigation Schedule**

X - performed on mission

Numbers in parentheses refer to landing sites listed on page 4.

| Investigation | I (1) | II (1) | III (3) | IV (6) | V (5) | VI (2) | VII (4) |
|---|---|---|---|---|---|---|---|
| 1. Terrain and outcrop study | X | X | X | X | X | X | X |
| 2. Sample collection (incl. biology and description) | X | X | X | X | X | X | X |
| 3. Photography | X | X | X | X | X | X | X |
| 4. Coring and logging | | X | X | X | X | X | X |
| 5. Participation of scientist-astronaut | | | | X | X | X | X |
| Geophysics: | | | | | | | |
| 1. Passive seismometry | X | X | X | X | X | X | X |
| 2. Active seismometry | | | X | X | X | X | X |
| 3. Gravimetry | X | X | X | X | X | X | X |
| 4. Geodetic observations | X | X | X | X | X | X | X |
| 5. Heat flow | ? | X | X | X | X | X | X |
| 6. Surface radiation | X | | X | X | X | | |
| 7. Electrical surveys | ? | | X | X | X | | |
| 8. Participation of scientist-astronaut | | | | X | X | X | X |

| Investigation Cont. | Mission Number (Site) Cont. | | | | | | |
|---|---|---|---|---|---|---|---|
| | I (1) | I I (1) | III (3) | I V (6) | V (5) | V I (2) | VII (4) |
| **Miscellaneous:** | | | | | | | |
| 1. Meteoroid and ejecta flux measurement | X | | X | | | | |
| 2. Atmosphere analysis | ? | X | X | | | | X |
| 3. Trafficability studies | X | X | X | X | X | X | |
| 4. Space radiation studies | X | | X | | | | X |
| 5. Meteoroid damage inspection of previously landed equipment | | X | | | | | |

## Landing Sites

The following represents a list of major physiographic features upon which it would be desirable to land if possible. All can be found within the Apollo landing area.

1. Mare area
2. Vicinity of Copernican age crater on mare
3. Vicinity of Copernican age crater on highland
4. Vicinity of chain crater on mare
5. Apenninian material
6. Pre-Imbrian material

It is evident that the selection of landing sites depends highly on the results of the first landing and the complete or partial fulfillment of the scientific tasks by the first landing. The list of suggested landing area shows areas of diverse geologic interest. It is altogether probable that not all of the instruments and experiments for the first flight will meet the flight schedule or be successfully integrated with the spacecraft so that some experiments may not be ready until later Apollo flights.

Sample Mission Profiles: N-1

N-1 (See the preceding section for explanations of numbered missions.) refers to the nominal first landing with a total of four (4) hours, including time for getting in and out of the LEM, available for the surface operations.

The major tasks to be performed on N-1 include the following:

1. LEM/landing site inspection and description
2. Telmetry antenna erection
3. Geological traverses
4. Contingency grab sampling
5. Scientific instrument emplacement
6. Television camera transmission.

To accomplish these tasks, the 240 minutes of available time can be divided into major phases for each astronaut as follows.

**First Astronaut** (S/C Commander) - 120 minutes:

Egress (15 min.), collect rock sample and return them to LEM ascend stage.

Walk-around inspection (10 min.), range, distance measurement.

Long-range traverse, sample collecting, incl. antenna erection (80 min.)

Reboard LEM (15 min.)

Second Astronaut (Systems Engineer) - 120 minutes

Egress (15 min.)

Television set-up and transmission (20 min.)

Geophysical instrument emplacement (25 min.)

Long-range traverse and sample collecting (45 min.)

Reboard LEM (15 min.)

While on the surface, each man will be continually observed by the man in the LEM; the first man out will be monitored by television camera through the LEM window if possible.

