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July 31–August 13, 1967

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-SP-157

1967 Summer Study of

LUNAR SCIENCE AND EXPLORATION

Directed by

Wilmot N. Hess

Manned Spacecraft Center, NASA

Held at the University of California-Santa Cruz,
Santa Cruz, California, July 31 - August 13, 1967, under the
auspices of Manned Spacecraft Center, NASA

Scientific una! Technical Information **Division**

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PREFACE

This is not an official NASA program for lunar exploration. It is being published as a special NASA report for distribution to scientists and other interested individuals for their information.

This study is a substantial contribution to NASA's planning effort for lunar exploration. It reflects the concerted opinions of a group of outstanding scientists. It was prepared under guidelines which were developed prior to the 1968 Appropriation Hearings by the Congress. Hence, the plans are optimistic in outlook and exceed the capability of the agency to execute. On the other hand, it will serve as excellent source material for review and use by the Lunar and Planetary Missions Board in the development of their recommendations for the scientific strategy for lunar exploration. It will also be used by senior NASA officials in formulating their ideas as to the manner in which the agency should proceed.

It is being distributed at this time to give the scientific community the benefit of the thinking of this selected group of scientists and, perhaps, to stimulate them to the generation of new ideas which might be beneficial. It should be reiterated that this is NOT an approved NASA program for lunar exploration and is not to be considered as presenting the official plans of the agency for activities on the Moon.

Homer E. Newell

Homer E. Newell
Associate Administrator

ACKNOWLEDGMENTS

I would like to express my thanks to several people who made the Conference a success. Dr. Francis H. Clauser, Vice-Chancellor of the University of California, Santa Cruz; Mr. W. Gilbert, Business Manager of the University of California, Santa Cruz; and Mr. Ronald W. Saufley, Residence Hall Manager (NASA Project Coordinator) of the University of California, Santa Cruz, contributed very substantially by making their beautiful Santa Cruz Campus available to us and in-helping us with the conduct of the meeting. I would like to thank Mr. John Harris of the Manned Spacecraft Center, the Editor of this report, for his excellent and rapid job in putting the document together. I would also like to thank Mr. Paul Penrod of the Manned Spacecraft Center, Conference Manager, for his excellent job on Conference arrangements and administrative matters.

Wilmot N. Hess, Director,
Science and Applications Directorate

CONTENTS

ABBREVIATIONS

AAP	Apollo Applications Program
AFA	Automatic Field Assistant
AIC	Apollo Intermediate Chart
AIMP	Anchored Interplanetary Monitoring Platform
ALM	Augmented Lunar Module
ALPM	Augmented LPM
ALSEP	Apollo Lunar Surface Experiments Package
AS	Augmented Surveyor
ASE	Active Seismic Experiment
ASL	Automated Soft Lander
CEP	Circular Error of Probability
CM	Command Module
CRT	Cathode-Ray Tube
CSM	Command and Service Module
DSN	Deep Space Network
EGO	Eccentric Geophysical Observatory
ELM	Extended Lunar Module
ESS	Emplaced Scientific Station
ExESS	Expanded ESS
GLEP	Group for Lunar Exploration and Planning
HFE	Heat Flow Experiment
IMP	Interplanetary Monitoring Platform
LAC	Lunar Astronautical Chart
LFU	Lunar Flying Unit
LDSS	Lunar Deep Seismic Sounding
LM	Lunar Module
LO	Lunar Orbiter
LPM	Lunar Payload Module
LSS	Lunar Surveying System
LSSM	Local Scientific Survey Module
LRL	Lunar Receiving Laboratory
MCC-H	Mission Control Center, Houston
MES	Manned Exploration Site
MOBEX	Mobile Excursion
MOLAB	Mobile Laboratory
MSC	Manned Spacecraft Center, Houston
MSFN	Manned Space Flight Network
NAS	National Academy of Science
NASA	National Aeronautics and Space Administration
NRL	Naval Research Laboratory
NQR	Nuclear Quadruple Resonance
PI	Principal Investigator
PLSS	Portable Life Support System
PSAC	President's Scientific Advisory Committee
PSE	Passive Seismic Experiment
RTG	Radioisotope Thermoelectric Generator
RGM	Remote Geophysical Monitor
S-M3	Saturn IVB
SDC	Scientific Data Center
SLRV	Surveyor Lunar Roving Vehicle
SM	Service Module
SNAP	System for Nuclear Auxiliary Power
SRT	Supporting Research and Technology
ULO	Unmanned Lunar Orbiter
USGS	United States Geological Survey

CHAPTER 1

INTRODUCTION

INTRODUCTION

Planning for the scientific activities on the early Apollo missions was accomplished in the summer of 1965 at the NASA Summer Conference on Lunar Exploration and Science held at Falmouth, Massachusetts. NASA is implementing selected programs based on the recommendations of the various Falmouth Working Groups. With these programs underway, attention must be directed to the later Apollo missions and to the post-Apollo period to develop detailed planning for manned and unmanned scientific missions. Also, advance plans must be made for the experimental hardware required to successfully perform the missions. It was with this broad objective in mind that NASA planned the Santa Cruz Conference.

The 1967 Summer Study of Lunar Science and Exploration met on the campus of the University of California at Santa Cruz, California, July 31 through August 13, 1967. The Conference was under the auspices of the Manned Spacecraft Center, Houston, Texas, and was directed by Dr. Wilmot N. Hess. Mr. John W. Harris of MSC was the Editor of the Conference Proceedings and Mr. Paul R. Penrod of MSC was the Conference Manager.

The Conference was organized into eight disciplinary working groups and a group of advisors who represented a broad knowledge of lunar problems, an engineering or programatic specialty, or a related organizational entity.

The chairmen and secretaries of the working groups were as follows:

GEOLOGY: Chairman, Alfred H. Chidester, U. S. Geological Survey; Cochairman, Eugene Shoemaker, U. S. Geological Survey; Secretary, Donald A. Beattie, NASA Headquarters.

GEOPHYSICS: Chairman, Frank Press, Massachusetts Institute of Technology; Secretary, Edward Davin, NASA Headquarters.

GEOCHEMISTRY: Chairman, Paul W. Gast, Columbia University; Cochairman, James Arnold, University of California, San Diego; Secretary, Michael B. Duke, U. S. Geological Survey.

BIOSCIENCE Chairman, Melvin B. Calvin, University of California, Berkeley; Cochairman, A. L. Burlingame, University of California, Berkeley; Secretary, B. C. Wooley, NASA, Manned Spacecraft Center.

GEODESY AND CARTOGRAPHY: Chairman, Charles Lundquist, Smithsonian Astrophysical Observatory; Secretary, James Sasser, NASA, Manned Spacecraft Center.

LUNAR ATMOSPHERES Chairman, Francis Johnson, Southwest Center for Advanced Studies; Secretary, Dallas E. Evans, NASA, Manned Spacecraft Center.

PARTICLES AND FIELDS: Chairman, D. J. Williams, NASA, Goddard Space Flight Center; Cochairman, Norman Ness, NASA, Goddard Space Flight Center; Secretary, D. E. Hagge, NASA, Manned Spacecraft Center.

ASTRONOMY: Chairman, L. W. Fredrick, University of Virginia; Cochairman, N. G. Roman, NASA Headquarters; Secretary, Roy C. Stokes, NASA, Manned Spacecraft Center.

A list of participants at the Conference is presented in appendix A.

The Astronomy Working Group met at Charlottesville, Virginia, during the first week of the conference. Dr. Roman joined the Santa Cruz Conference for the second week. During the last 3 days of the conference, the interdisciplinary Group for Lunar Exploration Planning (GLEP) met to integrate the ideas of the working groups into a coherent plan. The GLEP was composed of the following persons':

W. N. Hess	Chairman
E. King	Secretary
P. Gast and J. Arnold	Geochemistry
E. Shoemaker and R. Jahns	Geology
F. Press	Geophysics
C. Lundquist	Geodesy and Cartography
M. Calvin	Bioscience
F. Johnson	Atmospheres
D. Williams	Particles and Fields
N. Roman	Astronomy
P. Culbertson	NASA, Office of Manned Space Flight
R. Allenby	NASA, Office of Space and Science Applications!
H. Gartrell	NASA-MSC, Apollo Applications Program
H. Schmitt	NASA-MSC, Astronaut Office
M. Faget and W. T. Stoney	NASA-MSC, Engineering and Development Directorate

This document* contains the reports and recommendations of the discipline-oriented working groups and of the interdisciplinary GLEP developed at the Santa Cruz Conference. The reports and the recommendations do not constitute NASA policy or authorized programs. The information contained in this report was intended to provide NASA with expert information, from the most outstanding lunar scientists, for the

*This document has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

programatic planning for future missions and to stimulate simultaneously the interest and participation of the scientific community in the accomplishment of these programs.

The Conference was convened to meet the following objectives:

1. To obtain the consensus of the scientific community as to what the future Lunar Exploration Program should be

2. To prepare detailed science plans for future manned and unmanned lunar missions

3. To establish the order of priority of experiments to be conducted on all missions

4. To make recommendations on major hardware items required for the science programs

5. To make recommendations on the instrument development programs required for the science program and those required to meet Supporting Research and Technology Program needs

One of the original objectives of the Conference, the preparation of detailed science mission plans, was not accomplished. It was recognized quite early that more detailed engineering data than now exist were required to accomplish the mission planning. It is now planned that the GLEP and engineering personnel will gradually develop the detailed mission plans. The mission planning is an iterative process and will take some time to accomplish. The work of the Conference is not finished in this area; therefore, the scientific plans presented in this document are preliminary and illustrative and should not be considered as being final.

To achieve the stated objectives, the working groups were asked to prepare working papers on the following subjects prior to the meeting:

1. Scientific requirements for lunar surface mobility

2. Scientific requirements for lunar mission duration

3. Drafts of mission profiles for trips to Alphonsus, Aristarchus, and Copernicus or for polar lander and extended surface traverses

4. Scientific use of lunar orbital flights

5. Scientific utility of planned major hardware items, such as the Local Scientific Survey Module (LSSM), the Lunar Flying Unit (LFU), the Deep Drill, the Augmented Lunar Module (ALM), and the Shelter/Taxi.

Additional subjects were added to this list by some working groups.

Reference documents were provided for information on the previous work of other planners and on the engineering status and capabilities of various hardware systems. These input documents included the following:

1. Summary of Edited Transcript from the Lunar Exploration Program Review. Held at NASA, Goddard Space Flight Center, January 31 to February 3, 1967.

2. Apollo Applications Program Technical Summary. Prepared by the NASA Office of Manned Space Flight, May 1, 1967.

3. Draft of Summary Report of Apollo Applications Lunar Mission Ad Hoc Study Team, June 30, 1967.

4. The Space Program in the Post Apollo Period, Report of the President's Scientific Advisory Committee. Prepared by the Joint Space Panels, February 1967.

5. NASA 1965 Summer Conference on Lunar Exploration and Science. Falmouth, Massachusetts, July 19-31, 1965, NASA SP-88.

6. Space Research Directions For the Future, Report of a study by the Space Science Board held at Woods Hole, Massachusetts, 1965. Volumes I, II, and III.

7. A Strategy for Scientific Exploration of the Terrestrial Planets. Jet Propulsion Laboratory Report 900-28, July 12, 1967.

8. Lunar Mission Planning Data Book. Compiled by the Lunar Missions Office, Advanced Spacecraft Technoiogy Division, Manned Spacecraft Center, July 1967.

Certain ground rules were established to provide boundary conditions for working group discussions. The following was the most important ground rule:

> To studv both manned and unmanned automated svstems and to optimize the scientific return f[illegible] the [illegible] y combining their use.

This integration of the two major parts of the lunar program was carried on in the working groups and was emphasized in the GLEP meetings. Other important ground, rules were the following:

> To use the Apollo spacecraft and systems with minimal modification.

> To select the major support hardware items from those that are currently under consideration. (Do not start or re-design completely new systems.)

CHAPTER 2

SUMMARY AND RECOMMENDATIONS

SUMMARY AND RECOMMENDATIONS

The primary purpose of the Santa Cruz Conference was to arrive at a scientific consensus as to what the future lunar manned and unmanned exploration program should be, particularly in the time frame of the Apollo Applications Program (AAP). It was planned that the major results of the conference would include (1) a recommended list of lunar missions with detailed mission plans and priority experiment lists for each mission, (2) a priority list of major hardware items, and (3) recommendations for instrument development and for Supporting Research and Technology Programs.

The details of the findings and recommendations of the working groups are reported in later sections. The major recommendations of the conference and the proposed lunar exploration program include (1) systems development, (2) proposed mission sequence, (3) program planning and support, and (4) science mission plans.

SYSTEMS DEVELOPMENT

Lunar Surface Mobility

The most important recommendation of the conference relates to lunar surface mobility. To increase the scientific return from lunar surface missions after the first few Apollo landings, the most important need is for increased operating range on the Moon. On the early Apollo missions it is expected that an astronaut will have an operating radius on foot of approximately 500 meters. It is imperative that this radius be increased to more than 10 kilometers as soon as possible.

To increase surface mobility the following recommendations are made:

1. It is recommended that a Lunar Flying Unit be developed immediately to be used in AAP and, if possible, on late Apollo flights to increase the astronaut's mobility range.

This is the first step towards attaining reasonable mobility. It is expected that the Lunar Flying Unit (LFU) will provide a mobility radius of 5 to 10 kilometers, which is a considerable improvement over the present capability, but not nearly enough. Exploration of lunar surface features such as large craters and their environs will require a range of approximately 25 kilometers or more.

2. It is recommended that the Saturn V dual-launch capability be developed as soon as possible.

3. It is recommended that the dual-mode local scientific survey module (LSSM) be developed on the same schedule as the dual-launch Saturn V.

This wheeled vehicle should be capable of operating in an automatic or manned mode. The primary purpose of the dual-launch system is to carry the recommended LSSM and additional fuel for the Lunar Flying Units. The automated/manned LSSM has a greater capability than the one now planned. The LSSM used in conjunction with Lunar Flying Units should provide a mobility radius of approximately 25 kilometers.

The best type of lunar surface mobility system was the subject of considerable debate during the Conference. Two different philosophies of exploration of large scale areas arose.

1. The Geochemistry Working Group strongly favored the large lunar flying vehicle. A manned vehicle, which provides spot coverage over a wide area, would best afford the opportunity for observation and sample collection.

2. A substantial, but divided, opinion of the Geology Working Group was that the combination of Small Lunar Flying Units with the LSSM was best for spot coverage and for continuous ground coverage. The Geology Working Group emphasized that the continuous ground observation was essential to solve complex geological problems in areas of limited size. The geologists felt that experience had shown such studies are critical to solving much larger problems and are necessary to place geochemical and geophysical data in their proper geological context.

At the conclusion of the meeting, a substantial majority of the working groups were in favor of the shorter range, continuous surface traverse using a dual-mode LSSM rather than spot coverage over a large area with a Large Flying Unit. Another reason for the choice of the LSSM is that it is probable that the manned half of a **dual** launch will carry two Lunar Flying Units. Starting with this, the total mobility system using the LSSM seemed a better choice.

A very important reason for the choice of the LSSM involved the use of an automated mode of operation. Agreement was unanimous on the need for long unmanned traverses on the lunar surface. After the astronauts have returned to the Earth, the LSSM would be sent unmanned to a new destination. On its journey, the LSSM would accomplish the following:

1. Stereo TV on the LSSM will permit the LSSM to be controlled from the Earth. The LSSM would collect samples along the route. Some of these samples would be aseptically handled and packaged for return to the Earth by the next manned lander.

2. The LSSM would conduct a geophysical traverse of a large area using magnetometers, gravimeters, radar probing, et cetera.

3. The LSSM would deploy several small ALSEP-type Remote Geophysical Monitors along the traverse. In this way, a network of such units could be built. The Remote Geophysical Monitor (RGM) would carry instruments such as seismographs, atmospheric mass spectrometers, gravimeters, magnetometers, et cetera.

The dual-mode LSSM is more complicated and has greater capability than the vehicle presently planned. The LSSM should have the following characteristics and capabilities.

1. Articulation
2. The ability to pick up rocks
3. Stereo TV with the Apollo bandwidth and a fast shutter
4. Rock analysis (nondestructive) with a storage capacity of 50 pounds
5. A headlight (night and shadow operation)
6. Samples, stowage of approximately 100, maximum weight of 1 kilogram per sample with some aseptically sealed
7. The capability to carry and deploy 6 RGM's, each weighing 50 pounds and equipped with instruments such as a gravimeter, a radar probe and a magnetometer
8. Dead-reckoning navigation with altitude and horizontal ties to known controls
9. Manned (capability for carrying two men) with optional steering modes and capability for carrying 1 or 2 LFU's
10. Relay communications
11. Carry a backup portable life support system (PLSS) or an independent life support system

Block II Surveyor

Other systems working with the automated LSSM are probably needed to develop the geophysical network of Remote Geophysical Monitors on the Moon. This network requires about 10 automated stations distributed over the front face of the Moon with spacings on the order of 1000 or more kilometers. This system is required to obtain large-scale information about the interior of the Moon.

<u>It is recommended that a Block II Surveyor, or another system be available in the period from 1970 to 1975 which is capable of deploying experiments such as the following:</u>

1. A passive seismic/tidal gravimeter/tiltmeter (three components)
2. A corner reflector
3. A gravimeter (geodetic)
4. A mass spectrometer
5. A total-pressure gage
6. A Doppler transponder
7. A facsimile camera
8. A magnetometer
9. A plasma probe
10. Low-energy particles
11. Electric field
12. A γ-ray experiment or a-counter experiment

The Block II Surveyor will afford wide geographic coverage for instruments. Special care must be taken in deployment of experiments (magnetometer, λ-ray, et cetera) so that they are deployed in an appropriate environment.

Sample Return Capability

One important, if not the moat important, scientific result from the **AAP** missions will be the return of lunar samples. The amount returned must increase as the capabilities of the vehicles allow.

> It is recommended that the total returned payload from the Moon in AAP missions increase to 400 pounds so that a minimum of 250 pounds of lunar samples can be returned.

A consensus of the Conference was that a capability to return approximately 50 pounds of refrigerated samples was needed as soon as possible.

Modular ALSEP

It was clearly recognized at the Conference that Apollo lunar surface experiments packages or their derivatives such as Emplaced Scientific Stations or Remote Geophysical Monitors would be used on essentially all AAP landing missions. A number of new experimenters under development requires the ESS or RGM capability, and many of the current experiments should be used on the lunar surface in networks. The capability should be established to include new experiments on an ALSEP prior to a mission.

> It is recommended that future ALSEP stations be designed to allow a substantial degree of flexibility to react to new opportunities opened up by new developments or discoveries on the Moon. **A** modular concept to permit accommodation of new instruments with minimum disturbance of the basic ALSEP system would greatly facilitate such flexibility.

It is expected that the number of candidate experiments for a particular ALSEP mission will exceed the number that can be accommodated on that mission. Flight assignments for the mission should be made as close to the flight time as practical to reflect the state of knowledge at that time. The experiments would, therefore, be built to meet a standard ALSEP electrical interface and a suitably small choice of mechanical interfaces. This requires that the ALSEP central station have an appropriate number of standard electrical plug-in stations and a central data processor which assigns experiment data rates under the control of a stored program. The processor control program could be stored prior to flight or, preferably, on command from Earth. Remote reprograming is particularly desirable as it permits the real-time assignment of experiment data rates in response to acquired data.

Telemetry Capability

When several scientific packages are operating on or near the Moon for long periods of time, the capability to handle the increased data return will become a problem. The data return capability is presently a problem in some unmanned programs.

> It is strongly recommended that appropriate provision be made to insure continuous telemetry coverage of all scientific packages, both single and simultaneous operations, on and around the Moon. Provision must also be made to recover data continuously from the averted face of the Moon.

Orbital Subsatellites

Subsatellites could be injected from the AAP command and service module (CSM) vehicles into precision orbits to study the lunar environment, including magnetic fields and particle environment and the atmosphere and ionosphere.

> It is recommended that a subsatellite system be developed for deploying systems of instruments in close orbit around the Moon.

PROPOSED AAP MISSION SEQUENCE

To understand how the mobility systems fit into the program of flights and why they have been chosen, the proposed program of lunar landing missions should be examined. The programis not in final form and will not be for some time, at least until further mission studies have been made. The program of missions consists of three distinct mission types: **(1)** manned orbital flights, **(2)** single-launch Saturn V lunar landing flights, and **(3)** dual-launch Saturn V lunar landing flights. The proposed program is outlined in table I and figure **1.**

Manned Orbiter

The first recommended AAP flight is a manned lunar orbital flight with these objectives.

1. AAP landing sites mapping photography (return of film necessary)

2. Metric-mapping quality photography with returned film

3. Geochemical remote sensing using γ-rays and X-rays on a subsatellite left in lunar orbit or using a directional detector system on the CSM

4. Flying a family of remote sensors such as passive microwave radiometer, infrared radiometer, radar reflectivity, radio noise survey, magnetometer and plasma probe, multicolor photometry, meteoroid detector, radio radiometer, and fluoresence photometer.

Objective **4** has a somewhat lower priority than the first three.

The only way to obtain adequate data for cartographic purposes is to have the film returned to Earth for analysis. The photography from this flight should provide maps of the Moon in the IR region and (by analyzing the γ-rays) lunar contour maps of the concentration of potassium and uranium and possibly of other elements. Such data will be valuable in future mission planning.

The first orbiter flight should be followed by a second flight within a time frame so that new remote sensing instruments would be perfected (1) to increase the ability to map the Moon remotely in various electromagnetic frequencies and (2) to obtain greater information on the distribution of the elements.

Single-Launch Mode

The first AAP lunar landers will probably be single launches. Missions 2, 3, and 4 represent the proposed early single-launch landers. Because the crater Copernicus is such a large feature and because information about Copernicus is essential to the understanding of the Moon, two separate missions are proposed: one to the central peaks and one to the crater wall. A proposed science mission plan for the central peaks is presented later in this section.

The durations of this class of missions are flexible. It is desired that the dual-launch missions be started as soon as possible, however, a series of useful single launches could be continued for a number of missions. Suggested additional sites for the subsequent single missions are Copernicus H, Gambart, Mösting C, Hyginus Rille, Flamsteed, Dionysius, Hipparchus, the dome near Lunar Orbiter Photographic Site II-P-2, and the Surveyor landing and the Ranger impact sites. The Lunar Flying Unit would be used for mobility on these missions.

Dr. George E. Mueller suggested that the conference consider what scientific program should be carried out on Apollo flights after the first two or three successful lunar landings. The following ground rules were assumed:

1. Some system constraints will have been removed so that more payload is available on the Apollo CSM.

2. The lunar module (LM) will be able to land at rather rough sites but still in or near the Apollo landing zone of $\pm 10°$ latitude.

3. No substantial hardware changes will be made in the CSM or the LM.

It was decided that all of the suggested single-launch AAP landing sites would be appropriate for late Apollo, except Copernicus which requires more mobility. The most appealing sites were Copernicus H, Gambart, Mösting C, and the dome near site II-P-2. The lunar module might land close enough to these sites to allow access to the interesting areas. There was a strong feeling that there should be at least one highland landing site.

Additional mobility should be brought into the program as rapidly as possible. The LFU should be used even if it has only a 1- or 2-kilometer range which will significantly enhance the scientific return. If the LFU is not ready, the schedule for the Apollo lunar program should be adjusted, after the first few successful landers, to allow the LFU to be brought into these late Apollo missions.

Dual-Launch Mode

The future lunar exploration program must involve mobility systems that require two Saturn V launches. The dual-mode LSSM and a large amount of additional fuel for the Lunar Flying Units will be carried to the lunar surface in an unmanned lander. The manned Saturn V will land nearby later. The present LSSM cannot be carried to the Moon in a manned single-launch system.

A major feature of the dual-launch system is that the unmanned LSSM would make a long traverse (approximately 1000 kilometers) and arrive at the site of the next manned landing with a collection of surface samples from an extensive region of the Moon. These would be returned to Earth by the next manned lander. The suggested sequence of missions with automated LSSM traverses is shown in table I. This technique allows a much larger fraction of the lunar surface to be sampled than man can possibly visit during all of the proposed manned AAP missions (fig. 1).

PROGRAM PLANNING AND SUPPORT

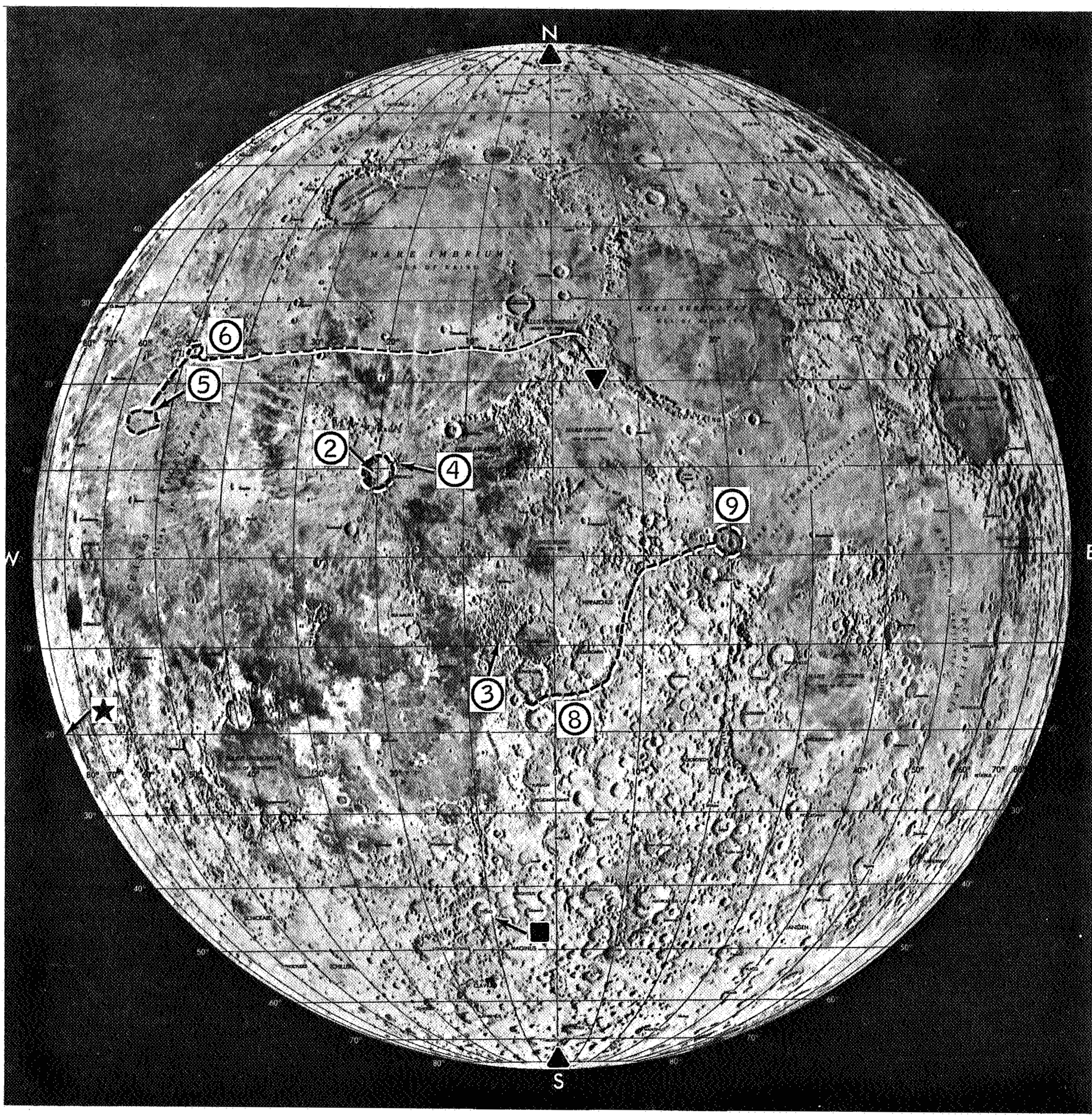
Fallback Position

If the AAP lunar program level should drop below one dual-launch or two single-launch missions per year, then the Group for Lunar Exploration Planning (GLEP) should meet again to reconsider mission plans. The program at this low level might need significant redirection. For example, in the case of severe budgetary restrictions or other problems that would preqent developing the Saturn V dual-launch capability, an automated system, such as Rover launched by a system less complicated than a Saturn V, might need to be developed.

Solicitation for Experiments

The selection of experiments from the scientific community was a major consideration at the Conference.

> To develop a strong science program in AAP, it is strongly recommended that any extension of the Apollo science program (that is, new Apollo hardware, follow-on ALSEP, or AAP), be implemented by open solicitation of experiments from the scientific community. Only in this way can the Manned Space Flight Program build the broad base of scientific support and participation necessary for an active and productive research program.



▲ North or South Pole
■ Tycho
★ Mare Orientale (20° S, 95" W)
▼ Hadley Rille

Figure 1. - Index map showing proposed mission sites and sequence. (Sites are identified in table 1).

TABLE I. - PROPOSED AAP MISSION SEQUENCE

Mission	Mission location	Schedule[a], yr	Launch mode
1	Manned orbiter	1st	--
2	Copernicus (central peaks)	1st	Single
3	Davy Rille	2nd	Single
4	Copernicus (walls)	2nd	Single
5	Marius Hills LSSM to the Cobra-Head	3rd	Dual
6	Cobra-Head LSSM to Hadley Rille	3rd or 4th	Dual
7	Manned orbiter	3rd or 4th	--
8	Alphonsus LSSM to Sabine and Ritter	5th	Dual
9	Sabine and Ritter {or end of Alphonsus LSSM mission)	5th	Single
▲	North Pole or South Pole[b]	--	--
□	Tycho[b]	--	--
*	Mare Orientale[b]	--	--
▼	Hadley Rille[b]	--	--

[a]Mission will occur within the program year(s) indicated.

[b]Times, launch modes, and sequence are not established; further study is required.

It is recognized that the time scales involved may pose problems in certain disciplines in implementing the above recommendation. However, experiments are available which could be delivered on a relatively short time scale and thus allow the possibility of a wider NASA scientific program.

Support of Basic Research

The NASA support of basic research programs has been a benefit to the space program and also to universities and other research institutions. This support should not be confined to flight programs, but should be continued in all areas of basic science which contribute to the overall NASA objectives of space exploration.

Support of Instrumentation Development

Many scientific experiments appear very promising for lunar exploration but are not feasible now because (1) detector systems have not been developed to the point of having the desired sensitivity, or (2) theoretical problems have not been fully investigated to insure proper design of the experiment or full interpretation of the results.

Three stages in the development of an experiment and the necessary hardware can be visualized. These are (1) detailed consideration of the importance and feasibility of an experiment, (2) development of necessary scientific tools to implement the experiment, and (3) production of flight hardware.

> To carry out the first two stages of producing an experiment listed previously, it is recommended that a strong program in scientific instrument definition and development and a substantial lunar Supporting Research and Technology Program be undertaken immediately. The amount of money being invested to produce experiments for AAP flights in the present budget is not compatible with the scope of the program. It is further recommended that adequate time be included in program planning and launch schedules to allow for the scientific development of the appropriate experiments.

Establishment of Project Scientist

It is now apparent that there is a need for more continuous scientific input into the development of scientific flight hardware for lunar missions.

> It is strongly recommended that a position of Project Scientist be established within the structure of the Manned Space Flight Program. The responsibilities of the Project Scientist are to represent the scientific requirements and objectives of the experiment to the Project Manager and his staff and conversely to represent to the Principal Investigator project requirements which may affect his experiment. At least one Project Scientist should be associated with every MSC project which includes

scientific experiments; more than one Project Scientist may be desirable for a large project in which the number of scientific disciples is large. Furthermore, it is strongly recommended that the Project Scientist should be a participating experimenter in the project for which he is responsible. The position of the Project Scientist within the organizational structure should be at a level which insures adequate science input into the program.

Astronaut Selection and Training

After basic classroom work and tutorials, the astronaut should be provided the time and opportunity to participate directly in the research and planning activities of the particular mission for which he is selected. This may require one or more thorough refresher tutorials covering the specific topics of prime scientific importance for the mission. In crew selection for any mission, flight-operations ability is, without question, the primary criterion.

It is strongly recommended that ability in field geology be the next most important factor in the selection of the crewmembers who will actually land on the Moon for the Apollo missions. For some of the complicated scientific missions in the later part of the AAP, the Santa Cruz Conference considers that the knowledge and experience of an astronaut who is also a professional field geologist is essential. In the interest of maintaining career proficiency, astronauts should be provided time to engage in some form of research activity within their professional fields.

SCIENCE MISSION PLANS

As previously stated, the science mission plans in this report are not in final form. Engineering studies must be made and appropriate modifications and plans developed.

It is recommended that an immediate and intensive program of detailed mission analyses be undertaken for all of the prime lunar landing sites and traverses that have been listed by this Conference.

Because of the rapid development of suitable launch capability and the growth of an extensive body of photogeological maps of the lunar surface and because of the lead-times required for development of selected systems, the working groups felt that such analyses are urgent. The analyses must be planned on an iterative basis to test the applicability of the recommended plans and of instrument development for the achievement of the general scientific objectives for lunar exploration.

Copernicus Mission Plan

The most intensively studied area on the Moon is Copernicus, a bright-rayed crater 50 miles in diameter in the central part of the Earth-facing hemisphere. Mare and highland stratigraphic units may crop out in crater walls that are almost 3 miles high. Ledges exposed in the central peak may include outcrop layers from a total depth of about 6 miles. A variety of features on the crater floor has been interpreted as volcanic in origin. The crater is the site of comparatively fresh outcrops, according to interpretations of Lunar Orbiter photographs, of geological units that could range from very ancient to very young.

The primary purposes for the mission to Copernicus are as follows:

1. To sample and determine the stratigraphic relations and nature of lithological units exposed in the central peaks.

2. To search for evidence of the origin of a bright-rayed crater.

3. To make field observations to confirm the validity of photogeological studies from Earth-based telescopes and from satellite photography.

4. To study the X-ray and micrometeoroid environment and the optical surface degradation for the examination of the Moon as a possible base for astronomical observations.

The following are the objectives for the Copernicus mission:

1. To study and sample important rock units in the central peak, floor, and walls.

2. To study a variety of features presumed to be of volcanic or impact origin, or to be mass wasting. Exploration of the crater floor will provide the best opportunity to check the geological mapping which is based upon Earth observation and satellite photography.

3. To emplace passive geophysical, astronomical, particles and fields, and atmospheres experiments.

The general mission flight plan is described in table II. Examples of specific traverse routes are shown in figure 2.

The Cobra-Head (Aristarchus Region) Mission Plan

Aristarchus, the brightest crater on the Moon, is within a complex area in the northwestern quadrant of the Earth-facing side of the Moon. The crater is the site of the most intense infrared anomaly that has been detected. Nearby, Cobra-Head and Schroter's Valley constitute the largest sinuous rill on the exposed face of the Moon. Many transient phenomena have been sighted in this region, including those described by cartographers at the Aeronautical Chart and Information Center (Lowell Observatory), as landslides at the head of Schroter's Valley. Domes and flows interpreted as

volcanic features are abundant on the Aristarchus plateau and are different from those exposed in the Marius Hills. Rough highland deposits blanketed by ejecta from the Imbrian basin crop out in the eastern part of the Aristarchus plateau.

Collections here could sample a wide range of ages and types of lunar material. In addition, geophysical traverses of Schroter's Valley should contribute to an understanding of the relationship between the narrow inner and larger outer valleys. The variety and complexity of geological phenomena will justify using the staytime and mobility resulting from a dual launch. The plans for this mission include the use of the LSSM/LFU mobility system and a combination of traverse geophysical measurements and emplaced geophysical stations.

The purpose of the mission is to study a complex area which shows one of the richest varieties of structures, rock relationships, and transient phenomena observed on the front side of the Moon.

The following are the objectives of the mission.

1. To examine and collect samples at Cobra-Head, a presumed volcanic feature at the head of Schroter's Valley.

2. To observe stratigraphic and structural relationships, and to make geophysical measurements in Schroter's Valley, particularly for evidence of recent landslide or volatile effluent phenomena.

3. To search for evidence of recent volcanic eruptions in the vicinity of Cobra-Head and to study the apparent volcanic domes and flows nearby on the Aristarchus plateau.

4. To sample the ejecta material from Aristarchus crater which is among the brightest on the Moon and has the largest infrared anomaly.

5. To establish from field observations and samples the historical sequence of the evolution of the Aristarchus region.

6. To emplace passive geophysical, particles and fields, and atmospheres experiments at locations of selected interest near Cobra-Head.

7. TO investigate the lunar horizon stability to aid in determining the suitability of the Moon as a base for astronomical observations.

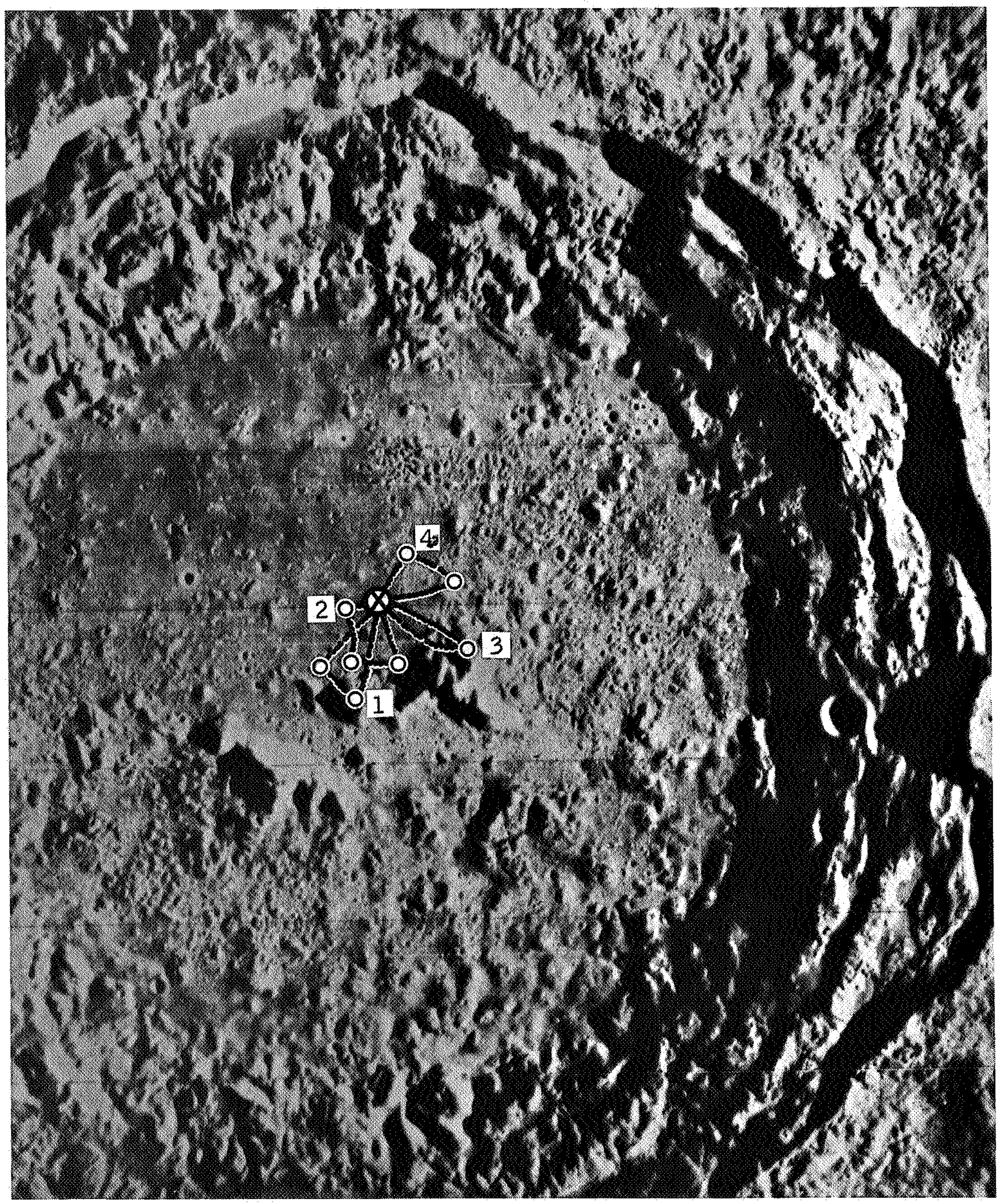
8. To rendezvous with the unmanned LSSM from the Marius Hills.

9. To place the LSSM in the unmanned mode at the end of the mission for an unmanned traverse to the Hadley Rille.

The general flight plan for the mission is described in table III. Examples of traverse routes are shown in figure 3.