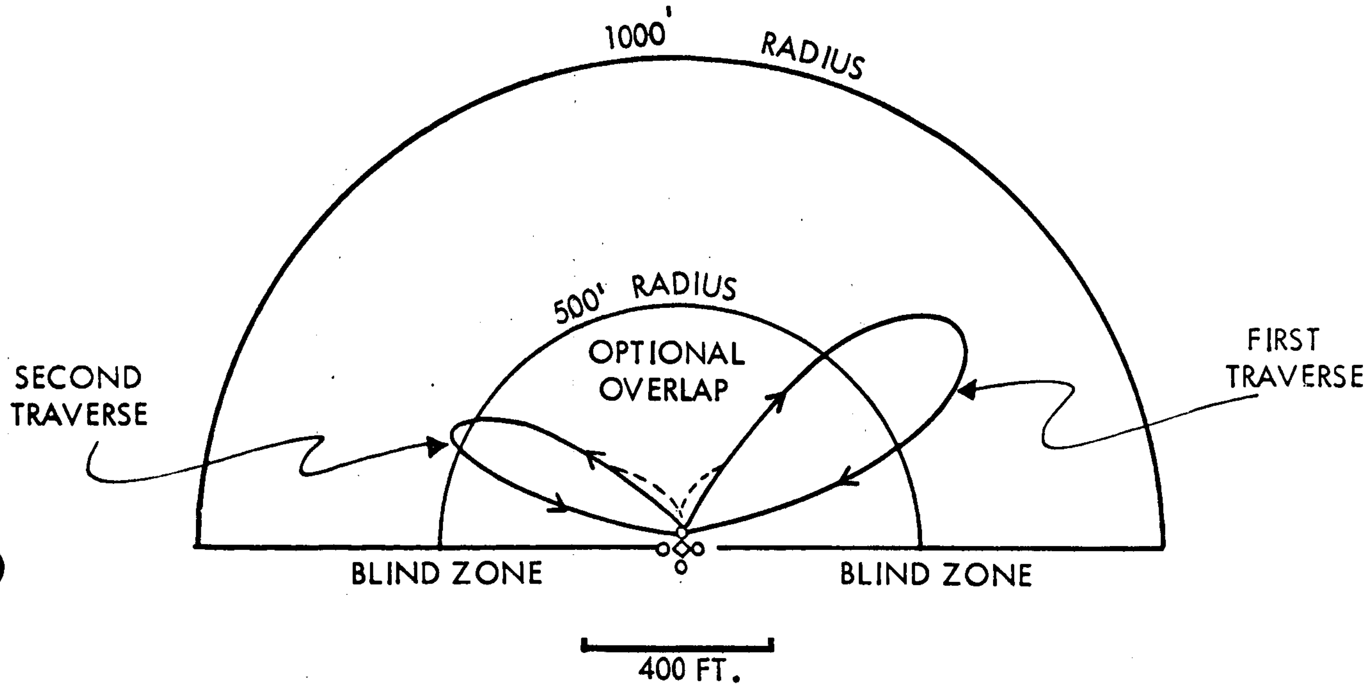
## Detailed Mission Profile (N-1)

**First Astronaut**

| Starting Time | Equipment and Operations |
|---|---|
| 0:00 | Equipment: walking staff/penetrometer; camera; geological equipment<br>Astronaut gets out of LEM and to foot of ladder at forward hatch. |
| 0:15 | Equipment: same<br>Astronaut checks footing and walking characteristics at foot of ladder, checks PLSS and communications operation. Makes walk-around inspection tour at base of LEM, including the following:<br>(1) Real-time verbal description of ground under LEM, general condition of LEM, and |

# Fig 1 LONG RANGE TRAVERSES

N-1 MISSION




FIRST TRAVERSE LENGTH ≅ 1600'
TIME ≅ 65 MIN.
SECOND TRAVERSE LENGTH ≅ 1100'
TIME ≅ 45 MIN.

personal status for real-time transmission to IMCC. If dust were raised by retro engine, describe dust settling and collect dust.

(2) Selection of three random float samples, possibly between +Y and +Z pads ("contingency grab samples") and return them to LEM ascend stage.

(3) Inspection of each leg and pad for condition, penetration, and stability - about 2 min./leg and any appreciable crater formed by retro jet.

(4) Two penetration tests per quadrant

0:25 Equipment: same plus telemetry antenna

Astronaut goes to antenna storage compartment in descent stage, unpacks TM antenna. Carries antenna with cable 50 feet from LEM along route of long-range traverse (Fig. 1), erects, aims, and activates it.

Astronaut then begins long-range surface traverse along a non-retracing loop as shown (Fig. 1), during which he does the following at his discretion:

(1) Continual verbal description of trafficability, microrelief, descent stage erosion,

and personal status for real-time transmission to IMCC.

(2) Study, sampling, description, and photography of outcrops or loose fragmental material.

(3) Nested terrain photography in direction of travel.

(4) Panoramic terrain photography outward at limit of traverse loop, selected according to points of interest.

(5) Penetration tests.

1:45 Traverse loop brings astronaut back to reboard LEM. Discards contingency samples if desirable.