Alphonsus Mission Plan

The floor of the crater Alphonsus in the central part of the Moon is an area of great complexity and variety, as revealed by telescopic studies and photographs taken by Ranger IX and Orbiter IV. Alphonsus has about the same diameter as Copernicus



LFU route — 2 Traverse number
LM — LFU stop

Figure 2. - Sample traverse routes in Copernicus.

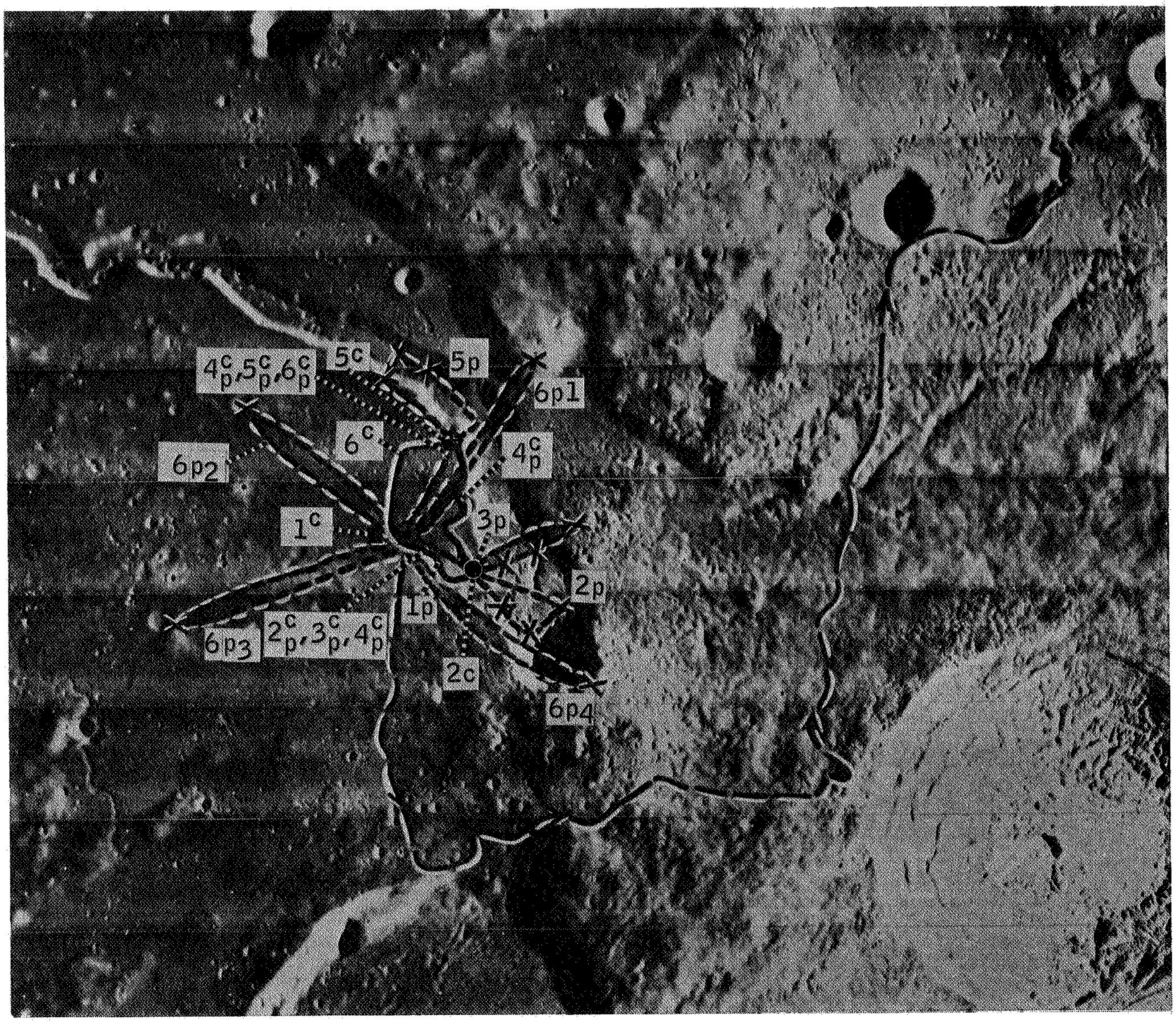
TABLE II. - GENERAL MISSION PLAN TO COPERNICUS

[Characteristics of the mission: Single-launch Saturn V with an Extended Lunar Module (ELM); staytime, 3 days for two men]

Day	Events	Tanks[a]
1	Landing:	
	ELM and 2 LFU on floor north of central peak	--
	LM stabilization and LFU preparation	2
	2-man, 1-hr, 1/6-g familiarization and LFU checkout	0.5
	2-man, 2-hr, ALSEP emplacement	--
	1-man, 3-hr LFU survey sortie 1 to top of central peak for photography, communications relay implant, sampling, and gravimeter deployment	1
	1-man, 3-hr excursion at LM to emplace 500-ft geophone spread and to obtain biological and rock samples	--
2	1-man, 3-hr LFU sortie 2 to survey and sample crater floor and hill features; to set up seismic charges and deploy gravimeter	1
	1-man, 3-hr lunar soil profiling at site close to LM	--
	1-man, 3-hr LFU sortie 3 to survey and sample peak and base of second central peak and to deploy gravimeter	--
	1-man, 3-hr sample examination, $\alpha K \alpha$ spectrometer sorting, packing at LM	--
	1-man, 3-hr LFU sortie 4,[b] examine and sample smooth floor material, hummocky floor material, and floor lineaments; set seismic charges and deploy gravimeter	--
	1-man, 3-hr survey local surface processes and features at LM	--
	2-man, 2-hr sample examination, selection, stowage, and emplace scientific stations	--
	2-man, 1-hr departure preparation	--
	TOTAL	4.5

[a]LFU propellant loadings.

[b]Flight distance limited to walk-back capability.



Legend:

- LSSM manned traverse
- ⊕ Termination point of LSSM traverse
- ---- LFU traverse flight line
- .... LFU ferry flight line
- X LFU landing point
- ■ Emplaced Scientific Station
- ● Remote Geophysical Monitor
- 2^c_p Day of lunar stay showing commander (c) and/or LM pilot (p) as performing activities
- 6p2 LFU flight by LM pilot on sixth day of mission showing number of flights that day
- —→— LSSM unmanned traverse

Figure 3. - Planned mission to the **Cobra-Head.**

TABLE III. - GENERAL MISSION PLAN TO COBRA-HEAD

[Characteristics of mission: dual-launch Saturn V with LM/LM truck; staytime, 6 days for two men]

Day	Events	Tanks[a]
1	Landing:	
	LM and LM truck landing near the Cobra-Head and possible rendezvousing with an unmanned LSSM from Marius Hills	--
	LM checkouts and traverse planning	--
	2-man, 1/6-g familiarization including checkout of LSSM and LFU, and sample collection from rendezvous LSSM (from Marius Hills)	2
	1-man, 3-hr LSSM traverse excursion ending at rim of the Cobra-Head	--
	1-man experiment deployment near LM and erection of analysis shelter	--
2	1-man, 3-hr LFU traverse into the Cobra-Head, operating from LSSM	3
	1-man foot traverse near LSSM	--
3	1-man, 3-hr LFU/geophysical traverse excursion across Schröter's Valley, operating from LSSM	3
	1-man, 3-hr ESS emplacement near LSSM	--
4	1-man, 6-hr LSSM traverse excursion to north ending at rim of Schroter's Valley	--
	€-man, 3-hr LFU/multiple traverse on foot from LM (within rescue capability of LFU) operating from the LSSM	2.5
5	1-man, 3-hr LFU traverse into Schroter's Valley, operating from LSSM	3
	1-man, 3-hr foot traverse near LSSM	--
6	1-man, 4-hr LSSM traverse ending at LM, conversion of LSSM to unmanned operations mode for proceeding to Hadley Rille	--
	4-man, 3- to 4-hr LFU point stop sorties to four sites operating from LM	4.5
	2-man, 3-hr departure preparation	--
	TOTAL	8

[a]LFU propellant loadings.

(about 90 km), but it lacks the diagnostic impact features that are so clearly evident at Copernicus. It may be an old, considerably degraded impact structure in the central highlands. Outcrops in the 6000-foot crater walls should yield data that will help establish the crater origin and add to the knowledge of highland units and history. Crustal rocks from a great depth below the crater may be exposed in the central peak. The central ridge has been interpreted as volcanic rocks extruded along a major tectonic break that cuts the northern and southern crater walls and continues far to the north through crater Ptolemaeus.

A polygonal set of faults and grabens cut the crater floor and continue into the crater walls. Dark-haloed craters (possibly pyroclastic cones) are distributed along some of the faults. Kozyrev* has observed possible volatile emissions in this region. Outcrops in the crater walls may include volcanic and ancient highland deposits that may cover a large span of lunar history; the floor appears to be covered by volcanic and impact craters.

The probable complex geology makes this site a prime target for a dual manned launch, not only for the study of lunar history, but for the study of many fundamental geochemical and geophysical problems. The possibility of the existence of effluent gases in the crater is equally challenging.

The following are the primary purposes for choosing the site:

1. To make geological and geophysical observations and to sample selectively in a crater site in an old highland region which offers an optimum combination of important features for establishing a sequence of lunar geological history.

2. To investigate the early stratigraphic history and related processes that formed the highland areas.

3. To investigate the pray and optical environments for examination of the Moon as a possible base for astronomical observations.

The objectives are to make sample collections and field observation in Alphonsus in sorties or groups of sorties and to examine the following:

1. Floor filling and its sequence in the vicinity of the landing site.

2. The central-peak and central-ridge region.

3. Dark-haloed crater and associated structures.

4. Western crater-wall structure and exposures of highland material.

5. Localities of possible recent gaseous emanations.

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*Kozyrev, N. A.: Invest. Krymsk. Astr. Obs., vol. 16, 1956, p. 148.

Also, an objective is to coordinate the mission by an unmanned/manned surface vehicle with automatic sensing capabilities. The vehicle should accomplish the following.

1. Precede a manned mission to reconnoiter geological materials of the western crater floor and collect uncontaminated geochemical and biological samples prior to a manned landing.

2. Provide technical and scientific information for precise landing-site selection.

3. Furnish astronaut transportation.

4. Provide followup reconnaissance of the central ridge and eastern floor of the crater wall for reconnaissance of the adjacent old highland region.

5. Emplace passive geophysical, astronomy, particles and fields, and atmospheres experiments.

6. Proceed unmanned across lunar highlands to the Sabine and Ritter craters.

The general flight plan for the mission is detailed in table IV. Figure 4 shows examples of specific traverses.

Astronomical Measurements

On several of the lunar orbital and surface missions, various measurements should be made to aid in the determination of the suitability of the Moon as a base for astronomical observations. Some of these measurements have been mentioned previously in the discussion of mission plans.

> It is recommended that the following list of observations be made on the lunar surface.

1. Micrometeorite environment
2. Radiofrequency noise levels
3. Surface impedance and conductivity
4. Density and extent of the lunar ionosphere (if it exists)
5. X-ray and pray intensities including zenith-angle distribution of intensities
6. Soil mechanics such as bearing strength and stability and depth profiles of temperature, seismic activity, and ionizing radiation
7. Thermal effects on astronomical instrumentation
8. Contaminants such as dust, spacecraft outgassing, spacecraft radiofrequency interference, and astronaut seismic noises
9. Deterioration of precision optical surfaces
10. Evaporation rates for optical coatings

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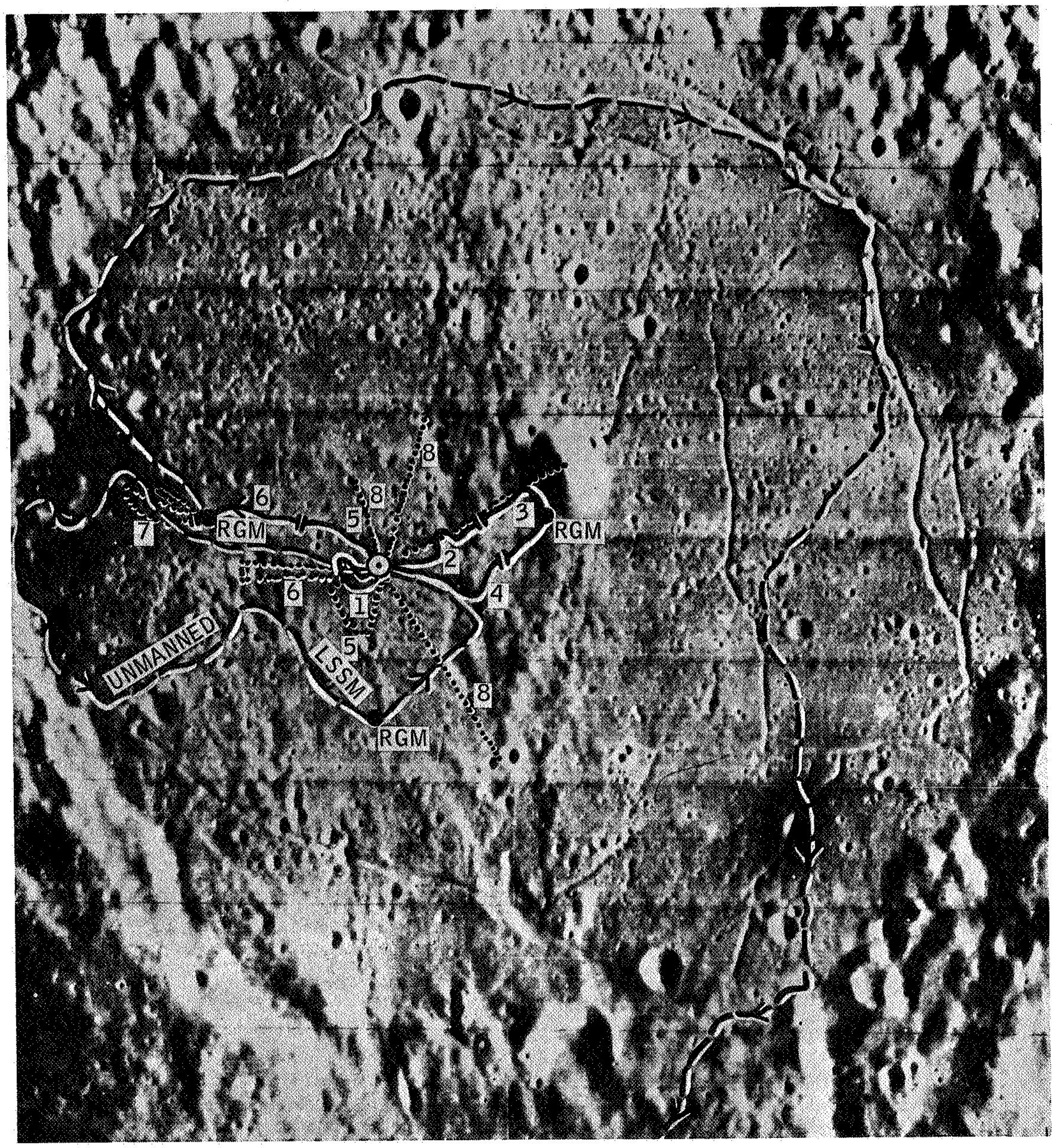

LSSM manned
LSSM unmanned
LFU
X LFU landing site
Overnight stop
RGM (Remote Geophysical Monitor)
5 Day of traverse
LM

Figure 4. - Sample traverse in Alphonsus.

TABLE IV. - GENERAL MISSION PLAN TO ALPHONSUS

[Characteristics of mission: dual-launch Saturn V with ELM/Lunar Payload Module (LPM) or ALM/Augmented LPM (ALPM); staytime, 7 to 8 days for two men]

Day	Events	Tanks[a]
1	Landing:	
	LM truck and ALM on western floor	--
	Premanned landing:	
	Unmanned LSSM sampling and reconnaissance traverse particularly to volcanic vents and west walls	--
	LM stabilization and LFU preparation	2
	2-man, 2-hr, 1/6-g familiarization and LFU checkout	1
	1-man, 3- to 4-hr survey of local area and preliminary sample collection	--
	1-man, 3- to 4-hr LSSM traverse to dark-haloed crater/rill complex	--
2	1-man, 6-hr LSSM and LFU traverse toward central peak across ridge/plain contact	1
	1-man, 3-hr excursion at LM to deploy ExESS	--
3	1-man, 6-hr LSSM and LFU traverse from ridge to foot of central peak, along contact and start back; emplace 2 RGM emplace Active Seismic Experiment (ASE) charges	0.5
	1-man, 3-hr drilling excursion at LM	--
4	1-man, 6-hr LSSM and LFU traverse from ridge to LM	0.5
	1-man, 3-hr LFU/foot traverse to top of central peak leaving communications relay	--
5	2-man, 2-hr loading of LSSM for unmanned mission	1
	1-man, 4-hr LSSM traverse toward the west	--
	1-man, 3-hr LFU point-stop sorties to four sites operating from LM	3
6	1-man, 6-hr LSSM traverse continuing toward west; emplace RGM; emplace ASE charges	0.5
	1-man, 3-hr LFU/foot traverse toward west to primary and secondary craters	--
7	1-man, 3-hr LFU/foot traverse on dark-haloed blanket	1
	1-man, 3-hr LFU/foot traverse and point stops on rim of dark-haloed crater	1
8	1-man, 3-hr LFU point-stop sorties to three locations	2.5
	1-man, 3-hr departure preparation excursion; LSSM proceeds unmanned to Sabine and Ritter	--
TOTAL		16

[a]LFU propellant loadings.

CHAPTER 3

REPORT OF

GEOLOGY WORKING GROUP

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INTRODUCTION

Lunar geological studies should be directed toward the ultimate goal of determining the origin and history of the solar system. This goal will be achieved by systematic pursuit of more limited specific objectives (outlined in the NASA Falmouth report[1] and in a report by the Space Science Board of the National Academy of Sciences[2]). The more limited objectives are directed toward such problems as the relative roles of impact, volcanism, and differentiation in the growth of a body of planetary dimensions; the composition, structure, and age of lunar materials; the nature and role of surficial processes on the lunar surface; and the nature of tectonism on the Moon. An additional important role of the lunar exploration program is to serve as the laboratory and testing ground for procedures and systems to be used for further exploration in the solar system.

An effective program for systematic geological exploration of the Moon depends upon a carefully considered definition of the scientific goals, a plan of exploration which will provide adequate coverage of areas that will produce the most significant scientific data, and the utilization of the best selection of Earth-based and manned and unmanned lunar surface and orbital systems. Such a program must also provide for extensive research in scientific instrumentation and in methods for carrying out lunar exploration, leading to an orderly development of scientific instrumentation, supporting systems, and Earth-based facilities. Finally, the program must provide an adequate level of geological training for the astronauts to carry out the investigations and must provide the means to carry out postmission analysis and synthesis of the returned data.

The activities of a lunar exploration program are varied and have a complex interrelationship (fig. 1). Each activity must be directed toward the greatest possible scientific yield from each mission, so that the principal consideration in all activities before, during, and after missions is to increase the efficiency and effectiveness of surface operations, particularly those of the astronaut. This consideration is more critical to geology than to any other scientific discipline because field geological investigations rest basically upon observation and description which, in turn, provide the framework for relating all other geological data and which can enhance the return of other scientific investigations.

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[1]Results of the conference were published as NASA 1965 Summer Conference on Lunar Exploration and Science. NASA SP-88, 1965.

[2]Referenced as Space Research Directions for the Future — Report of a Study by the Space Science Board. Parts I, II, and III, 1965.

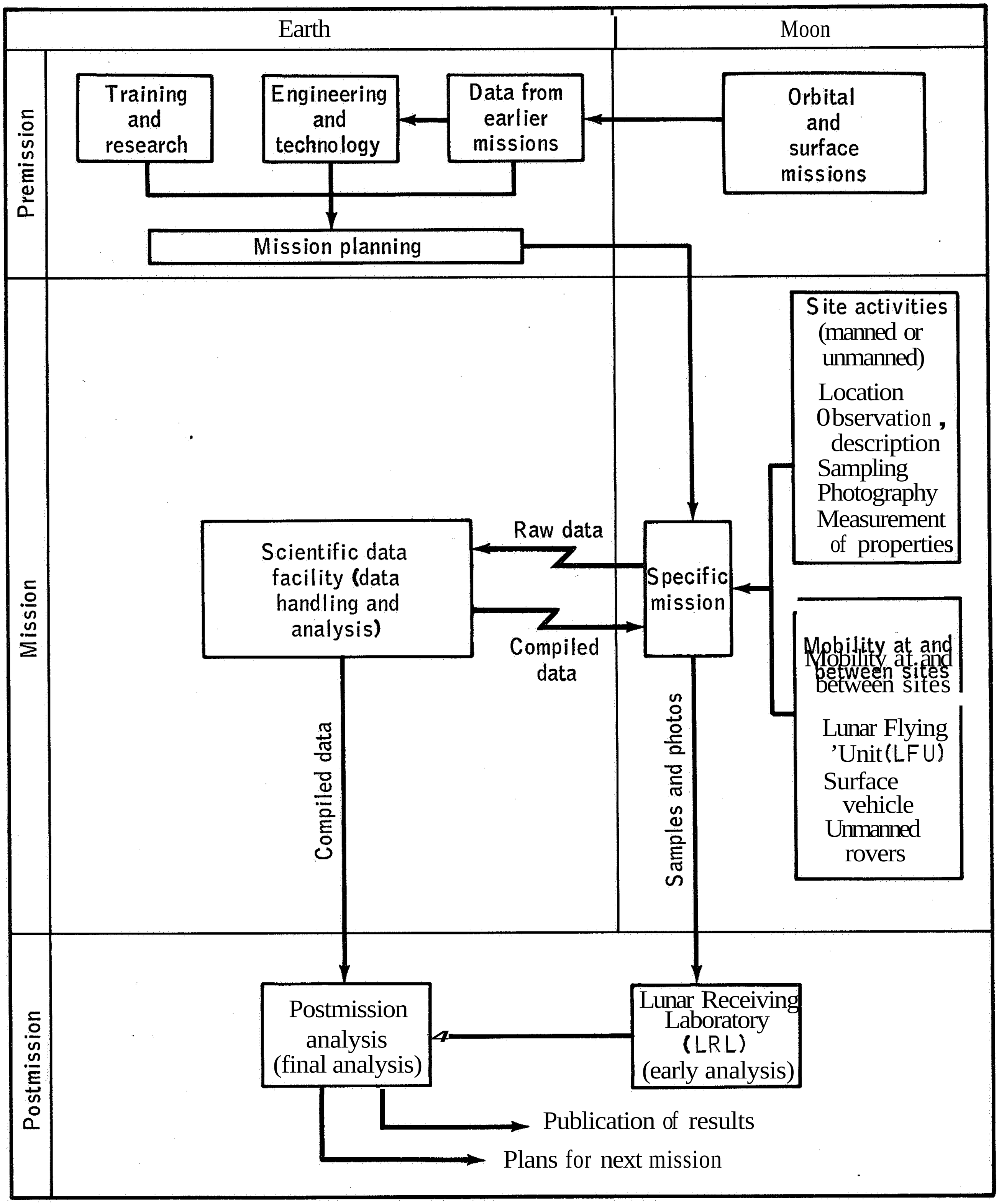


Figure 1. - The mainstreams of scientific activity for a lunar mission.

EXPLORATION PLAN

The exploration plan proposed in this report covers primarily a period of about 5 years following early Apollo missions, a period for which the limiting technological capabilities of launch systems, mobility systems, instrument systems, and supporting facilities can be broadly defined. The plan has limited but specific goals to outline a program which, within the limitations of present planning capabilities, will yield the best return of scientific knowledge and which, upon completion, will provide the basis for evaluating the need and requirements for further lunar exploration.

The objectives of the exploration plan are to carry out reconnaissance geological studies of representative parts of the major geological and physiographical provinces and to carry out more detailed studies of a wide variety of specific sites and features, utilizing both geological and geophysical techniques. The purpose of the reconnaissance studies is to obtain geological information extrapolatable to as wide an area of the Moon as possible. The detailed studies would center on features and areas critical to an understanding of lunar geological processes and to determining stratigraphic and structural relations.

Target areas in the exploration plan are chosen for their intrinsic value in' clarifying major problems of lunar evolution, but the selection has also been made to facilitate and to derive help from simultaneously conducted investigations in geophysics, geochemistry, lunar bioscience, and some fields of planetologically oriented physics. Unmanned and manned missions are integrated into a definite program which increases step by step in mobility and staytime and, therefore, in potential scientific output.

Each proposed mission in the Apollo and Apollo Applications Program (AAP) series has specific objectives that contribute to the basic scientific goals of geological exploration of the Moon. The following are the essential and guiding objectives:

1. To determine at appropriate scales the type, form, structure, distribution, and relative-age relations of the various masses of material which constitute the accessible portions of the Moon

2. To determine the physical, chemical, mineralogical, and petrogenetic nature of lunar materials? both surficial and deep-seated

3. To characterize from direct observations the operative processes (and their products) which are actively modifying the superficial features of the lunar surface; includes both endogenetic (volcanism, tectonism) and exogenetic (meteorite impact, solar wind) processes

4. To evaluate in the light of observational data past and current processes which may have contributed to the origins and evolution of the present major structural and lithological features of the Moon, including accretion and impact of extralunar bodies, volcanism, gas emanation, deep-seated.magmatism, tectonism? and other processes reflecting important mechanisms of energy transfer in the Moon

5. To interpret the most probable extension with depth of major crustal features from the nature and geometry of their surface exposures and with the aid of geophysical methods

6. To develop a comprehensive geological history of the Moon integrating the results of both direct and remote geological investigations with geochemical and geophysical studies to establish the times of initiation, duration, and product formation for the major episodes in lunar history

7. To provide a physical understanding and historical perspective for the ecological setting and protoorganic material base in which the presence or absence of lunar life is established

8. To synthesize the results of lunar investigations with the available knowledge of the Earth and meteorites to guide further investigations of the origin and evolution of the solar system and the life forms within it

Methods of Exploration

The practical limitations inherent in a program of lunar exploration severely restrict the choice of methods for carrying out the program. At best, manned exploration on the lunar surface can be expected to cover only a very small percentage of the Moon. It is incumbent, therefore, that manned activities be planned to best utilize the capabilities of man and that these activities be extended and supplemented to the fullest extent possible by automated unmanned systems. Such a program requires careful selection and integration in the use of manned and unmanned systems potentially useful in carrying out scientific investigations.

The principal components of an integrated lunar exploration program are manned surface missions, unmanned surface missions, and orbital missions. The program presented in this report combines the capabilities of these concepts to provide a postulated near-maximum cost effectiveness. However, caution is needed to prevent the degree of mission interdependence that could bring the entire program to a halt through failure in either the development or the operation of one particular component.

In an integrated program, the design of missions depends on the particular capabilities of individual systems and methods to achieve the specific objectives of a mission. The roles assigned individual systems and methods depends upon the assessment of their capabilities on the basis of the following three primary considerations.

Unique capability of man for surface investigation. - The unique capability of man to investigate certain geological problems on the Moon will probably entail a high frequency of redirection, redefinition, and rapid choice of most significant observations during their investigations. Such problems require in situ judgment, decision, and perspicacity; and the role of experienced observational scientists in these investigations is obvious. Other less complex lunar problems, however, may not require the full abilities of in situ observers, and investigation by orbiting sensors or by an unmanned surface vehicle controlled by Earth-side scientists could provide necessary data at a far lower cost. Thus, one basis of integration is to use manned surface mis-

sions only where it can be shown that the lunar problems require the unique capabilities of man for their solution and not for their definition.

Definition of lunar problems. - The definition of geological problems of the Moon has been derived largely by visual and photographic observations of the lunar surface. The definition of the problems is thus photogeological, and the correspondence and interrelations between photogeological units and truly lithogenetic units are generally uncertain. Some problems, such as the stratigraphy and crater mechanics of Copernicus, are well studied; and the particular goals and questions are well defined. The development of lunar problems from photogeology has in some other cases not proceeded to the degree that the problems are either significant or succinct, meaning that plans for manned exploration are clearly warranted for these problems. New data for further definition appear to be required as inexpensively and as rapidly as possible, Remote observations from orbital flights can provide increased resolution and new data at various electromagnetic frequencies to supplement the degree of definition of a particular problem. Further, mobile unmanned vehicles can be deployed to such areas with a mission of in situ reconnaissance of geometric and lithologic variations, emplacement of instruments, or collection of samples for enhanced scientific evaluation of the site. These supplementary orbital and unmanned missions provide the basis for critical decisions of whether a problem is sufficiently significant or well defined to send **a** manned mission.

Between-mission support. - The coordination of between-mission support for various phases of an exploration program, which incorporates several vehicle modes, can enhance the scientific return from particular measurements made by each mode. Therefore, each mission should be performed with a view toward acquiring data that can support the scientific yield of other missions. For example, geological interpretations of orbital sensing data may be vastly improved by the use of surface data collected by unmanned vehicles on surface traverses. Further, lateral extension of detailed observations by manned missions can be made by orbital sensors and unmanned rovers.

Manned Surface Investigations

The geological investigations to be conducted by astronauts on the lunar surface fall into three main categories: **(1)** investigation of the geological structure of the landing sites or geological targets of each manned landing mission; (2) collection of samples, guided by the observations of geological structure; and (3) simple field experiments simulating or stimulating geological processes and the observations of such processes which may occur naturally. These field studies provide the basis not only for interpretation of the geology and geological history of the areas examined directly by the astronauts, but also for interpretation or calibration of the results from less detailed observations of larger areas by means of unmanned roving vehicles and orbiting spacecraft.

Investigation of geological structure. - Investigation of geological structure on manned lunar surface missions will consist primarily of detailed visual observations (recorded by numerous photographs and television images) along traverses and.at local sites of special interest. Correct analyses of the structure of the superficial

layers of fragmental debris and of the bedrock, which is largely concealed by the layers of debris, are a fundamental step in interpretation of the origin of lunar surface features. The analyses are also important to the complete interpretation of any sample brought back to Earth for further laboratory examination.

Several kinds of field observations are required to understand the nature and origin of the surficial layer of fragmental debris. The observations will be made of (1) the lithologic heterogeneity of the macroscopic fragments and the fine-grained matrix of the debris; (2) the scale and distribution of the observed heterogeneity; (3) the relation of the lithology, texture, and surface form of the debris to craters of various types and to troughs and ridges in the patterned ground or other structural features; (4) features of the debris produced or modified by processes of creep or flow, such as rock streams, filets on the sides of large blocks, and varying degrees of burial or exhumation of coarse fragments; (5) features on the coarser fragments produced by processes of erosion (solid-particle bombardment, or evaporation of material by high-energy radiation) such as pitted surface texture, rounding of edges, differential erosion along layers or joints, and differential effects on exposed versus buried surfaces on the fragments; (6) alteration profiles in the debris layer, including vertical alteration profiles in the debris and alteration rinds or coating on coarse and fine fragments (which may be produced by high-energy radiation and nuclear transformations, sputtering and selective loss or redistribution of chemical constituents, escape of volatiles from the lunar interior, or impregnation of the lunar surface by extralunar constituents); (7) the existence of unusual fragments of exotic provenance such as pieces derived from distant parts of the Moon or meteorites; and (8) various effects of shock metamorphism in fragments or shock-compressed aggregates, such as fracturing, brecciation, slaty cleavage, selective shock vitrification, and frothy shock-melted glasses and spherules.

Solution of the bedrock structure will depend on the following steps: (1) identification of bedrock outcrops in crater walls, ridge crests, flow or fault scarps, and other areas of local relief by examination of the structural continuity within and between exposures; (2) observation of the lithologic heterogeneity and the scale of heterogeneity of the bedrock from the available outcrops and determination of the spacing of observations required to solve the bedrock structure; (3) observation and measurement of attitude, spacing, and dimensions of structural features such as joints, flow banding, breccia zones, and faults; (4) determination of the relationship between types of fragments in the superficial debris and the lithology and structure of the bedrock and of the degree to which observations of the debris can be used to solve the bedrock structure; (5) location of the limits of the bedrock lithologic units along traverses and their relation to photogeological contracts; (6) solution of problems in the field of the structural and stratigraphical relationships of the bedrock and lithologic units and the decision of when sufficient observations have been obtained; and (7) searching for critical structural and textural features of bedrock units which have a bearing on origin, such as vesicularity, compositional lamination, clastic textures, or crystal-intergrowth textures.

Collection of samples. - Collection of samples on the manned landing missions includes selection of appropriate samples on the basis of geological observations of the surficial debris and the bedrock; acquisition of the samples by tongs, drive tube,

scoop, or any other device; insertion of the samples into labeled containers; and packing and return of the samples to Earth. The astronauts play an important role in each of these steps.

Selection and documentation of samples will be one of the most critical tasks of men on the lunar surface. Both structural relationships of the geological units Sampled and the precise relationships of each sample to the unit from which it is taken should be determined as thoroughly as time and geological evidence permit. This requires observation of the relationship of the sample to its immediate environment and close examination of the sample and of the comparison of the sample with other nearby material. Ideally, the site at each sample should be documented by stereophotographs taken before and after the sample is acquired, supplemented by verbal description of relationships not shown in the pictures and of effects of the sampling process on the sample and its environment. In many cases, it will be desirable to mark the sample in situ or to provide some other control to recover information about the original orientation of the sample.

The versatility and the manipulative abilities of a man are prime assets in the acquisition and examination of samples. Depending on field relationships and objectives of later laboratory analysis, the choice of sampling techniques may include (1) simply picking up a large or small coherent specimen; (2) breaking off or coring out a piece from a large fragment or outcrop; (3) driving a tube or drilling a hole through incoherent fragmental debris; (4) scooping incoherent fragmental material from the surface; (5) digging a pit and scooping spot samples or cutting channel Samples from the pit; or (6) cutting a channel sample from a crater wall or other natural surface. Most of these techniques can be carried out with simple handtools, and the sample can be examined thoroughly as it is taken.

In the final step of packing the samples for return to Earth, further judgment may be necessary to select the most important samples to be returned to Earth, in the event that more samples are collected than can be accommodated in the Apollo spacecraft.

Field experiments. - A variety of simple field experiments can be carried out on manned landing missions that could provide insight or key information for the interpretation of processes affecting the surface of the Moon. In addition, some natural processes can be observed in operation, although most natural processes on the Moon are probably so slow or take place as such rare events that visual observation during a manned mission is unlikely. Some diagnostic information may come from the disturbances of the lunar surface as the astronauts walk or climb about and take samples.

Disturbances produced by the astronauts can be used to test the stability of slopes and the pattern of mass movement of the fragmental debris, particularly on relatively steep slopes. Small experimental low-velocity-impact craters can be made by throwing coherent fragments and weakly coherent clots of fine-grained material against the lunar surface, and the character of these manmade craters can be compared directly to the numerous small natural craters. Changes in the coherence and density of the fine-grained matrix of the debris after mild compression can be studied by scooping out material beneath footprints, or by packing material with the hands as in making a snowball.

The astronauts could attempt to stimulate drainage by poking a rod or tube into the apex of a dimple crater or along the axis of a trough in the patterned ground, or by jumping on the surface. Other simple experiments on the effects of electric and magnetic fields on the movement of fine particles could be made with electrostatically charged insulating materials and with a hand magnet.

Natural transient eyents that might be observed on the lunar surface include micrometeorite impacts (recognized from the low-velocity spray of ejecta), landslides or rocks tumbling down steep crater walls, or the emission of gas or gas-entrained debris in local active areas of the lunar surface.

Unmanned Surface Investigations

The following four roles of unmanned missions outline the spectrum of responsibility placed with automated systems in accomplishing the goals of an integrated geological exploration of the Moon. The principal objective of all these roles is to increase cost effectiveness of lunar exploration by sending such a system to investigate problems which either do not demand the capabilities of man, are too poorly defined to judge their significance, or may be too hazardous for manned landings. The roles are not competitive, and any combination could be employed. The roles only illustrate the utility of unmanned missions in an integrated program.

Reconnaissance. - Unmanned reconnaissance missions provide an intermediate exploration phase in the sequence from photogeological problem definition to detailed in situ analysis by manned missions. The objectives are to amplify and evaluate photogeological work by obtaining spatial data on the lithologic and geometric properties of significant terrain units. This second-stage reconnaissance will permit a decision of whether a problem warrants a manned mission. The data from the unmanned mission itself, however, can show the correspondence between photogeological units and lithogenetic units. Largely, the work involved in identification of material and structures in many rock units may be routine and within the scientific capabilities of unmanned rovers. The use of reconnaissance vehicles for collection of more routine data will allow astronauts to focus their efforts on more critical problems. A time sequence of reconnaissance rovers before manned missions at certain sites is inferred here; an additional benefit is the certification of the site for landing safety.

Support. - A support role of unmanned missions increases the effectiveness of manned missions during or after those missions. A principal method is the extension of knowledge gained by men on the lunar surface to adjacent areas by contemporaneous deployment of unmanned rovers from the lunar module (LM) or by deployment by Earth launch to designated positions. In this role, the problems are defined by manned exploration, and the unmanned craft assist in their solution. The spacecraft capabilities and instrument packages for support roles would be largely similar to those employed in the reconnaissance role; the difference exists in phasing.

Investigation of remote areas. - Unmanned vehicles are used in the investigation of remote areas which might be hazardous for manned exploration because of terrain roughness or global position. The goals in this investigation are similar to goals in the reconnaissance role except that more variations in scientific payloads are possible

in remote area investigations. Because unmanned craft will essentially replace manned missions for these operations, the instruments must include those which can answer the particular questions posed as a basis of the mission. For example, the detection of gases, radioisotope abundances, thermal radiation, depth of dust, and so forth, are special measurements which may be required at certain remote places.

Instrument net. - Unmanned vehicles are useful as a potential means for delivering instruments as synchronously as possible to a number of positions on the lunar surface. The instrument arrays are of principal interest to geophysics and will not be considered further here.

Orbital Investigations

Geological orbital experiments can be divided into two general categories: (1) photographic systems for mapping missions and (2) remote-sensing systems for determining physical and chemical properties of the surface and near-surface rocks which can then be integrated with ground-based observations and experiments to provide a more detailed understanding of the regional geological history and the processes that occur on the Moon. The orbital techniques developed in the lunar program and their utility in determining the most appropriate geological sites as tested by subsequent surface observations will be of great assistance in the early phases of missions to Mars and the other solid bodies of the solar system.

The unmanned Lunar Orbiter program has provided a wealth of geological and cartographical information on the entire lunar surface at a resolution ranging from one to three orders of magnitude greater than the Earth-based telescopic observations of the Earth-facing side. Furthermore, this photography has been used in selecting sites for detailed geological exploration of the surface. The coverage of the proposed AAP sites will require additional high-resolution orbital photography of the following sites: Davy Rille, Sabine and Ritter, Posidonius, the floor of Alphonsus, and all the unmanned surface traverses.

One of the newest and possibly one of the most fruitful means of regional geological exploration of the Moon lies in the study of the reflection and emission of electromagnetic energy from the solid surface. The first lunar remote-sensing measurements were astronomical observations made from Earth-based telescopes. Observations of the infrared and visible brightness of the lunar surface provided information about the porous lunar soil and surface roughness and about the presence of thermal anomalies, a number of which are related to young, fresh craters. Although the observations are historically important to understanding lunar geology, the restrictions of telescopic resolution and the atmospheric absorption of the Earth severely limit the usefulness of Earth-based observations for regional geological information, Thus, remote sensing from lunar orbiting vehicles is a natural and appropriate evolutionary step.

A large number of remote-sensing experiments in all parts of the electromagnetic spectrum have been proposed at various times for inclusion on manned and unmanned orbital flights. This discussion involves only those experiments which have a proven value in a geological framework, recognizing that the utility of the others will

depend on more detailed field, laboratory, and theoretical examination than has been provided up to the present time.

Thermal emission of the Moon, observed terrestrially through the 8- to 14-micron atmospheric window during the eclipses and lunar night, has indicated the presence of thermal anomalies which correlate closely with some of the fresh-appearing bright-rayed craters and with some older craters of the Eratosthenian and Copernican class. The usefulness of extending these observations over the entire lunar surface at a higher resolution (100-m resolution appearing instrumentally feasible and geologically significant) is thus established. An additional bonus easily obtained from this experiment is to measure the infrared (IR) heat flux from regions of permanent shade at high latitudes to provide both a measure of the internal heat flow of the Moon and information on the thickness and nature of the breccia lens below the crater floors.