Second Astronaut

2:00 Equipment: walking staff/penetrometer; camera; geological equipment; TV camera; geophysical instrument package and associated equipment.

Astronaut gets out of LEM and to foot of ladder at forward hatch.

2:15 Astronaut checks PLSS and communications operation, goes to geophysical instrument compartment in descent stage and unpacks instruments, placing on light weight carrying device. Walks to TM antenna or 50 feet out along traverse route (see Fig. 1) carrying TV camera and towing geophysical instruments. Sets up, turns on, and checks operation of TV camera. Scans terrain 360° around camera, zooming on interesting features. Scans LEM, zooms on +Z landing pad and leg.

2:35 Emplaces seismometer/gravity meter, radiation meters, and micrometeoroid detector and other instrument or experiment near TM antenna or at other appropriate site at least 50 feet from LEM. Makes geological description (incl. sampling and photography) of instrument site, with special attention paid to coupling of seismograph.

Walks approximately 100 feet beyond instruments just emplaced with magnetometer; emplaces it. Makes geological description of magnetometer site, samples.

3:00 Makes long-range geological traverse, as shown in Fig. 1, along a non-retracing loop with a total length of about 1100 feet (distance based on speed of 25'/min., which allows for sampling and description.) The exact route should be guided by exposures and

| | |
|---|---|
| | points of interest. Operations same as first astronaut's traverse, but with more emphasis on geology, less on rocket erosion. Should use remaining sample and film capacity. |
| 3:45 | Returns to LEM, discards excess samples and expendable equipment, reboards LEM. |

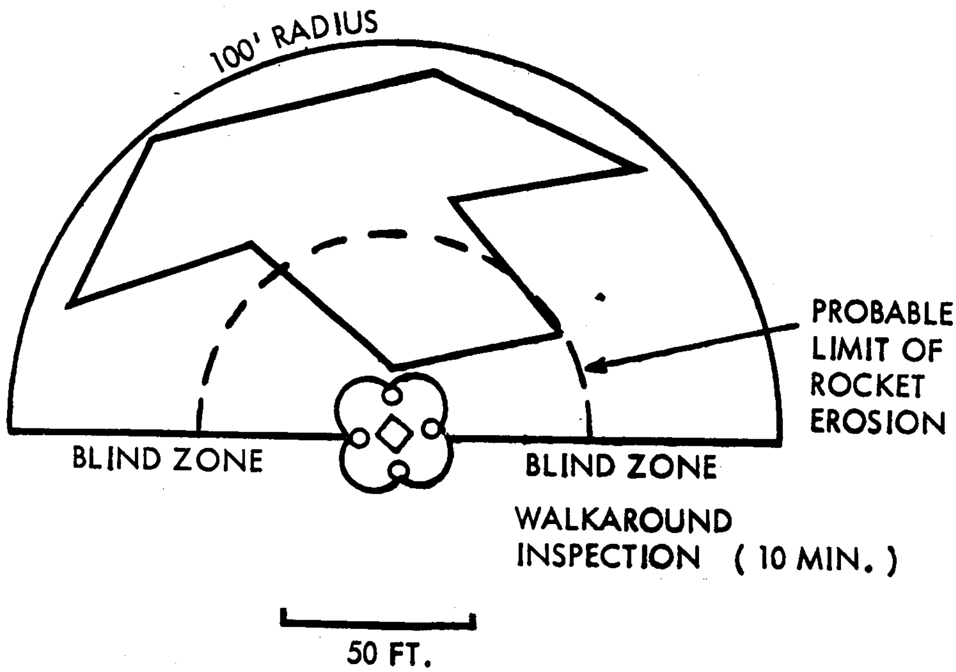
**Mission Profiles:** L-1

L-1 refers to a limited first mission in which one astronaut spends a total of one hour in surface operations.

| Starting Time | Equipment and Operations |
|---|---|
| 0:00 | Egress as in N-1 carrying geological equipment, walking staff, and camera. |
| 0:15 | Walk-around inspection as in N-1. |
| 0:25 | Short-range geological traverse within 100 feet of LEM; possible route shown in Fig. 2. Operations same as in long-range traverse, but attempt should be made to collect total weight of samples and to use all film. Systems engineer should keep TV camera on first astronaut from inside the LEM, with two terrain scans if possible. |
| 0:45 | Short-range loop will bring astronaut back to LEM at forward hatch. Discards excess samples and expendable equipment, reboards LEM as in N-1. |

## Fig 2 SHORT-RANGE TRAVERSE

L-1 MISSION (1 HOUR SURFACE
TIME)




TOTAL TRAVERSE LENGTH ≅ 400'
TIME @ 20'/MIN. ≅ 20 MIN

Mission Profiles: L-2

L-2 refers to a limited first mission in which from one to four hours surface operations time is available. Although both astronauts might have time to get out, it is felt that time would be too valuable to permit the systems engineer to get out.