Normal albedo maps (made from a full-Moon photograph, that is, near zero phase angle) of the Moon in the visible spectrum have played a major role in the photogeological interpretation of different terrain units. It is extremely desirable to extend terrestrial-based resolution measurements (about 1 km) to at least 100-meter resolution for incorporating the information in the regional geologic maps at 1: 100,000 scale and to provide a more meaningful basis for employing photoclinometric data for topographic control in the medium- and high-resolution Orbiter photography that has been obtained.

Lower priority experiments that could supply some meaningful data in the interpretation of regional lunar geology include active radar, passive microwave, and multispectral or multiband ultraviolet (UV), visible, and IR. The spectral experiments promise detailed composition information. However, no terrestrial observations of the Moon by these techniques have been sufficiently conclusive to support a strong recommendation for their inclusion at the present time as a high-priority experiment. It may become highly desirable to test the utility of the terrestrial observations in lunar orbit with limited spatial coverage on a manned orbital mission which will be available during the dual-launch mode. A very necessary step in application of the observations is a much more detailed and thorough theoretical and laboratory study than has been made in the present program.

The general requirements for the orbital geological experiments include the following:

1. Unmanned, low-altitude, circular polar orbits are required as a follow-on to the present Unmanned Lunar Orbiter (ULO) program with a similar weight capacity and an optical system having a ground resolution of 100 meters. The collector aperture for the thermal emission experiment must be at least 10 centimeters for an 80-kilometer orbital altitude.

2. A feasibility study of the possibility of carrying either a ULO in the command and service module (CSM) during the AAP flights for delivery to lunar orbit, or modification of the CSM to carry the photographic and remote-sensing instruments and to operate them from this vehicle in a continuous mode is required. This operation will provide the first opportunity to return film of a purely photographic mission, a necessary feature to provide geometric fidelity and hence precise topographic control of the

AAP sites and sufficient resolution to conduct trafficability studies to plan mobile vehicle traverses on the surface.

3. A feasibility study of the construction of critical experiments in the multispectral UV, visible, and IR regions is required. The possibility of utilizing an astronaut in the selection of sites and the merits of continuing the experiments should be investigated. Using fixed spectral ranges rather than spectral sweeps, it is possible to construct simple experimental systems to examine the feasibility of using compositional mappers, especially in regions of the spectrum where atmospheric absorption precludes Earth-based examination (vacuum UV, $<8\mu$, 9μ ozone absorption, and $>14\mu$ regions).

Missions

A statement of specific plans for extended geological investigations of the Moon must be presented at this time (August 1967) in the context of a well established and continuing geological mapping program of the lunar surface, utilizing Earth-, satellite-, and probe-based photography and other remote-sensing systems. The program is providing the preliminary geological maps, which delineate the major morphological, structural, and stratigraphical features that constitute the distinctive features of the lunar surface. ,These maps and photographs are the major body of preliminary data on the form, distribution, and relative abundance of major lunar features, from which a set of specific sites has been selected for the direct exploration of important geological relationships by Apollo and AAP missions.

Each site has been evaluated in terms of possible contributions to the primary scientific goals, and a specific set of objectives for achievement in each mission has been formed. Table I summarizes the important scientific objectives for each of the manned missions of the Apollo and AAP series. At each selected site, the opportunities for significant observations and sampling are extensive enough to require a tentative ordering into primary and secondary objectives. Planning for each mission will of necessity require a more detailed, yet flexible, analysis of this type.

Table II summarizes the specific objectives of a selected series of unmanned missions. Unmanned mobile lunar probes have important dual roles in coordination with manned missions as onsite reconnaissance and support functions, for independent missions to obtain important but remote features and to make extended traverse experiments.

Basis of Site Selection

Selection of landing sites for surface missions beyond the first two or three Apollo landings should be governed by the following guidelines:

1. The sites should provide fundamental data to allow a logical development of concepts concerning the origin and history of the Moon, the Earth-Moon system, and the solar system. Ideally, the sites should progress from simple, easily studied sites yielding fundamental data to complex sites permitting refinements of fundamental data and requiring more extensive and detailed study.

TABLE I. - MAJOR SCIENTIFIC OBJECTIVES FOR **MANNED LUNAR** MISSIONS

[P signifies primary objectives and S signifies secondary objective]

Objective	Site: Early Apollo 1	Early Apollo 2	Early 4 1o 3	Copernicus	Davy Rille	Marius Hills	Polar Region	Aristarchus Region	Alphonsus	Posidonius	Apennine Front	Mare Orientale	Sabine and Ritter
Variations in rock compositions, textures, and structures	P	P	P	P	P	P		P	P		P	P	P
Impact structures and related phenomena	P	P		P				S	P	P	S	P	
Effects of extralunar processes	P	P	P	P	S	S	P	P	P	S	P	P	S
Volcanic phenomena				S	P	P		P	P			P	P
Rill phenomena					P			P	S	P	P		
Volatile emanations from the lunar interior					S	P		P	P				
Residual volatiles in lunar surface environments			S				P	S					
Organic and protoorganic materials	P	P	P	P	S	P	P	P	P		S	P	
Rock movement in the lunar gravitational field				P	S		S	P		P	P		P
Major crustal deformation features			P						P	S	P		
Fracture patterns	S	S	S				S		S		P	P	
Mare sampling and structure	P	P	P		S					P	P	P	P
Upland sampling and structure			S	S	S		P	S	P	S	P	P	
Deep-seated magmatism				P	P	P			P				P
Oldest rocks on the Moon (primitive material)	S	S	S	P			S		S		P	P	
Historical significance				P	P	S	S	P	P	S	P	P	P

TABLE II. - MAJOR SCIENTIFIC OBJECTIVES FOR UNMANNED LUNAR MISSIONS

[P signifies primary objectives and S signifies secondary objectives]

Objective	Site								
	Mösting C to Copernicus by way of Gambart	Harbinger Mountains to Cobra-Head by way of Schröter's Valley	C. Herschel to Apennines by way of Archimedes	Doppelmayer to Gassendi by way of Mare Humorum	East side of Alphonsus to west side of Alphonsus	Sulpicius Gallus to Posidonius by way of Dawes	Alpine Valley to Apennines by way of Plato	Tycho to Straight Wall by way of Deslandres	Azout to Geminus by way of Mare Crisium
Variations in rock compositions, textures, and structures	P	P		P	P	S	P	P	P
Impact structures and related phenomena	P			P				P	
Effects of extralunar processes	S				P	S	P	P	
Volcanic phenomena	P	P			P	P			P
Rill phenomena		P	S	S	P	P			
Volatile emanations from the lunar interior		P			P				
Residual volatiles in lunar surface environments							S	S	
Organic and protoorganic materials	S	P			P	P	P	P	
Rock movement in the lunar gravitational field				P					
Major crustal deformation features			S					P	
Fracture patterns	S		P	P	P				P
Mare sampling and structure	P		P	P		P	P	S	P
Upland sampling and structure	S			S			P	P	S
Deep-seated magmatism									
Oldest rocks on the Moon (primitive material)							S	P	
Historical significance	P	S			P	P	P	P	P
Lunar basin structure			P	P		P	P		P
Reconnaissance sampling with manned sample return	S	P	P		P	S	P	P	
Direct support of manned exploration	S	P			P		S	S	
Emplacement of instrument net and traverse geophysics	S		P	P	S	P	P	P	P
Access to important but remote features	P	P		P	S	P	P	P	P

2. The complexity of the sites should be tied to and should reflect the continuing evolution of scientific space-flight hardware systems anticipated during the next decade. Sites that can be adequately studied in a short time with limited mobility should be visited early in the sequence; conversely, sites requiring detailed study by sophisticated methods, long time period, and/or extensive mobility should be visited later in the sequence.

These guidelines impose serious conflicts upon the selection of sites and upon the lunar exploration program in general. Possibly, the fundamental early data will have to be gathered by relatively crude methods. This inefficiency in the early exploration can and must be reduced by judicious selection of early sites. Sites cannot be justified solely on the basis that they look interesting from previous terrestrial and orbital observations. Equal consideration must be given to the amenability of the site to meaningful exploration by the techniques and equipment available at the time of the flight. As a result of these restrictions, the question of revisiting a previously studied site will almost certainly arise. At some sites, additional data could be gathered by unmanned vehicles, but the option of additional manned visits should not be discarded even though the scientific justification would have to be very strong to justify such a course of action.

Sites

Based on the considerations previously defined in this report, three sites for early Apollo missions, nine sites for AAP manned surface missions, and seven sites for AAP unmanned missions are listed in table III and shown on figure 2 with an indication of the type of spacecraft which might best be utilized to explore the particular site. The order of exploration given is a reflection of the current status of spacecraft development. Some of the scientific objectives to be accomplished at each site are described in the following paragraphs.

Early Apollo sites. - Although restricted by design and operational considerations, enough scientific capability is afforded in the early Apollo missions (EA 1, EA 2, and EA 3) to satisfy significant scientific objectives. Among the most important are a comprehensive sampling of mare materials. observations on the genesis of mare craters, and an evaluation of the fine structure and of some of the processes at work upon the mare surfaces. The proposed mare sites present an opportunity to sample and observe mare of more than one type. In the third early Apollo mission, a site selection may clarify the structural and compositional relations at the junction of a major mare and its bordering upland.

Copernicus. - The most intensively studied area on the Moon is Copernicus, a might-rayed crater 50 miles in diameter in the central part of the Earth-facing hemisphere. Mare and highland stratigraphic units crop out in crater walls that are almost 3 miles high. Ledges exposed in the central peak may include layers from a total depth of about 6 miles. A variety of features on the crater floor has been interpreted as volcanic in origin. This crater is the site of comparatively fresh outcrops (according to interpretations of Lunar Orbiter photographs) of geological units that could range from very ancient to very young.

The primary purposes for the mission to Copernicus are as follows:

1. To search for evidence of the origin of a bright-rayed crater

2. To determine the stratigraphic relationships and nature of lithologic units exposed in the 3-mile high wall and in the central peaks

3. To make field observations to confirm the validity of photogeological studies from Earth-based telescopes and satellite photography

The following are the objectives to be accomplished at the site:

1. To study and sample important rock units in crater wall, central peak, and crater rim and floor

2. To study a variety of features presumed to be volcanic in origin in the crater floor; best opportunity for direct checking and elaboration of the type of geological mapping based upon Earth observation and satellite photography provided by exploration of the crater.

Davy Rille. - Davy Rille is a graben and chain of large, fresh craters that cross the Mare Nubium highland contact northwest of Ptolemaeus in the central part of the Earth-facing hemisphere. The rill crosses plains-forming materials in an upland basin and pre-Imbrian rocks that are cut by Imbrian sculpture and which are blanketed by Imbrian basin ejecta. Deposits interpreted as volcanic surround craters distributed along the graben. The craters resemble the terrestrial volcanos that have brought deep-seated rocks from depths as great as 50 to 70 kilometers. Three upland units and the possibly volcanic deposits around the craters could be examined during a single-launch mission. Geophysical traverses at the site could cross the Mare Nubium highland contact and the rill.

Davy Rille may contain rocks brought up from deep levels by volcanic processes. These would complement Copernicus samples, which may include the deepest rocks brought to the surface by impact processes and would thus provide further evidence on whether the Moon is a differentiated body.

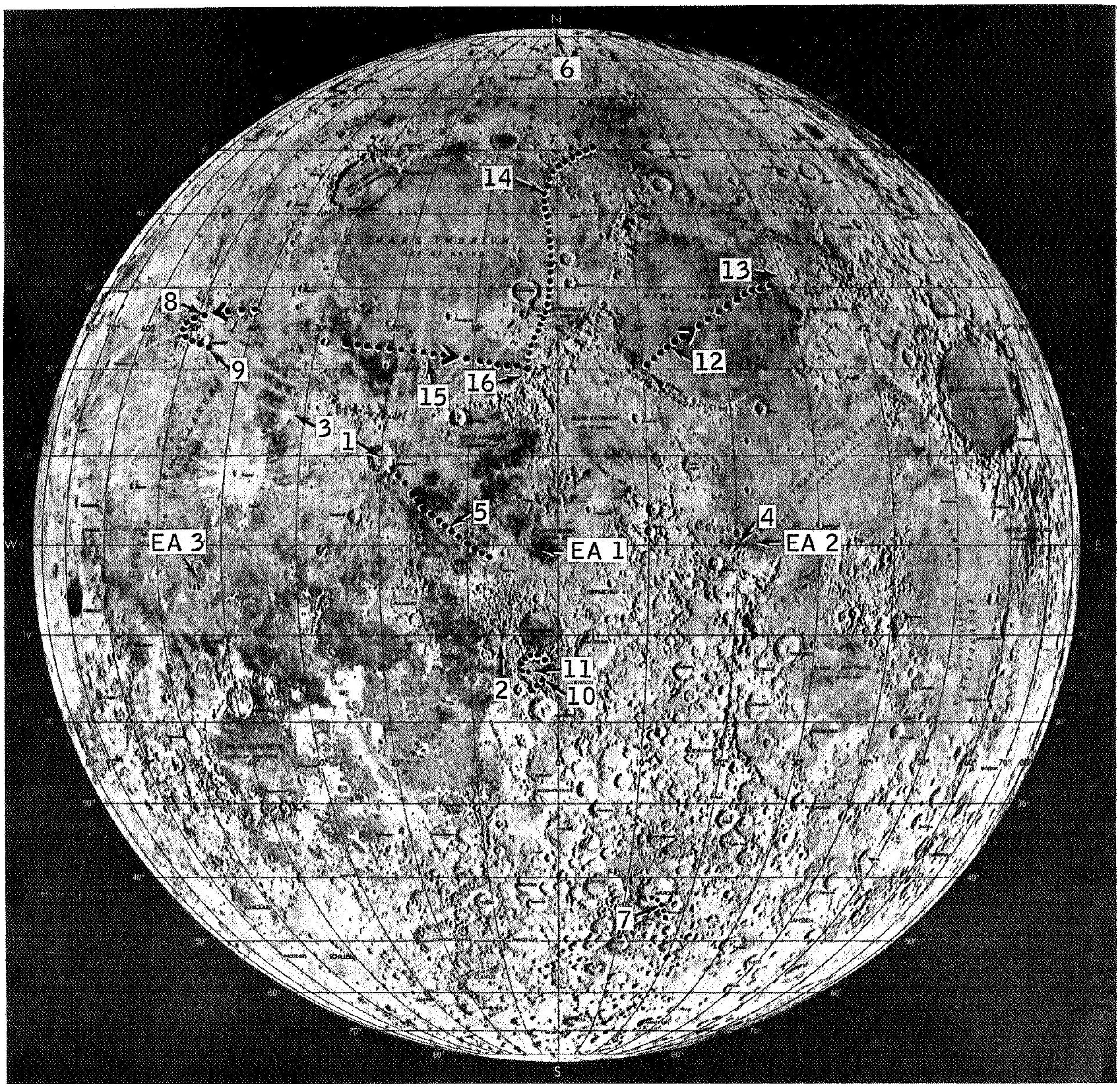
The choice of Davy Rille as a site is to investigate the origin of Davy Rille and of associated chain craters to study possible active volcanic and tectonic processes on the Moon, The craters, which may be the equivalent of terrestrial diatremes, are appropriate sites to search for deep-seated lunar materials in the form of volcanic ejecta.

The following are the objectives of the site:

1. To examine the structural basis for the development of the rill (fault, graben)

2. To observe and sample the rocks in the crater chain

3. To observe and collect samples of the pre-Imbrian highland rocks as well as of the upland basin filling and Imbrian ejecta materials



Early Apollo missions: (EA 1) Sinus Medii; (EA 2) I-A-3 Mare; (EA 3) II-12-B Flamsteed.

Apollo Applications Program missions (dotted lines are unmanned traverses)

(1) Floor of Copernicus
(2) Davy Rille-Hyginus Rille
(3) Marius Hills
(4) Sabine and Ritter
(5) Mosting C to Copernicus
(6) North Pole
(7) Marolycus and Barocius
(8) Harbinger Mts., Schröter's Valley with Aristarchus rendezvous
(9) Aristarchus
(10) Alphonsus reconnaissance
(11) Alphonsus
(12) Sulpicius Gallus Rilles to rendezvous in Posidonius
(13) Posidonius
(14) Alpine Valley
(15) Imbrian basin
(16) Apennine Front

Figure 2. - Index map showing sites selected for lunar missions.

TABLE III. - PRELIMINARY LIST OF SITES FOR APOLLO AND AAP GEOLOGICAL EXPLORATION

Mission	Spacecraft	Site
Early Apollo 1	LM	Sinus Medii
Early Apollo 2	LM	I-A-3 Mare Fecunditatis
Early Apollo 3	LM	II-12-B Flamsteed[a]
AAP-1	ELM	Floor of Copernicus
AAP-2	ELM	Davy Rille or Hyginus Rille
AAP-3	ELM	Marius Hills
AAP-4	ELM	Sabine and Ritter
AAP-5	Unmanned	Mösting C to Copernicus
AAP-6	ELM	North Pole.
AAP-7	Unmanned	Maurolycus and Barocius
AAP-8	Unmanned	Harbinger Mountains, Schröter's Valley with Aristarchus rendezvous
AAP-9	Dual launch	Aristarchus
AAP-10	Unmanned	Alphonsus reconnaissance
AAP-11	Dual launch	Alphonsus
AAP-12	Unmanned	Sulpicius Gallus Rilles to rendezvous in Posidonius
AAP-13	Dual launch	Posidonius
AAP-14	Unmanned	Alpine Valley
		rendezvous at Apennine Front
AAP-15	Unmanned	Imbrian basin
AAP-16	Dual launch	Apennine Front

[a]Oceanus Procellarum.

4. To look for volcanic effluents

5. To search for possible deep-seated lunar materials brought to the surface as volcanic ejecta

Marius Hills. - The broad, low domes; steep, rough domes; and sinuous rills of the Marius Hills are probably features in a volcanic field. Geomorphically, the forms resemble features produced by terrestrial eruptions of intermediate-composition volcanic rock. The area includes the best examples of these types of features on the visible face of the Moon. Copernican ray deposits that overlie the supposed volcanic deposits suggest a minimum age of Eratosthenian. A single-launch manned landing on smooth terrain near the eastern margin of the hills should allow exploration of the different morphological types.

The choice of Marius Hills as a site was made to determine the composition, distribution, and origin of the many domes and rills present in the area.

The following are the objectives to be accomplished at the site:

1. To make field studies and collect samples in a variety of domes presumed to be of volcanic origin and thereby investigate possible magmatic differentiation

2. To search for evidence of volcanic effects and to sample them, if found

3. To search for deep-seated lunar materials

4. To observe and sample older mare materials as well as younger Copernican ray debris

5. To examine sinuous rills and their relationships to domes and other rill structures

6. To make heat-flow and other physical measurements in the volcanic-field area

Sabine and Ritter. - Photographs by Ranger VIII and Lunar Orbiter IV cover the moderate-sized craters Sabine and Ritter in the eastern half of the equatorial belt that is accessible during early Apollo missions. The craters are interpreted to be possible volcanic calderas because, although crater sharpness indicates little degradation, many features commonly associated with impact structures are missing. Thus, the craters may offer sampling sites for collecting different types of lunar rock and geophysical sites for studies comparing the possible calderas with impact craters of similar size. A single-launch manned landing should permit the collection of critical data from crater deposits and along the contact with surrounding mare material.

The choice of the craters was made to obtain field relations and sample rock units to determine the origin of the craters since the craters lack the typical assemblage of impact features associated with other lunar craters of similar size.

The following are the objectives to be accomplished at the craters:

1. To sample floor and wall materials and to compare them to adjacent mare materials

2. To study structural relations to surrounding mare material

3. To make a geophysical investigation of the crater structure for comparison with other craters

Polar region. - A landing at high latitude($>65°$) would permit the search for deposits of frozen volatiles liberated from the surface of the Moon by degassing and trapped in the permanently shaded areas. Also, the polar landing would permit sampling of heavily cratered upland units at a site far separated from the equatorial belt. possible heat-flow studies in and near the regions of permanent shade, and the emplacement of a geophysical station greater than one lunar radius in distance from the equatorial-belt sites.

The purpose of the landing is to study geological environment of a heavily cratered polar upland region which contains permanently shaded areas.

The following are the objectives to be accomplished at the site:

1. To make field observations and sample collections from various rocks and structures of the northern upland to establish historical sequence in the region

2. To observe the lunar surface processes for comparison and contrast with surface activity in the equatorial region

3. To study and sample possible condensed volatile constituents in permanently shaded areas

4. To sample the surface materials near or in shaded areas for possible life and protoorganic systems

5. To make important comparative physical observations (heat flow, IR, thermal and electrical conductivities, et cetera) across the boundaries between permanently shaded and illuminated regions

Xristarchus region. - Xristarchus. the brightest crater on the Moon, is within a complex area in the northwestern quadrant of the Earth-facing side of the Moon. The crater is the site of the most intense IR anomaly that has been detected, Nearby, Cobra-Head is at the upper end of Schröter's Valley and is the largest sinuous rill on the exposed face of the Moon. Many transient phenomena have been sighted in this region, including those described by the Aeronautical Chart and Information Center (ACIC) cartographers (Lowell Observatory) as landslides at the head of Schröter's Valley. Volcanic domes and flows on the Aristarchus plateau are different from those exposed in the Marius Hills. Rough highland deposits blanketed by ejecta from the Inibrian basin crop out in the eastern part of the Aristarchus plateau.

Collections here could sample a wide range of ages and types of lunar material. In addition, geophysical traverses of Schröter's Valley should contribute to an understanding of the relationship between the narrow inner and larger outer valleys. The variety and complexity of geological phenomena will justify the staytime and mobility of a dual launch.

The primary purpose for choosing the site is to study a complex area which shows one of the richest varieties of structures, rock relationships, and transient phenomena observed on the front side of the Moon. The following are the objectives to be accomplished in this region:

1. To examine and collect samples at Cobra-Head, a presumed volcanic pile at the head of Schröter's Valley

2. To observe stratigraphical and structural relationships in Schröter's Valley (a large, fresh, sinuous rill on the Moon) particularly for evidence of recent landslide phenomena

3. To search for evidence of recent volcanic eruptions in the vicinity of Cobra-Head and to study the various volcanic domes and flows nearby on the Aristarchus plateau

4. To sample the ejecta material from Aristarchus crater which is the brightest on the Moon and has the largest IR anomaly

5. To establish from field observations and samples the historical sequence of the evolution of the Aristarchus region

Alphonsus. - The floor of the crater Alphonsus in the central part of the Moon is an area of great complexity and variety, as revealed by telescopic studies and photographs taken by Ranger IX and Orbiter IV. Alphonsus is similar to Copernicus in diameter (about 90 km), but it lacks the diagnostic impact features that are so clearly evident at Copernicus. It may be an old, considerably degraded impact structure in the central highlands. Outcrops in the 6000-foot crater walls should yield data that will help establish the crater origin and add to the knowledge of highland units. Continental rocks from a great depth below the crater may be exposed in the central peak. The central ridge has been interpreted as volcanic rocks extruded along a major tectonic break that cuts the northern and southern crater walls and continues far to the north through the crater Ptolemaeus.

A polygonal set of faults and graben cut the crater floor and continue into the crater walls. Dark-haloed craters, possibly pyroclastic cones, are distributed along some of the faults. Alter and Kozyrev have observed emissions in this region. Outcrops in the crater walls include volcanic and ancient highland deposits that may cover a large span of lunar history; the floor is covered by volcanic and impact craters.

The well-exposed complex geology makes this site a prime target for a dual manned launch. The geochemical and geophysical problems and the possibility of temporary atmosphere are equally challenging.

The following are the primary purposes for choosing the site:

1. To make observations and to selectively sample a crater site in an old highland region which offers an optimum combination of important features for establishing a sequence of lunar geological history spanning a major portion of upland and post-upland time

2. To investigate the early stratigraphic history and related processes that formed the highland areas

The objectives are to make sample collections and field observations of Alphonsus. in sorties, or groups of sorties, and to examine the following:

1. Floor filling and its sequence in the vicinity of the landing site

2. The central-peak and central-ridge region

3. Dark-haloed craters and associated systems

4. Western crater-wall structures and exposures of highland material

5. Localities of possible recent gaseous emanations

Also, to coordinate the mission by an unmanned surface vehicle with automatic sensing capabilities is an objective. The vehicle should have the following capabilities:

1. To precede a manned mission and reconnoiter geological materials of the western crater floor

2. To provide technical information for precise landing-site selection

3. To provide followup reconnaissance of the central ridge and eastern floor of the crater wall for reconnaissance of the adjacent, old highland region

Apennine Mountain Front. - The Apennine Mountain Front, almost as high as the Himalayas, is another scene of tremendously varied lunar geology. The oldest exposed rocks on the Moon may crop out near the foot of this formation. The rocks are covered by the ejecta from the Imbrian basin and by later Xpennine bench deposits. Also exposed are the ejecta from the younger but pre-mare Archimedian crater deposits.

The volcanic deposits in Palus Putredinis near the mouth of Hadley Rille, second only to Schröter's Valley as a sinuous rill, are some of the darkest, freshest, smoothest, and presumably youngest on the Moon. The rill originates on the great faultline along the Apennine Mountain Front that appears to have been reactivated many times since the Imbrian event. The geology is complex. Deciphering the geological, geophysical, and geochemical relationships of units that represent a large part of decipherable lunar history will require a manned dual launch.

The choice of the site was made to determine the lunar history of types of processes from the study of a well-exposed stratigraphic sequence along the part of the

Apennine Mountain Front in the vicinity of Hadley Rille. The following are the objectives to be accomplished at the site:

1. To examine and sample the deep-seated, older rocks exposed along the base of the Apennine fault scarp

2. To investigate the genetic relation of the head of Hadley Rille to this fault

3. To examine and sample the materials which form the walls and floors of Hadley Rille

4. To evaluate rock movement in the gravitational field along the front

5. To develop historical sequence and age data extending from the ancient rocks underlying the Apennine fault hills, the overlying ejecta from the Imbrian basin, the still younger Apennine bench deposits, and the pre-mare Archimedian crater deposits to the material distributed from the activity in Hadley Rille

Posidonius. - The crater Posidonius, on the eastern margin of Mare Serenitatis, is about the same diameter as Copernicus, but the crater depth of Posidonius is much less and the central peak rises almost to the level of the rim. One proposed explanation is that isostatic rebound has lifted the floor with central peaks intact to virtually fill the crater. Geophysical measurements, compared to those from Copernicus, should settle the issue of the reality of isostatic processes on the Moon and the rate of readjustment. One of the most complex sinuous rills on the Moon occurs in the mare filling of the inner circumferential lake. Geologically, geochemically, and geophysically, this is a varied area with a dual-launch manned landing justified to derive critical information on fundamental lunar processes.

The purpose in choosing the site is to determine the mechanism of apparent uplift of the crater floor and of the origin of the complex rill and bench structure in the floor of this large crater.

The following are the objectives to be accomplished at the crater:

1. To examine and sample the walls and central peaks for deeply buried highland and mare materials

2. To observe and measure the structural features of the floor and central peak

3. To utilize geophysical measurements to investigate the possibility of the local isostatic rebound producing the uplift

Mare Orientale. - Mare Orientale is the most spectacular feature on the lunar surface and has been photographed by Orbiter IV. The investigation is scheduled for late in the program because its position on the western limb and back side involves operational difficulties. The enormous size of Mare Orientale also requires either a minimum of three dual launches or the mobility of a mobile excursion (MOBEX) type vehicle. The young volcanic features on the floor of the mare basin, the amazing array of probable impact features, and the concentric and radial fault zones and associated eruptive volcanic rocks offer an unparalleled challenge to geological, geochemical, and geophysical investigators.

The site was chosen to determine the origin of the most complex, single concentrically layered feature on the lunar surface. The objectives of the investigation are to study the impact structure with associated concentric and radial fault scars and to study the extraordinary complex of base surge and ballistic impact ejecta. The mare filling and the associated volcanic rocks offer the most challenging opportunity for integrated geological, geochemical, and geophysical studies of any lunar site. Specific objectives must be determined with relation to the extended multiple-launch and mobility capabilities which must be developed to undertake this mission.

Sample Mission Profiles

In the AAP, the single-launch and dual-launch systems, with ground mobility supplied by flying units and local scientific survey module (LSSM) type roving vehicles, increase enormously the capability for significant geological investigations. The following examples of the types of ground traverses designed with the capabilities of single- and dual-launch **AAP** missions are presented for areas in Copernicus and Alphonsus.

Copernicus. - Copernicus is a bright-rayed crater 80 kilometers in diameter in the central part of the Moon. A thick section of rocks, probably representing a wide age range, is exposed in the crater rim, on the central peaks, and in the floor of the crater. One of the most intensively studied craters on the Moon; Copernicus, displays a large spectrum of geological units that should provide highly critical information about a significant part of lunar history and lunar surface missions. The single-launch mode is expected to provide a 3-day staytime and the use of two lunar flying units with a 12-kilometer-radius operational capacity. The lunar flying units will use residual fuel which will nominally provide four, or possibly five, sorties. Although these constraints restrict the range of ground operations and thus do not permit an integrated study of the crater, the single-launch mission would provide observation and sampling of some of the most significant geological features and rocks associated with the central peak area and of two or three distinctly different rock units in the crater floor. Sample mission time lines are presented in table IV. Traverse routes drawn on an Orbiter photograph of Copernicus are shown in figure 3. Mission characteristics and a general flight plan include the fcllowing considerations (table V).

Crater Alphonsus. - Crater Alphonsus, about 90 kilometers in diameter, lies in the central highlands and is either a degraded impact structure.or a crater of different origin. The floor of the crater is geologically complex, suggesting a long geological history of alternating deposition and tectonism. Older upland-type rocks in the 6000-foot-high walls of the crater are available for investigation. Crustal rocks from a great depth below the crater floor may be exposed in the central peak.

Because of its size and geological complexity, significant geological exploration of the crater requires a dual-launch manned mission, preferably with extended areal coverage through the use of an automated ground rover that will provide critical ground information on the parts of the crater floor beyond the range of manned operations. As shown in figure 4, a dual-launch landing area can be selected in the western part of the crater floor that brings the most critical geological localities into the range of manned observations, assuming the use of flying vehicles having an operational radius of 25 kilometers and an LSSM-type ground vehicle having an operational radius of

TABLE IV. - SAMPLE MISSION TIME LINE FOR A COPERNICUS MISSION

Day	Time, hr:min	Activity for astronaut - 1	Activity for astronaut - 2	Number of stops	Backpacks for astronaut - 1	Backpacks for astronaut - 2	LFU payload, lb Carried	LFU payload, lb Returned	Cumulative sample, lb
1	800	Touchdown and deactivate LM							
	1000	Don suit and prepare egress							
	1030	Prepare and emplace ALSEP		--	1	1	--	--	20
	1200	Ingress to LM							
	12:30	Personal hygiene, food, rest, communication							
	1530	Egress							
	16:00	LFU sortie 1[a]	Monitor astronaut 1; local sampling; sample selection	2	1	1	b55	c80	55
	1900	Ingress to LM							
	1930	Personal housekeeping; science communication							
	2200	Sleep							
2	7:00	Personal housekeeping							
	8 30	Egress							
	9 00	Monitor astronaut 2; local sampling; sample selection	LFU sortie 2[a]	3	1	1	d45	c80	90
	12:00	Ingress to LM							
	1230	Personal housekeeping							
	1530	Egress							
	1600	LFU sortie 3[a]	Monitor astronaut 1	2	1	1	d45	c80	125
	1900	Ingress to LM							
	19:30	Personal housekeeping; science communication							
	2200	Sleep							
3	7:00	Personal housekeeping							
	830	Egress							
	9 00	Monitor astronaut 2	LFU sortie 4[a]	2	1	1	d45	c80	160
	1200	Ingress to LM							
	1230	Personal housekeeping							
	1530	Egress							
	1600	Sampling and geologic traverse locally	Prepare samples for return	--	1	1	--	--	200
	1900	Ingress to LM							
	1930	Personal housekeeping; science communication							
	2200	Sleep							
4	6 00	Personal housekeeping							
	7:00	Reactivate LM							
	8 00								

[a]See map for proposed traverses.
[b]Consists of gravimeter (10 pounds), seismic charges (10 pounds), geologic tools (25 pounds), and camera (10 pounds).
[c]Consists of gravimeter (10 pounds), geologic tools (25 pounds), camera (10 pounds), and samples (35 pounds).
[d]Consists of gravimeter (10 pounds), geologic tools (25 pounds), and camera (10 pounds).

10 kilometers from the LM shelter. Flying sorties will provide spot observations and sampling of the rocks and structures of the highly important central ridge, central peak, crater rim, and crater floor units. The LSSM ground-operational mode is required for detailed studies of the numerous floor units needed to solve the geology and history of crater development. Plate 1* illustrates the scope of geological field investigations that would be accomplished in such a mission.

The efficiency of the exploration of Alphonsus will be increased if an unmanned surface vehicle is first deployed to examine lithologic and geometric characteristics of the complex array of terrain units before a manned mission goes to Alphonsus. The objectives are to obtain a first approximation of the correspondence of the terrain units to lithologic units and a finer delineation of the most basic scientific problem in Alphonsus to which the manned mission should be directed. Figure 4 illustrates a nominal path in the crater the vehicle might follow; the track is selected to cross the terrain unit considered most significant and to follow negotiable terrain. The integral distance of the track is about 200 kilometers. The measurements should include stereoimaging of the surface morphology and observation of the fine surface textures to a resolution of 1 millimeter. Coupled with good photometric accuracy, the imaging system will increase the knowledge of the similarities and differences of the surface geometrics of the units and allow better approximation of the processes of formation of each unit from theory and Earth analogy. The second principal set of measurements is lithologic, principally an assessment of the mineral assemblage, element abundance, and perhaps microscopic textures. The measurements here will in no way be as exacting as those obtained in an Earth laboratory; but they will be sufficiently quantitative to indicate lithologic differences between units, establish the existence of equilibrium assemblages, and suggest the origin of certain units. For example, it may be clear whether the central ridge is volcanic or not, and if so, whether it is composed of basaltic lava or more siliceous material akin to ash flows on Earth. Such information should provide a firm basis for better definition of the principal problems of Alphonsus.

The capabilities specified in this report for the rover include sample acquisition and storage. Ostensibly, some or all of the samples taken during reconnaissance can be kept by the vehicle and can be picked up by the manned mission. A sampling of the entire floor of Alphonsus is thus obtained, although the area actually covered by man is but a small fraction of the total area. The ability to deliver samples to the point selected for manned landing requires that the rover be redirected to return to thatpoint following its reconnaissance traverse.

It appears highly desirable to direct the vehicle, after completing its reconnaissance of Alphonsus, to use the rest of its range (around 700 km) and lifetime in the exploration of regions beyond Alphonsus. For example, a path proceeding from Alphonsus toward Mare Nectaris across the central uplands is shown in plate 1. In this way, both roles of reconnaissance and remote area exploration are performed by a single roving vehicle. Mission characteristics and a general flight plan are presented in table VI.

Fuel on board plus 700 pounds of residuals will permit 12 sorties with the intermediate LFU. A minimum of 150 kilometers of traverse with the LSSM is required, not considering possible maneuvering requirements.

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* Plate 1 is a large lunar map attached inside the back cover.

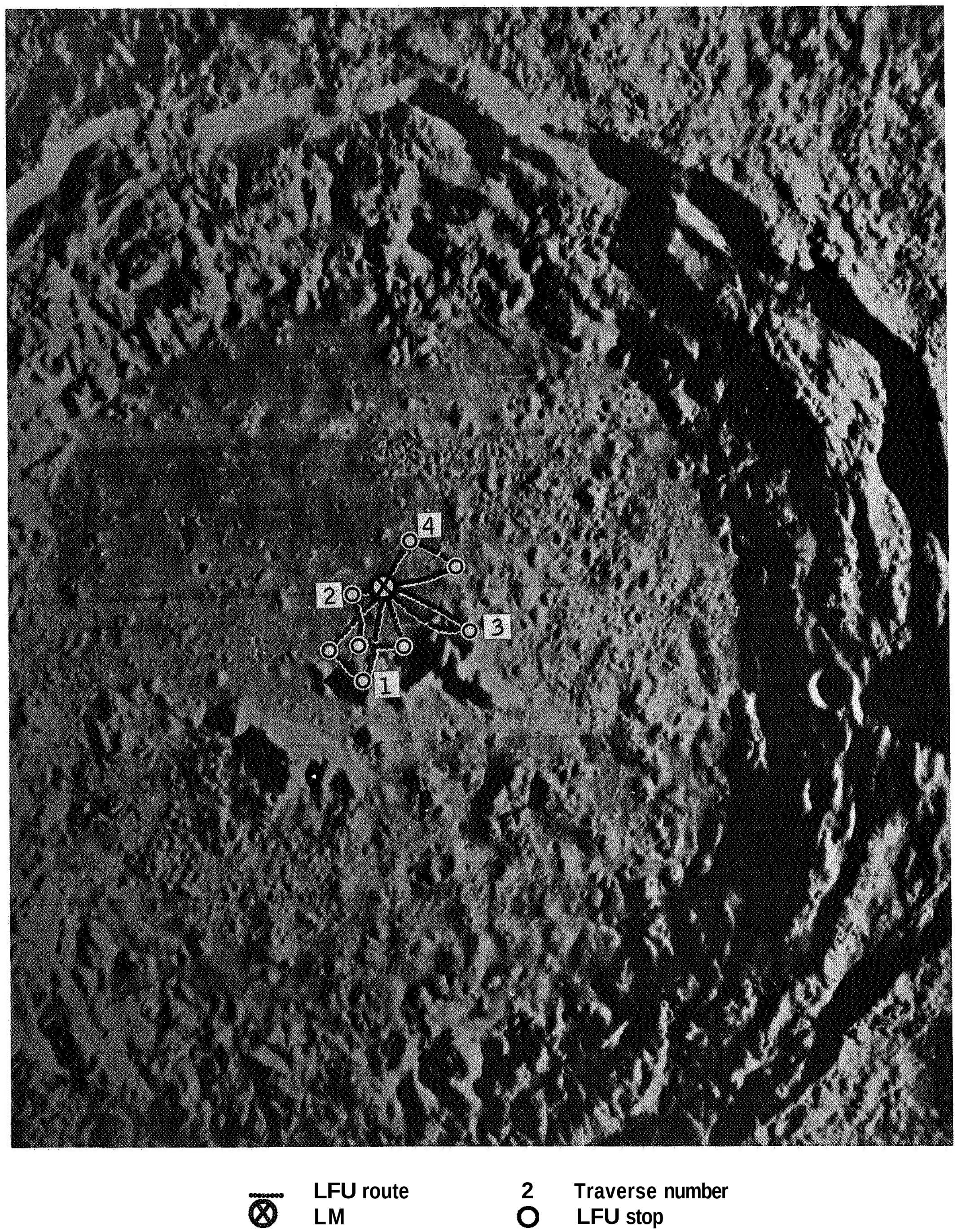


Figure 3. - Sample traverse routes in Copernicus.