The optimum L-2 mission would be the same as L-1 above, with additional time spent in surface traverse operations.

Mission Profiles: L-3

L-3 refers to limited first missions on non-nominal sites, with no large-scale maps available. If the IMU can satisfactorily determine the position of the LEM, no major changes in the mission profile seem necessary. Otherwise, some time may have to be spent on geodetic measurements such as resection with a compass from surrounding terrain.

L-3a (no more than two hours outside time) - same as L-1 or L-2.

L-3b (nominal time period) - same as N-1 except as noted for additional position location.

Mission Profiles: A-1

A-1 refers to an alternate first mission resulting in a one-pass circumlunar orbit or a long cislunar orbit. Assuming that the malfunction responsible for the alternate mission has been taken care of and the crew is in no danger, the following investigations might be carried out.

1. Photography with hand camera of:

   lunar surface

   earth

   solar corona

   planets

   zodiacal light

2. Astronaut description of lunar surface features, coordinated with photography

3. Photography of lunar surface with LEM ascent stage cameras, if feasible

4. Activation of LEM instruments before jettison to permit tracking in circumlunar orbit

5. Jettison of some geophysical instruments into lunar orbit if feasible (possibly magnetometer, radiation detectors?)

Mission Profiles: A-2

A-2 refers to achievement of lunar orbit but without LEM descent. If the LEM separates and is operational, the optimum salvage operation would be to use the ascent stage cameras, the hand camera, and the TV camera for lunar surface reconnaissance. First priority should be given to the intended landing sites, with subsequent photography of:

High latitudes, earthward face

Far side of the moon

Sun

Earth

Planets

Zodiacal light

Operations 4 and 5 of A-1 should also be carried out before returning to earth.

Mission Profiles: A-3

The A-3 mission consists of a descent by the LEM without landing. Since this would be essentially an emergency situation, very little astronaut participation in experiments during the landing approach could be expected. The following investigations are suggested.

1. Automatic photography of landing site during descent by 70mm cameras mounted on the ascent stage
2. Automatic deployment of plume sampler mounted on ascent stage
3. After return to lunar orbit, the cameras and plume sampler would be recovered. If feasible, the photography suggested for the A-2 mission would then be carried out.

Mission Profiles: A-4

In the A-4 mission, the LEM lands successfully and stays for some time but the astronauts are not able to get out. The following investigations could be carried out.

1. Automatic landing site photography as in A-3

2. Automatic deployment of plume sampler on surface

3. Punch sampling or other sampling device operated to collect dust raised by retro from LEM

4. Photography and TV scan of landing site and surrounding terrain

5. Retention of all cameras on return to lunar orbit, in place of samples, for orbital photography as in other alternate missions.

6. Lower instrument to the ground to start some experiment.

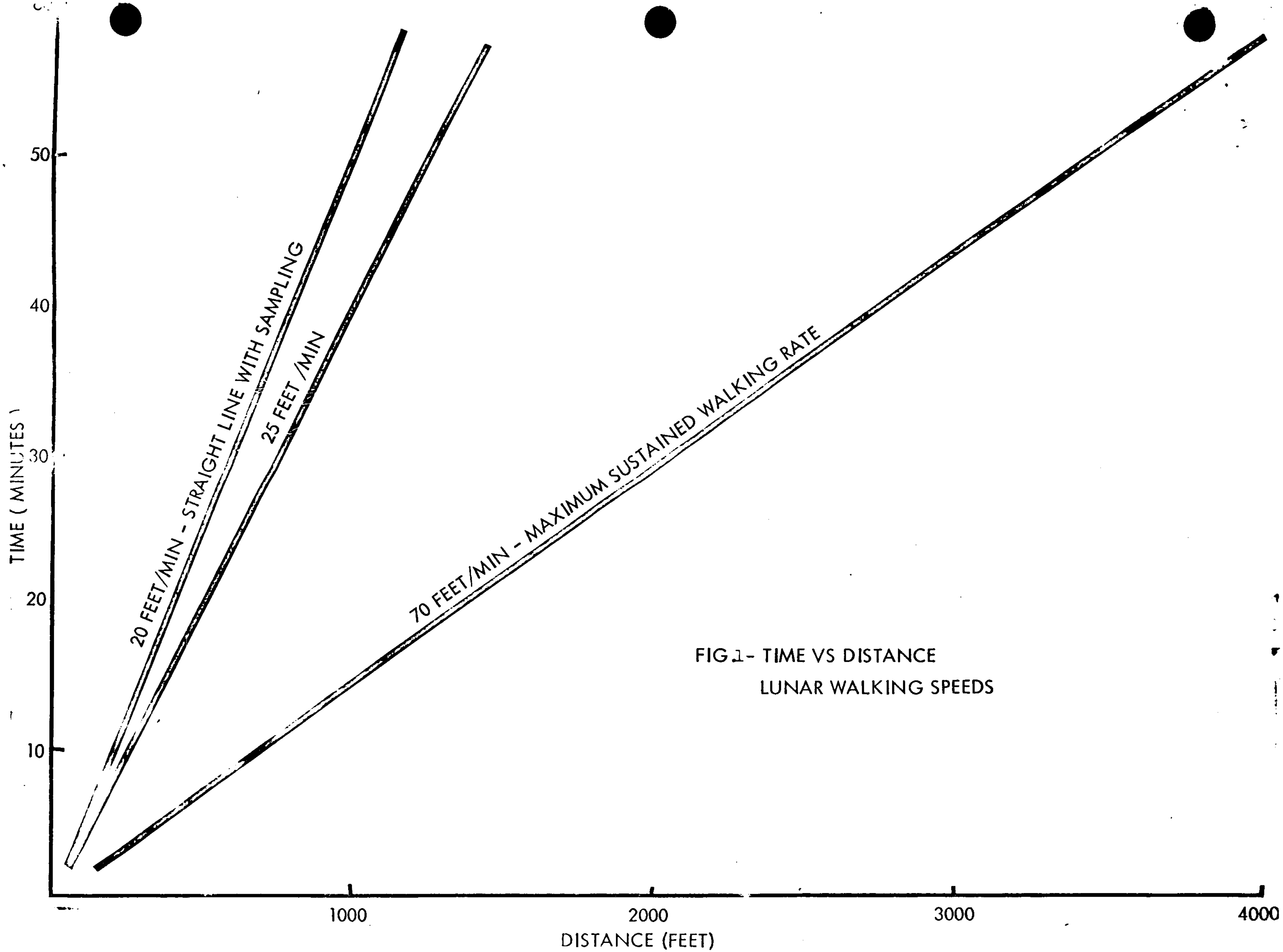



FIG 1 - TIME VS DISTANCE
LUNAR WALKING SPEEDS

NEED FOR LUNAR ATMOSPHERE MEASUREMENTS IN THE APOLLO PROGRAM N66-18678

Lunar Atmosphere Measurements Team
Apollo Science Program

## 1. Background

Measurements of the lunar atmosphere are of interest from an atmospheric physics viewpoint. Additionally, however, such measurements can be expected to significantly supplement the geologic data gathered on the moon, since the lunar atmosphere may have evolved from solid lunar material. Geology without lunar atmospheric studies, or vice versa, would unnecessarily increase the number of conjectures that must be made to properly appreciate the lunar evolutional process and its current state of evolvement. Since Apollo missions may contribute significantly to the contamination of the lunar atmosphere, it is important that measurements of the lunar atmosphere be accomplished as near the beginning of the program as possible.

The lunar atmosphere is known from optical measurements to be less dense than about $10^{-6}$ that of the earth's atmosphere (Dollfus, A., Ann d'Astrophysique, 19, 71 (1956)) and the ionized component is less than about $10^3$ ions/cm$^3$, as determined by radio measurements (Elsmore, B., Phil. Mag., 2, 1040 (1947)). Beyond these upper limits, all else is inferred.

In a steady-state atmosphere, the concentration of particles of a given kind is determined by the input rate and the loss rate. The measurements mentioned above therefore limit either the input rate to a very low value, or the loss rate to a very high value, or both. The former extreme would be characterized by a residual atmosphere of gravitationally bound heavy gases (i.e., zero input rate), while the latter extreme would be characterized by a rapid escape mechanism (e.g., solar-wind particles striking atmospheric particles and driving them away).