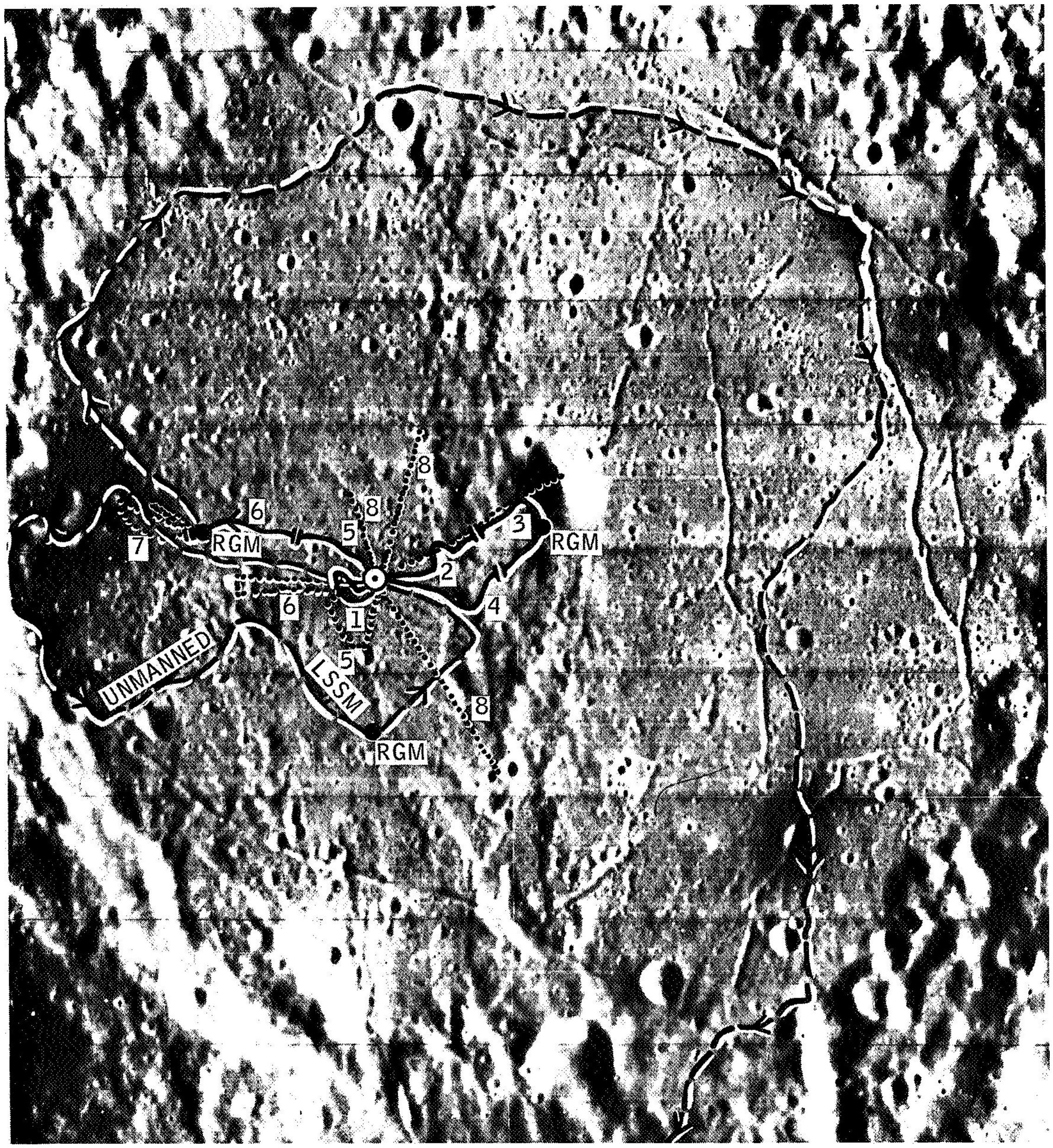
TABLE V. - GENERAL MISSION PLAN TO COPERNICUS

[Characteristics of the mission: Single-launch Saturn V with an Extended Lunar Module (ELM); staytime, 3 days for two men]

Type	Items	Unit weight, lb	Total weight, lb
Mobility devices	2 LFU (each with a 12-kilometer radius)	310	
	LFU support equipment	30	
	Communication and navigation equipment (2 units)	50	390
Geological field equipment	Lunar Survey System Staff including film, camera, and penetrometer	75	
	Handtools[a]	30	130
	Map package	5	
	Binoculars (2 units)	20	
Geophysical traverse equipment	Gravimeter	10	
	ESS	200 to 300	
	Explosives	10	320
Analytical equipment	$\alpha K\alpha$ spectrometer	--	20
Geotechnical support equipment	Soil sampling equipment	20	
	Landing dynamics instrumentation system	2	22
Sample containers	--	--	20 to 100
Spare PLSS[b]	2 units	--	140
LFU tankage and fuel	--	--	1000 (residuals)
TOTAL			2122

Flight plan: Day	Events	Tanks[c]
1	Landing:	
	ELM and 2 LFU on floor north of central peak	--
	LM stabilization and LFU preparation	2
	2-man, 1-hr, 1/6-g familiarization and LFU checkout	0.5
	2-man, 2-hr, ALSEP emplacement	--
	1-man, 3-hr LFU survey sortie 1 to top of central peak for photography, communications relay implant, sampling, and gravimeter deployment	1
	1-man, 3-hr excursion at LM to emplace 500-ft geophone spread and to obtain biological and rock samples	--
2	1-man, 3-hr LFU sortie 2 to survey and sample crater floor and hill features; to set up seismic charges and deploy gravimeter	1
	1-man, 3-hr lunar soil profiling at site close to LM	--
	1-man, 3-hr LFU sortie 3 to survey and sample peak and base of second central peak and to deploy gravimeter	--
	1-man, 3-hr sample examination, $\alpha K\alpha$ spectrometer sorting, packing at LM	--
3	1-man, 3-hr LFU sortie 4,[d] examine and sample smooth floor material, hummocky floor material, and floor lineaments; set seismic charges and deploy gravimeter	--
	1-man, 3-hr survey local surface processes and features at LM	--
	2-man, 2-hr sample examination, selection, stowage, and emplace scientific stations	--
	2-man, 1-hr departure preparation	--
	TOTAL	4.5

[a]Hammer, scoop, sample bags and small containers, drive tubes, aseptic sampler, tongs, tool carrier, and hand lens/scriber/brush.
[b]Portable life support systems.
[c]LFU propellant loadings.
[d]Flight distance limited to walk-back capability.



LSSM manned
LSSM unmanned
LFU
X LFU landing site
+Overnight stop
RGM (Remote Geophysical Monitor)
5 Day of traverse
LM

Figure 4. - Sample traverses in Alphonsus. Compare with Plate 1 and text.

TABLE VI. - GENERAL MISSION PLAN TO ALPHONSUS

[Characteristics of mission: Dual-launch Saturn V with ELM/Lunar Payload Module (LPM) or ALM/Augmented LPM (ALPM); staytime, 7 to 8 days for two men]

Equipment list				Flight plan			
Type	Items	Unit weight, lb	Total weight, lb	Day	[illegible]		
Mobility device	LSSM (10-km radius)	1000		1	Landing:		
	LSSM recharge	200			LM truck and ALM on western floor		
	Off-loading device	100			Premanned landing:		
	Command and navigation	100					
	LFU (two with 2-km radii)	530			Unmanned LSSM sampling and reconnaissance traverse particularly to volcanic vents and west walls		
	LFU support equipment	30					
	Command and navigation (2 units)	100	2060		LM stabilization and traverse planning		
Geological field equipment	LSS and camera	30			2-man, 2-hr, 1/6-g familiarization and vehicle checkout		
	Handtools[a]	30					
	Field maps	3			1-man, 3- to 4-hr survey of local area and preliminary sample collection		
	Electromechanical line tracer	4	67		1-man, 3- to 4-hr LSSM traverse to dark-haloed crater/rill complex	--	
Geophysical traverse equipment	Gravimeter	5		2	1-man, 6-hr LSSM traverse toward central peak across ridge/plain contact	3	1
	Magnetometer (single station)	3					
	Refraction seismic experiment				1-man, 3-hr excursion at LM to deploy ExESS	--	--
	Instruments	12		3	1-man, 6-hr LSSM traverse from ridge to foot of central peak, along contact and start back; emplace 2 RGM; emplace Active Seismic Experiment (ASE) charges	3	005
	Explosives	25	45				
Analytical equipment	Traverse						
	Gas analyzer	15			--man, 3-hr drilling excursion at LM	--	--
	αKα spectrometer	16					
	LM			4	1-man, 6-hr LSSM traverse from ridge to LM	3	0.5
	Diffractometer	30			1-man, 3-hr LFU/foot traverse to top of central peak leaving communications relay	--	--
	Petrographic microscope	10					
	Sample preparation	50	[illegible]				

[a]Hammer, scoop, sample bags and small containers, drive tubes, aseptic sampler, tongs, tool carrier, and hand lens/scriber/brush.

[b]Probably available for science.

[c]LFU propellant loadings.

TABLE VI. - GENERAL MISSION PLAN TO ALPHONSUS - Concluded

[Characteristics of mission: Dual-launch Saturn V with ELM/Lunar Payload Module (LPM) or ALM/Augmented LPM (ALPM); staytime, 7 to 8 days for two men]

Equipment list

Type	Items	Unit weight, lb	Total weight, lb
Geotechnical support equipment	Soil sampling equipment	20	
	Penetrometers	10	
	Borehole probe	15	
	Trafficability data acquisition system	10	
	Landing dynamics instrumentation system	2	
	LM laboratory devices	10	7
Emplaced Scientific Station			300
Sample containers (Apollo type)			20 to 160
LSSM-mounted drill			50
Moderate-depth drill (LM mounted)			250
Power for drill	Fuel cells		315
Spare PLSS's	2 units		140
Spare space suits	2 units		140
LFU tankage and fuel			5000
TOTAL			8715

Flight plan

Day	Events	Unscheduled man-hours[b]	Tanks[c]
5	2-man, 2-hr loading of LSSM for unmanned mission	3	1
	1-man, 4-hr LSSM traverse toward the west	--	--
	1-man, 3-hr LFU point-stop sorties to four sites operating from LM	--	3
6	1-man, 6-hr LSSM traverse continuing toward west; emplace RGM; emplace ASE charges	3	0.5
	1-man, 3-hr LFU/foot traverse toward west to primary and secondary craters	--	--
7	1-man, 3-hr LFU/foot traverse on dark-haloed blanket	6	1
	1-man, 3-hr LFU/foot traverse and point stops on rim of dark-haloed crater	0	1
8	1-man, 3-hr LFU point-stop sorties to three locations	0	2.5
	1-man, 3-hr departure preparation excursion; LSSM proceeds unmanned to Sabine and Ritter	--	--
	TOTAL	21	16

[b]Probably available for science.

[c]LFU propellant loadings.

One LSSM sortie and two LFU sorties would be scheduled per day for 6 days with the first and last days open.

Lunar Surface Operations

The lunar surface phase of each mission will consist of three major components: (1) site activities, (2) mobility between sites, and (3) communications and telemetry between Earth and the Moon. The success of lunar investigations depends upon the effectiveness with which these components are directed toward increasing the efficiency of site activities. The broad relationships between the three major components and Earth-based support are shown in figure 5. The word site in figure 5 is used in a restricted sense, that is, any place where the astronaut happens to be gathering information. By simple expansion or contraction, figure 5 will fit any specific mission objective.

Site Activities

At each place where the astronaut carries out geological investigations, he will deal with a complex array of rocks, topographical features, structures, and their interrelationships. To study and collect information on these geological features, the astronaut must perform the following:

1. Location of himself, vehicles, observation and photography points, samples, and instrument-measurement points

2. Observation, description, and photography of rocks, topography, structures, and their relations

3. Sampling of rocks and soils in the surface and shallow subsurface

4. Measurement of attitudes and properties of rocks and soils for petrological, geophysical, and geotechnical engineering studies

In addition to his field observations, the astronaut must be able to gather semiquantitative information concerning the chemical, mineralogical, and microtextural nature of the geological units with which he is dealing. This is especially important in the longer duration, dual-launch missions, which will be scheduled for studying larger and more complex areas than those visited during the earlier missions. Most of the information can be obtained in a lunar shelter after the return of samples from each sortie. By helping the astronaut to further understand the materials with which he is working, the information will guide subsequent activities of the field investigation and aid the astronaut in selecting the most representative and significant samples during his surface traverses. The analyses will also enable him to select the best grouping of samples for return to Earth and will provide valuable information on those samples that are discarded before return to Earth.

Exploration geophysics is required to extend in depth the surface mapping accomplished by geological methods, Therefore, the geophysical measurements should reflect some aspect of subsurface rock units that can be identified with surface units.

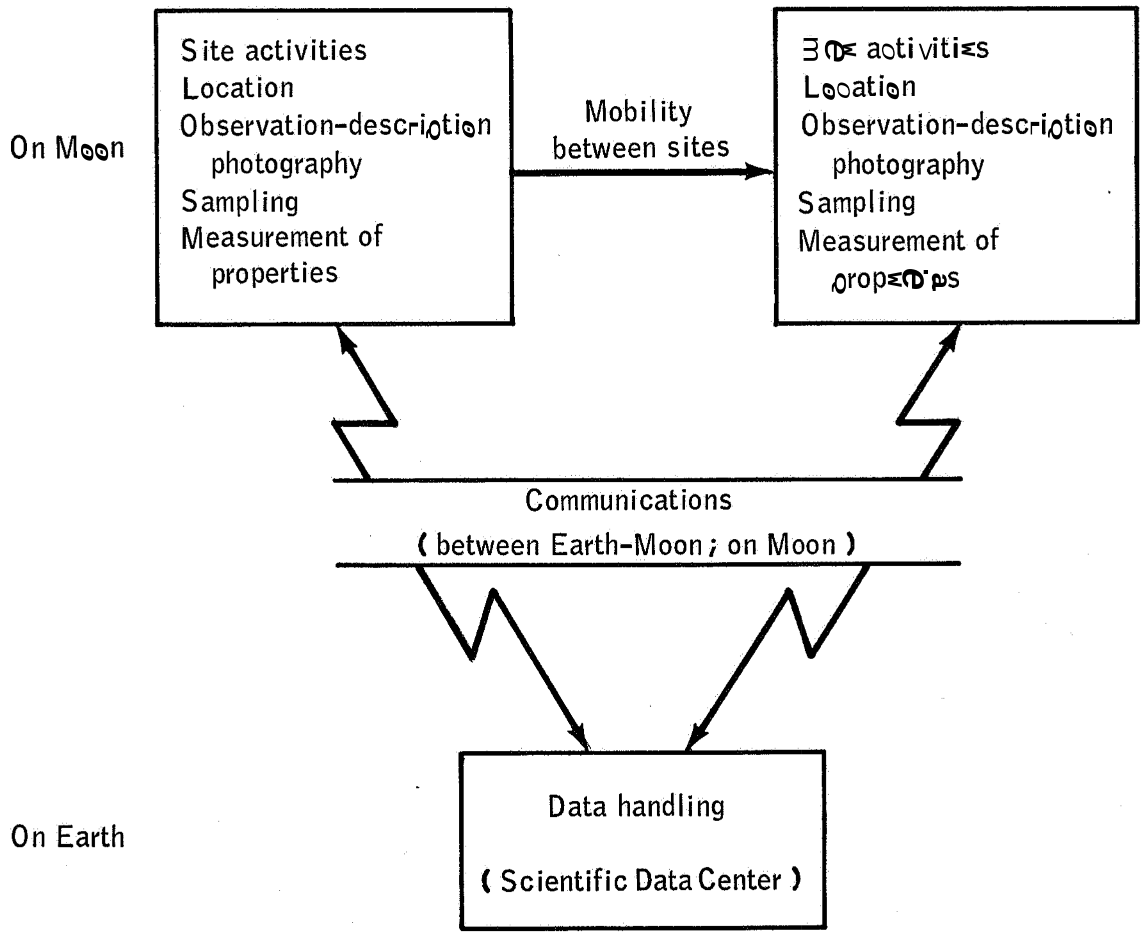


Figure 5. - Diagram showing broad relations between the major components of the lunar surface phase of a lunar mission. These apply at any scale, manned or unmanned, single- or dual-launch, Apollo or post-Apollo.

Of the proposed methods, seismology has the potential of mapping physical properties (velocity and elastic moduli) which can be most clearly correlated with probable lithology. In the long-range view, the systematic compilation of rock velocities offers the opportunity for extending calibrated, detailed studies to remote areas by unmanned systems.

The principal use of gravity is to locate vertical discontinuities in density. In terrestrial mapping, such features as dikes, igneous intrusions, faults, cavities, and basin deposits are reflected by associated gravity anomalies. The most useful characteristics of a gravity anomaly for critical interpretation are well-defined gradients. Gravity measurements also provide the means of determining whether surface features of large relief are in isostatic equilibrium.

The utility of magnetic measurements is based on whether significant magnetic anomalies exist. Recent measurements suggest that the inducing field, if present, is not of sufficient magnitude; remnant anomalies depend on whether fields of sufficient magnitude existed in the past. If remnant anomalies are present, however, they will provide not only information of subsurface units, but also data on prior magnetic fields. In this sense, they are a possible source of information on lunar history.

Adequate knowledge of the engineering properties and the probable behavior of local material in various mission sites is essential to the success of a scientific mission. Problems that will be encountered during AAP missions and which will depend on engineering property data for their solution, include landing support for spacecraft and lunar flying vehicles, surface erosion by rocket engine blast, surface and subsurface contamination by rocket exhaust, astronaut and surface-vehicle trafficability, sampling, drilling, interaction of various instruments and tools with the lunar surface materials and environment, selection of sites for location of emplaced scientific stations and observatories, and definition of hazardous areas.

In addition to providing a means for solving specific problems, knowledge of the engineering properties of lunar materials can contribute directly to understanding lunar geological processes such as crater formation, collapse-feature formation, landslide development, surface erosion and deposition, and interpreting shallow active seismic geophysical measurements.

The unique environmental conditions on the Moon will also provide an excellent natural laboratory for the study of the physical and physicochemical behavior of soil and rock materials, which should increase greatly the basic understanding of the behavior of these materials on Earth.

Simple tests which do not require extensive astronaut time or complex instrumentation, or which involve the study of interaction of existing systems with the lunar surface, should be employed whenever possible for acquisition of needed data. Such experiments can be carried out without an excessive increase in cost or demand on astronaut time, The data from the tests should, in turn, be correlated with orbital photography and Earth-based laboratory data and should be part of a well-coordinated Earth-based research program.

The proper application of geotechnical engineering studies can contribute to the success of studies in geology, geophysics, geochemistry, astronomy, and the

biosciences. Conversely, valuable information can be derived from the results of studies in other disciplines that will aid in the subsequent solution of lunar-soil and rock engineering problems. Proper geotechnical information will be required for planning scientific missions requiring long traverses or for constructing lunar facilities.

Information gathered during the lunar missions should be transmitted to Earth for analysis during the missions so that an evolving geological picture can be transmitted back to the astronauts for detailed planning of succeeding sorties,

Mobility

Because of the topographically and geologically complex nature of the lunar surface, several types of mobility must be developed to achieve the best scientific use of the launch capability available through the early 1970 period.

The basic requirements of the geologist for surface exploration are four main categories:

1. The ability to study, map, and sample in detail certain small, carefully selected areas

2. The ability to reach key areas quickly in spite of distance and topography

3. The ability to observe larger features of an intermediate scale and to determine their time-space relations over areas of several square kilometers

4. The ability to connect these intermediate and small-scale features by reconnaissance or by detailed traverses between the different areas

The first of the categories, examination of small-scale features in detail, requires that the astronaut work on foot in the lunar environment. Sufficient insight is expected to be gained into many lunar geological processes from this kind of investigation during early Apollo missions (even though early Apollo will be planned largely from operational considerations) for planning increased area coverage on AAP missions.

Several mission areas, critical to the geological interpretations, require several spot checks over an area with a radius of a few kilometers. Other mission areas require that the astronaut spot check scattered sites and that he be able to establish the interrelationships of features over areas several thousand meters in extent. To establish the relationships, the astronaut needs the capability to traverse slowly across the surface, observing closely and making whatever stops are necessary. Thus, the astronauts can construct a geological framework within which they can place information gained by spot checks. To extend geological observations to large areas of the Moon, the capability to carry out unmanned traverses over long distances (1000 km) with automated scientific equipment is required.

INSTRUMENTS AND SYSTEMS

The variety and complexity of lunar surface operations discussed in the preceding section indicates the need for analytical instruments and supporting systems to meet the requirements for mobility, geological and geophysical investigation, geotechnical engineering, and communications for manned and for unmanned missions. The instruments and systems range widely in stage of definition, from a stage of early research and feasibility study to an advanced stage of development. This section sets forth the operational specifications for the principal systems and instruments required for lunar surface operations.

Mobility Systems

The exploration plans presented previously show the need for a variety of mobility systems. The systems set forth here are derived from scientific requirements for a lunar exploration program. The mobility requirements were established without compromising the utility of the systems should a contingency situation arise. However, upon reviewing the capabilities provided for in the requirements, note that this family of vehicles will allow for a reasonable amount of flexibility in the exploration program. The two major categories of mobility systems required are (1) in support of manned exploration and (2) in support of unmanned exploration.

Manned systems. - In manned systems, a large effort must be devoted toward the development of space suits into highly mobile and reliable devices to effectively conduct detailed studies of the lunar surface during foot traverses from the LM in early Apollo missions and from the vehicles in later missions. Attention should be given to the following:

1. For walking, it is especially important that the hip, knee, and ankle movements require a minimal amount of exertion.

2. Geological exploration requires much close examination of the surface; therefore, the suit should allow the man to kneel with ease and reach the ground with his hands.

3. Because the man must carefully observe details, the optics of the faceplate should be designed for a minimal amount of distortion.

4. The glove should be designed for manipulation of small objects and for gripping tools, such as the hammer, without undue exertion.

A one-man lunar flying unit (LFU) must be developed for use in single-launch, extended LM missions and also for use from a surface vehicle during dual-launch missions. The LFU should have the following characteristics!