## 2. Possible Sources of Lunar Atmosphere

The wide variation in theoretical predictions concerning the lunar atmosphere arises mainly from differing concepts concerning the source mechanisms. Rather than discuss the theories, we here simply mention the various possible mechanisms and how they pertain to the measurements. The possible atmospheric control mechanisms are:

(a) An original atmosphere with no further accretion. In this case, the remnant atmosphere would be examined by a surface instrument. An exceedingly slow loss mechanism (e.g., $t_{loss} > 10^8$ years) would be required to leave any trace of the original atmosphere. Since thermal-escape undoubtedly occurs to some extent, it can easily be shown that the only remaining components of an original atmosphere would be heavy gases such as xenon or krypton, (L. Spitzer, Jr., Atmospheres of the Earth and Planets (Ed. G. Kuiper) Univ. of Chicago Press, Chicago, Ill. (1952)). A mass spectrometer would therefore detect only heavy gases.

(b) Volcanism or outgasing in general of volatiles from the interior of the moon. Atmospheric components so generated should be mainly water vapor plus traces of $SO_2$, $NH_3$, $CO_2$. etc. (i.e., typical volcanic efflux). If the loss rate is large compared to the rate for photodissociation in the solar radiation, then these components would be detected as molecules, while for the contrary situation, monatomic oxygen would be the principal constituent detected; this would arise from photodissociation of water vapor, where the hydrogen escapes rapidly due to its small mass.

Gases may also be released from rocks or magmas near the lunar surface. Gases entrapped in and evolved from rocks are, after $H_2O$, primarily $CO_2$, HCl, $Cl_2$, $H_2$, $H_2S$, CO, $CH_4$, $N_2$, and $O_2$. Rocks and magmas of different composition evolve varying amounts of these gases, and thus allow an estimate of the composition of the rocks from which the gases are evolved. Gas compositions are also useful in following the process of magmatic differentiation, and would be of significant value if the composition of gases emanating from a volcanic vent on the moon could be measured for a period of time.

Recent work on gases in terrestrial rocks indicates the following generalizations:

1. Gases other than water range from 0.1 to 6 $cm^3/g$,
2. $CO_2$ is generally near 50 percent of the total gas other than $H_2O$ in basalts, but it is generally low in rhyolites and intermediate in granites and andesites,
3. $H_2$ is the dominant gas in granites, but it is highly variable in other rocks,
4. Sulfur, reported as $S_2$, is generally 2 to 9 percent of other gases in basalts, is also high in some andesites, but is generally low in obsidians and granites,
5. $Cl_2$ is commonly 10 to 30 percent in rhyolites and some andesites, it is less than 10 percent in basalts, and it was found to be

less than one percent in two samples of granite,

6. $F_2$ is the dominant gas in most obsidians and in some basalts, and it ranges from 10 to 30 percent in most other rocks,

7. CO, $N_2$, and Ar do not show systematic differences.

It has been postulated that strong Earth-induced tidal forces acting upon the moon cause fault lines in the lunar crust to shift and slip to the extent that there will be brief periods when trapped subsurface gases will be released. Large scarps and fissures on the lunar surface are consistent with this concept. Detection of gases released from such vents would be extremely valuable to the understanding of the moon's internal structure. Continuous monitoring of regions of sporadic or periodic outgasing would be desirable in order to detect gases with short retention times in the lunar atmosphere.

(c) Meteoric Volatilization. The effect of meteoritic bombardment of the lunar surface causing agitation of the surface material may have significant effects in accelerating the geological evolution of the gaseous atmosphere by releasing the occluded and absorbed gases in the lunar surface material. This is similar to (b) except that individual inputs could be distinguished by the rapid rise and subsequent decay of fluctuations in the atmosphere due to the sudden release of gas rather than the relatively slow outgasing process. Furthermore, simultaneous seismic measurements of impact could also aid in distinguishing such events. The seismic experiments that have already been proposed should integrate meaningfully with the atmospheric measurements.

(d) Release by Energetic Particles. Impact on the lunar surface by energetic particles, especially protons from the solar wind, will tend to break down compounds and produce free potassium, aluminum, cadmium, etc. The vapor pressure of many of these materials is high enough so that they may contribute significantly to the lunar atmosphere. Since these materials are not present in the terrestrial atmosphere, it may be possible to prepare the lunar instrumentation so that it will not release such materials on outgasing, and it should be possible to detect much lower concentrations of these materials than of water vapor or other terrestrial gases.

(e) Solar Wind Accretion. Gas so accumulated will initially be essentially ionized and monatomic, due to the high temperature of the solar wind ($> 10^5$ °K) and the even higher temperature of its source, the corona ($> 10^6$ °K), but it may become neutralized and combined into molecular forms after reaching the moon. The composition would be similar to the sun, possibly altered by diffusive separation, and the solar wind would therefore provide an atmosphere composed mainly of oxygen and nitrogen. A large proportion of nitrogen would then serve to distinguish (e) from (b) and (c). Furthermore, a solar wind incident on the lunar surface should be directly detectable.

3. Importance of Measurements

The analysis of gases at the lunar surface will be of value to geologists in determining the kinds of geologic processes, especially those involving magma generation, that were or are present within the moon. From the composition of the gases evolved during magmatic processes, much can be determined concerning the composition of the rocks and magmas within the moon, which in turn will aid in determining the history and origin of the body. It is evident that measurement of time variations in the lunar atmosphere is potentially capable of distinguishing among the more plausible accretion and loss mechanisms.

The possible existence of volcanism is exceedingly important since such phenomena may provide volatiles that are useful for life support (both intrinsic and extrinsic). The location of volcanic sites, if they exist, can be facilitated by deploying several atmospheric pressure gages (one per Apollo mission, for example): time variations at different locations could be interpreted to locate the volcanic site, analogous to the location of earthquakes with several seismographs. The feasibility of such a program cannot be judged until at least one pressure gage is in place, and if proven feasible, then two more gages should be desirable at widely spaced locations (i.e., three Apollo missions in all). Therefore the first gage should be landed at the earliest opportunity. In brief, the first datum, no matter how crude the information or how poor the resolution, should be obtained just as soon as possible, hopefully before the exhaust gases from retro rockets have had a chance to disrupt seriously the lunar atmospheric composition.

4. Contamination

The total mass of lunar atmosphere in terms of the particle concentration at the surface is approximately 100 g/(particle/cm$^3$). Present experimental and theoretical estimates give $\sim 10^6$ particles/cm$^3$ for the particle concentration, or about 100 metric tons for the total atmospheric mass. The Apollo excursion module will release up to 5 metric tons of exhaust gases. The above estimate involves important uncertainties, and the Apollo reaction products may even dominate the atmosphere. It is unfortunate that the vehicle carrying the atmospheric-measurement experiment may itself seriously contaminate that atmosphere, and the experiment should therefore be capable of operating for an extended period. At the very least, the loss rate for the contaminant gases can thereby be determined. If these loss rates are sufficiently large, then the atmosphere will return to its steady state and be observed by the lunar atmosphere experiment. Loss due to solar wind interaction may give rise to loss time constants of the order of one month, or about one lunar day. Thus the experiment should last, at the minimum, for several months. It is desirable, in any event, to observe any changes in the atmosphere that may occur between lunar day and lunar night, since this can provide further information on composition (e.g., the freezing out of volatiles during the very cold lunar night).

The contamination problem provides a powerful argument that a first attempt at lunar atmosphere direct measurement should be made from an orbiter. The merit of such an approach, assuming that the altitude of the orbit would be low enough, is that: (a) a reasonable opportunity would be available for making measurements prior to contamination, (b) any burst of volcanic origin such as that recently detected optically might well be detected directly, and (c) outgasing at the dawn meridian might be detected. It is very important to have the opportunity to look for such gases before significant contamination takes place.

An environmental factor that may be altered by rocket gases during the first and succeeding lunar missions is accumulation of condensed rocket gases upon possibly existing primitive deposits of frozen water and carbon dioxide in permanent or semi-permanent shaded regions on the lunar surface. During future lunar surface exploration into these shaded regions, the question may arise as to whether any frozen constituents were primary in origin or products of rocket gases, or possibly both. Knowledge of the diffusion and retention times of rocket exhaust gases around the moon's surface would aid in determining the answer.

With the advent of more rocket landings and surface exploration activity, considerable amounts of rocket gases will be added to the lunar atmosphere, and these gases will be modified by charged-particle and electromagnetic-radiation energy from the sun. This action of the solar radiation will result in a continously changing atmosphere. These changes could affect scientific investigation of the overall lunar surface materials due to absorption and desorption of gases. These gases may react upon mineral deposits exposed on the lunar surface as the gases condense during the long lunar night (14 earth days).

It is, therefore, imperative that consideration be given to retention times of rocket exhaust gases in the lunar atmosphere and their effect upon future manned lunar surface exploration.

5. <u>Recommended Measurements</u>

Optimally the lunar atmosphere experiment should measure the following neutral constituents:

(a) total pressure,

(b) mass spectrum,

and the following ionic constituents:

(c) total concentration,

(d) mass spectrum,

(e) directed flux.

The most direct approach to lunar atmospheric measurements is the use of some type of mass spectrometer to measure the neutral gas composition and an ion mass spectrometer for ion composition. A total neutral pressure measurement alone should be done only as a last resort if an adequate mass spectrometer cannot be developed. It would appear, at the present state of the art of mass spectrometry, that considerable development work to create a device compatible with the possible ranges of lunar atmospheric pressure must be performed before a practical package can come into existence. With the estimates of lunar atmospheric pressures ranging from $10^{-10}$ torr down to $10^{-15}$ torr, a major improvement in sensitivity of a mass spectrometric device will be necessary. In addition, the ion-generating region for a neutral gas spectrometer should employ some technique other than a thermionic emitter in order to avoid outgasing of the system and gettering of the gas molecules, thus presenting a biased composition.

Relative to the Apollo program, the possibility of leaving behind a mass spectrometer package to telemeter the lunar atmosphere over a period of time seems to be most desirable. It would provide information concerning the rate of cleanup of the atmosphere after departure of the LEM as well as day and night atmospheric composition. Further, some information concerning solar activity and its effect upon the composition of the lunar atmosphere could be obtained.

Charged-particles analyzers should be set up on the lunar surface to examine the energy spectra of both positively and negatively-charged particles and their directions of arrival. If the solar wind impinges without disturbance on the lunar surface, the measurements made with this instrument would be simply those of the undisturbed solar wind. It is more likely that a region of disturbance or shock wave exists for some distance out from the moon, in which case the measured particle fluxes would not be characteristic of the undisturbed solar wind.

An ion mass spectrometer and ion trap should also be included in the instrumentation; these measurements would be especially useful if the solar-wind particles reaching the moon are completely thermalized or if there is significant ionization of lunar gases. An ion mass spectrometer can provide information on relative concentrations, but it is not very good for establishing absolute concentrations. An ion trap is particularly effective for determining the absolute concentration but it has poor capability for analyzing the relative abundances of different constituents except in very idealized situations. Thus the two instruments complement one another.

Pressure gages should be used on all missions. It is probable that pressure gages are the only instruments sufficiently developed to be useful in an orbiter, where there could be a real payoff in the sense of detecting discrete sources of morning surface outgasing.

In summary, the maximum direct information on the lunar atmosphere must come from measurements on the neutral components, while the experimental techniques are better developed for measuring the ionized components of the atmosphere. The total neutral particle pressure can be measured with available techniques. The mass spectrum should be measurable, depending on progress in instrument development in this area. We therefore suggest the following priorities among the possible atmospheric measurements for the first three Apollo missions.

First Mission:

1) neutral mass spectrum (if adequately developed)
2) neutral particle pressure
3) total ion concentration
4) directed ion flux
5) ion mass spectrum

Second Mission:

1) neutral particle pressure
2) directed ion flux
3) ion mass spectrum
4) neutral mass spectrum
5) total ion concentration

Third Mission

1) neutral particle pressure

2) neutral mass spectrum

3) ion mass spectrum

4) directed ion flux

5) total ion concentration

The development of a neutral particle mass spectrometer capable of operating in the expected pressure range ($10^{-13}$ atm.) should be pushed with the nominal intention of sending that instrument on the first mission; the ion equipment also should be included if space is available. In any case, it should be available as a replacement if development difficulties delay the neutral mass spectrometer so long that it cannot fly in early Apollo missions.

6. Availability of Instrumentation

Except for neutral mass spectrometers, instrumentation of the type and sensitivity required for the recommended program has been developed and is presently in use in space systems. Ion traps and ion mass spectrometers have been flown in many vehicles, including EGO. The directed ion flux could be measured with a solar wind detector, of which that flown in Mariner is a good example, or with a spectrometer for low-energy particles, such as that in the ISIS program. Pressure gages of the Redhead type have been extensively used and are essentially on-the-shelf items.

Neutral-particle mass spectrometers of the required sensitivity have not yet been operated in the laboratory. What is required, however, is apparently only a marriage of existing techniques. The addition of electron multipliers and counting techniques to an instrument of the quadrupole type can probably supply the required sensitivity, while the introduction of coincidence techniques may provide an even better instrument. Instrument development rather than research appears to be the requirement, and it appears probable that a suitable instrument can be developed in time for the early Apollo missions.

GPO 892-803