1. A communications relay (repeater) from the suit radio to Earth.

2. A navigation system (refer to the section entitled "Surface Vehicle Navigation System").

3. A science payload of at least 40 kilograms.

4. A traverse range of at least 25 kilometers; an ascent capability of at least 1000 meters.

5. The ability to be carried on and operated from a mobile surface vehicle.

6. Must be capable of at least four sorties per day.

For intermediate scale and intermediate detail studies of areas critical to the understanding of large portions of the Moon, a mobile surface vehicle (to be used with a shelter laboratory) must be developed for dual-launch missions. The system should include the following:

1. The LFU for special sorties and for rescue.

2. The capability of operation by one astronaut and the capability of carrying two astronauts.

3. Provisions for a continuous communication and telemetry stream, either through direct Earth link or LM-to-Earth link, with at least a 500- and preferably a 1000-kilocycle bandwidth available for scientific purposes.

4. A navigation system (refer to the section entitled "Surface Vehicle Navigation System").

5. A scientific payload of at least 300 kilograms.

6. An operational capability of fourteen 6-hour sorties.

7. An operational radius of at least 10 kilometers with a total of 30 kilometers of traverse length per sortie at speeds up to 10 km/hr on smooth, flat surfaces.

8. The provision for each man to get on and off the vehicle frequently and with ease.

9. Provisions for taking samples with a long-handled manipulator or scoop and for taking photographs from the vehicle.

10. The provision for all onboard scientific equipment that might be operated during vehicle travel (navigation unit, magnetometer, etc.) and monitored from riding positions by both men.

11. The capability of remote operation from Earth before and/or after the manned portion of the mission, according to the specifications in the following section.

Unmanned systems. - Mobility systems for unmanned exploration should be capable of supporting two kinds of missions: (1) those in which the entire surface operation is carried out without the participation of man on the lunar surface and (2) those in which the vehicle is used part of the time for either manned or unmanned operations.

In terms of costs, it would be desirable that a vehicle used on unmanned missions have the capability of being launched with smaller launch systems such as the Atlas-Centaur or Titan IIIC.

The mobile vehicles to be used in manned and unmanned missions have many requirements in common. Therefore, it is desirable to study the feasibility of developing a single vehicle to serve all manned and unmanned operations. The following specifications are for operation of vehicles in the unmanned mode:

1. The capability of being launched directly from Earth and automatically landed using either the Atlas-Centaur or Titan IIIC launch systems or of being carried on the LM truck during the dual-launch manned Saturn V missions.

2. A science payload (including acquired samples) of approximately 200 pounds.

3. Extended mobility of at least 1000 miles.

4. A lifetime of 6 to 12 months or longer if possible.

5. Capability of gathering and transporting samples.

6. The function of carrying equipment for surface analytical measurements,

7. The capability of deploying instruments on the lunar surface.

8. The capability of being operated from Earth in real time using a TV system.

9. The capability of being located within 100 meters at all times from Earth by a navigation system.

10. The capability to rendezvous with a manned mission.

It is anticipated that the requirements for an automatic roving vehicle on Mars (Voyager Program) will be similar in most respects to the lunar vehicles previously described. It is strongly recommended that consideration be given to the design of a rover that could serve the lunar and planetary programs. The cost advantage in developing a single system may be significant. There are also advantages in gaining experience with an automated roving system on the Moon before using a mobile system on Mars.

Systems for Post-AAP Missions

Advanced manned mobile laboratories have been considered to meet the requirements of long surface traverses. The systems are considered to be appropriate to lunar exploration following the AAP time period and are not discussed in detail in this report.

Field Instruments

The following instruments (table VII) are those which will be used to gather the information required for any comprehensive field geological study. Some instruments (such as the geologist's pick) are very similar to terrestrial instruments, modified slightly to meet limitations imposed by the lunar environment or the restrictions of a space suit. Other instruments (such as the cameras) are more elaborate than those used on Earth because a few minutes saved on the lunar surface are worth many hours of study and data reduction upon return of the information to Earth. Another category of instruments (such as the tracker) are essentially new systems developed for specific use in lunar exploration to replace instruments that perform the same function in terrestrial exploration but are too time consuming for lunar use.

Lunar surveying system (LSS). - An engineering model of the LSS is under development at the Manned Spacecraft Center, Houston, Texas. The system is composed of two major components: (1) the staff which serves as a monopod for several instruments and which the astronauts will carry on foot and (2) the tracker-surveillance system to be mounted on the LM during single-launch missions and on the surface vehicle during dual-launch missions. The system will continually track the astronaut on foot and will provide real-time monitoring and continuous recording of the activities and observations of the astronaut, images that can be photogrammetrically and photometrically reduced, and in situ measurements of specific rock and soil properties. A general list of design criteria for the components of the system follows; the automatic override and modular instruments are not under current development, but should be included

1. The components

   a. A TV camera with 800-line resolution and a frame rate of one frame/ 3.2 sec

   b. An orientation subsystem which gives the trend and plunge of the camera axes to approximately ± 25' of arc

   c. Modular instruments, such as a penetrometer or γ-ray flux meter, mounted on the base of the staff

   d. An attachable stereometric film camera (refer to paragraph entitled "Stereometric Film Camera")

2. The tracker-surveillance system components

   a. A laser tracker with vertical and horizontal angles measured to ± 3.4' of arc and ranging to ± 30 to 100 centimeters; also includes a search and acquire mode

   b. A TV-surveillance camera slaved to the tracker with 800-line resolution and a frame rate of one frame/3.2 sec (should include automatic override for remote control from Earth for both the manned and unmanned portions of the mission)

Data from all components of the LSS are transmitted in real time through the vehicle telemetry system to Earth.

TABLE VII. - LUNAR SURFACE INSTRUMENTS AND POTENTIAL MISSION USE

Instrument	Mission: Early Apollo	Mission: AAP single launch	Mission: AAP dual launch
Location			
Tracking/ranging	Manual azimuth rangefinder	Automatic on LM, LFU	Automatic on LM, LFU, LSSM
Automated staff	--	To be used (LSS)	To be used (LSS)
Navigation system	--	--	LFU, LSSM
Observation			
Surveillance TV	Apollo TV	LM	LSSM
Staff-mounted TV	--	To be used	To be used
Description			
Orbiter photomaps	To be used	To be used	To be used
Electromechanical scanner	--	--	LSSM
Electromechanical tracer	--	--	LM, LSSM
Photography			
Cameras	Hasselblad	Stereometric and stick	Stereometric and stick
Sampling			
Apollo lunar hand-tools (ALHT)	To be used	Upgraded ALHT	Upgraded ALHT
Drill	Handheld, 3 m	Handheld, 3 m	LSSM mounted, 3 to 10 m; LSSM mounted, 30 m
Property measurement			
Petrologic			
Spectrometer	--	LM (outside)	LM (outside)
Diffractometer or diffractometer-spectrometer combination	--	LM (outside)	Shelter (inside)
Microscope	--	--	Shelter (inside)
Geophysical			
Magnetometer	To be used	To be used (if remnant magnetism exists)	To be used (if remnant magnetism exists)
Gravimeter		To be used	To be used
Seismic system	Passive	Active	Active

TABLE VII. - LUNAR SURFACE INSTRUMENTS AND POTENTIAL MISSION USE - Concluded

Instrument	Mission		
	Early Apollo	AAP single launch	AAP dual launch
Geotechnical engineering[a]			
Soil samplers	To be used	Disturbed soil	Disturbed and undisturbed soil
Penetrometers	--	Staff mounted	Staff mounted, LSSM supported
Borehole probes	--	--	To be used
Laboratory devices	--	--	To be used
LSSM trafficability hazard sensor	--	--	To be used
LM landing dynamics	To be used	To be used	To be used
LSSM performance instrumentation (obstacle negotiability, sinkage, slip, power consumption)	--	--	To be used
Drilling	--	--	Rate meters, temperature sensors
Plate bearing tests at LM site	--	--	To be used
Soil sample preparation tools for classification and laboratory testing	To be used	To be used	To be used
Spacecraft time-dependent settlement instrumentation	To be used	To be used	To be used
LFU performance instrumentation (landing, takeoff)	--	To be used	To be used

[a]The geotechnical categories listed are chiefly areas of investigations needed, not specifically a list of recommended instruments.

LFU navigation system. - A navigation system for the LFU must be developed which will permit flight to a predetermined point of scientific interest. The system should also telemeter to Earth the X, Y, and Z coordinates of the landed vehicle with a precision of at least ± 1 percent of the distance traveled (or ± 250 m in a 25-km flight) with respect to the LM. Additional accuracy is highly desirable if a system can be developed. The system must be automated as much as possible.

Surface vehicle navigation system. - A surface vehicle navigation system for the LSSM must be developed which will continuously and automatically telemeter to Earth location data in the X, Y, and Z coordinates with respect to the LM. The system must have a provision for updating the data to reinitialize the basic navigation unit *so* that the accumulated error does not exceed ± 0.1 percent of the distance traveled (± 10 m at 10 km).

A plotting board for a base map must be included on the LSSM, which will display the vehicle location and heading to the astronaut at all times. A provision for changing the map scale must be included for base maps at scales of 1: 25,000 and 1: 50,000.

Electromechanical line tracer. - The electromechanical line tracer will provide a means for transmitting to Earth detailed geological map information such as contacts and faults. The device would consist of a transmitter into which the appropriate map or photograph would be registered and which would resolve lines traced onto the map into two independent electrical parameters representing the X and Y coordinates. The parameters would be telemetered to the Scientific Data Center (SDC) on Earth where they would be reconverted into line information scribed onto duplicate maps or photographs and accurately registered into the reproducing unit. A provision for frequent calibration would enhance accuracy of the line information.

The unit would have to be portable and would best be mounted on the LSSM console next to or combined with the vehicle position plotter.

Orbiter geological photomap, - The Orbiter geological photomap will be part of a map package and will serve several purposes,

1. Compilation at various scales for definition of geological problems and for planning scientific missions

2. Guidance to the astronaut in preparing surface traverses and to permit precise location of sampling and observational points along traverses

3. Compilation of surface data in areas of observation

4. Extrapolation of the surface information to other parts of the Moon as a basis for reevaluation of lunar geology and planning of later missions

The maps are under study and development now. The general characteristics of the map package are as follows:

1. Small-scale maps with explanations to show regional relationships

2. Large-scale maps of selected places with 25-percent overlapping coverage with explanations and diagrams of salient geological features present in the mapped area (with observational and sampling instructions) printed on the back

3. An 8- by 10-1/2-inch size frame as a rigid base for the maps to facilitate handling and marking

Electromechanical scanner. - An electromechanical scanner (camera) would be of great help in producing accurate topographic base maps of landing sites, The scanner would obtain and transmit photogrammetric image data on the landing site. By photoelectric transducing and mechanical line scanning, the radiant flux of a scene would be transformed into electrical signals that could be transmitted to Earth. Photographic display would be in near real time.

The automatic operation of the subsystem during the postlanding checkout of the LM would permit the near-real-time photogrammetric compilation of a preliminary topographic base map of the area within 80 to 100 meters of the site and the postmission photometric compilation of areas beyond these distances, The photogrammetrically compiled map would be available before or soon after the start of the first surface excursion, It would allow Earth-based analyses of the general geological and topographical setting and would provide a base map for the real-time location and display of the staff tracking and physical-properties data and for postmission analysis of the geology.

The electromechanical scanner subsystem would be housed in a 2-meter telescoping mast to be deployed from the top of the LM during single-launch missions and on the surface vehicle during dual-launch missions.

Stereometric film camera. - The stereometric film camera will provide detailed physical dimensions and color and photometric and polarimetric properties of lunar surface features in the near field; near field is defined as that between the identifying resolution of the premission orbital photographs and the dimensions that can be obtained from returned samples.

The camera will take high-resolution, dimensionally stable stereoscopic and surveying photographs. The specifications for the camera have been defined in NASA MSC Specification No. IESD 25-130. General features of the camera are as follows:

1. Two matched lenses with a base separation of at least 160 millimeters

2. A telephoto lens centered between the matched lenses

3. A 35-millimeter film with a resolution of at least 100 lines/mm

4. A data block on each frame showing the lens number, focus, iris setting time, filter number, and camera orientation in tip and tilt

5. The capability of being mounted on an automated staff to provide telemetering of orientation data

6. A viewfinder readily usable by the astronaut

Stick camera. - The stick camera is a handheld photomicrographic instrument which will take high-resolution stereophotographs of fragile lunar surface features,' which cannot be returned to Earth intact. Such features include soil and rock textures and structures (disturbed and undisturbed).

The device will be mounted on a stick to facilitate its use. The only control will be a shutter release on the stick. Pictures are taken by placing the open end of the camera housing against an object and pressing the shutter release in the handle.

The camera uses 35-millimeter film with matched stereo lenses of f/20 to f/40 aperture to work perhaps between unity magnification and at one-third scale. The field of view is a 24-millimeter square at unity magnification. Illumination will be from a strobe unit incorporated into a housing surrounding the field of view. The interior of the housing is a reflector. The focus, aperture, and shutter speed are fixed. The shutter is merely a gate in which the flash duration actually determines the exposure. Film transport can be accomplished either electrically or by a manually operated lever on the handle to save battery weight and complication. A resolution of 40 microns was suggested as readily obtainable from the tiny, relatively simple lenses. The weight is estimated at 2 pounds. (Further details on astronaut photography are in appendix B.)

Apollo lunar handtools (upgraded versions). - Geology handtools will be inherited from early Apollo missions and will probably include a hammer, a scoop, sample core tubes, aseptic samplers, tongs, a scriber, a lens, sample bags, a tool carrier, and a sample return carrier.

Drill. - For the AAP, a vehicle-mounted drill for the LSSM should be developed. The drill should be capable of either plugging or coring a hole approximately 5 centimeters in diameter with nominal drilling depths of 3 to 10 meters. Furthermore, the drill should be capable, including power source, of drilling at least 14- to 30-foot holes or an average of one hole/day in 14-day missions. The drill holes would provide subsurface cores, data for shallow cross sections, and utility holes for activities such as heat-flow measurements, down-hole logging measurements, and emplacement of seismic charges.

Analytical Instruments

During the AAP geological investigations, the astronaut will require a number of analytical instruments to help describe surface materials for sample selection, field definition, and areal trend information. The information the astronaut will use in the study will be chemical, mineralogical, and rock-textural features which will be obtained from instruments in the petrologic equipment package. Standard pieces of equipment will be a spectrograph, an X-ray diffractometer, and a polarizing microscope with an attached television camera. This equipment may be supplemented in some missions by more specialized equipment for specific tasks. Other instruments, such as a nonpolarizing microscope for examining specimens in plain light, may augment the microscope capability. The following discussion of specific instruments and analytical requirements is as specific as possible at this time and includes information derived from field testing several instruments.

Chemical analysis. - Methods and instrumentation for chemical analysis of lunar surface materials should be developed for satellite and for manned and unmanned mission configurations. For satellite use, such an instrument can only give an indication of gross chemical changes over the lunar surface, but the instrument would give the first chemical trend data of the lunar exploration program. An example of such an experiment would be y-ray spectrometry.

For surface work, an instrument must be provided to determine the abundance of the geologically important rock constituents Si, Al, Ca, Mg, Fe, Na, K, and Ni and of a few of the minor elements such as P and Mn (or if substantially different than Earth materials, the group of elements characteristic of the first lunar rocks recovered). The method must allow experimental accuracy as near 5 to 10 percent of the amount present as possible with minimum sample preparation and analytical time. The instrument should require do sample preparation for use on an unmanned vehicle.

Such an instrument has been under development at Goddard Space Flight Center for 2 years. The $\alpha K\alpha$ spectrometer using a Cm^{242} source can be used to determine elements $11 \leq Z \leq 30$ with an analytical accuracy of approximately 15 percent of the amount present. The instrument can be used on a manned or unmanned vehicle and in the shelter and can analyze either a solid or a finely comminuted sample. The resulting spectrum, however, must be separated by computer, and it will be necessary to transmit data directly to the Scientific Data Center (SDC) before any useful information can be obtained. The instrument weighs 4 pounds, and the power supply weighs 10 pounds. The final instrument design should provide the following:

1. A radiation source strong enough to produce 10 000 counts per 2- to 4-minute integration time

2. Adequate shielding for operation without personnel radiation shields

3. A convenient sample-loading arrangement that can be operated with gloves

Auxiliary equipment should include power supplies for the detector bias (200 V dc), a low-voltage supply for amplifier and channel analyzer equipment, an amplifier network for detector signal output, and a multichannel analyzer. The channel analyzer should be capable of at least 200-channel simultaneous storage at 10^5-size numbers and should have the capacity to dump in 10 to 15 seconds.

Mineralogical analysis, - X-ray diffraction is a time-proven method of obtaining unique mineral or chemical-compound structural information. The lunar chemistry of the Moon will probably be similar to that of Earth, but the chemical-atomic combination may vary ‘significantly. A diffractometer is suitable for manned and unmanned surface operation if the proper sample-preparation equipment can be developed.

A miniaturized powder diffractometer built for NASA has been extensively field tested and found to be satisfactory. The experimental method consists of packing the powdered sample into a sample cup and placing it in a monochromatic X-ray beam.

The diffraction pattern should be digitized and telemetered back to Earth for computer analysis. Additional work should be done on the following:

1. The sample holder should be convenient to work with, at least 2 millimeters deep, and should cover the entire X-ray beam. A sample-holder train should be developed so that at least 10 samples could be loaded into the diffractometer at once.

2. The goniometer, X-ray tube, and detector should be flight qualified. The detector should be of the Geiger type. The apparatus should have the capacity for (a) continuous up-angle angular scan from 2° to $3^\circ \times 20$ to $70^\circ \times 26$, (b) adequate shielding during sample loading and running, and (c) an angular scanning speed of about $4^\circ \times 2\theta/\mathrm{min}$, (d) an angular accuracy of $0.01^\circ \times 26$, (e) a rapid-repositioning drive or slewing attachment, and (f) an adequate interlock system for radiation and electrical hazards.

3. Power supplies should be developed for (a) the detector bias (up to 2 kV), (b) an X-ray-tube cathode potential (25 kV), and (c) low voltage for the goniometer motors, and the preamplifier and amplifier for the signal from the diffractometer.

4. Readout is provided by a limited-display device such as a strip-chart recorder which is necessary in the LM for checking the calibration of equipment and the goniometer settings. A feasibility study should be made to determine whether or not a cathode-ray tube (CRT) strip chart, or plotter can be used for this purpose on several instruments and which device would be most versatile.

5. The telemetry link to the SDC requires a continuous two-channel capability. One channel will distinguish pulses at 0.15-second intervals with no number value. A fiducial mark is all that is required. The second channel will handle numbers in the range up to 10^5 size at no greater than 0.15-second intervals.

6. Data handling by the development of a computer program to reduce raw telemetered data to mineral or chemical compounds should be continued. This will take about 0.5 man-year and should be completed for the first remote use of the diffractometer.

A feasibility study should be made on a combined X-ray spectrometer and diffractometer instrument to reduce the number of separate steps in the rock analysis task. For example, a Ross filter experiment might be mounted on the side of a diffractometer, which would involve adding a small amount of instrument weight, but would mean that from one instrument a diffractogram and a partial chemical analysis could be obtained. From present information on this analytical system, only one Sample need be prepared, the analytical time will be increased somewhat, and the technique will be slightly more complex.

Textural analysis. - A polarizing microscope is used in the mineralogical study of rocks and rock fragments for the identification of minerals and for determining rock textures. It is the only experimental technique which will allow the direct analysis of mineral sequence of formation, and it is the most direct method for physical-chemical equilibrium information. Textural analysis will be the best means of screening rock

samples which potentially can give direct evidence as to the presurface lunar processes. A television camera mounted in the optic train will allow the work of the astronauts on the rock sections to be supplemented by Earth-based scientists.

The optic tube, sample stage, and support for auxiliary equipment for the microscope should be built into the LM walls so that a small amount of bench space on either side of the microscope is allowed and so that the astronaut can sit and view the specimen. The ocular magnification power should be approximately 10 with a crosshair and a metric-scale reticle; the objective turret should have at least three parfocal objectives in the ranges of 2 to 3, 6 to 8, and 40 to 45 power. A second coupled ocular tube is necessary for the vidicon so that a televised image of what the astronaut is viewing can be obtained at all times. Two light sources are required, one below the stage and one above the stage for vertical reflected illumination. Both below- and above-stage specimen-analyzer polarizing attachments are required and should be mounted with the pass direction, one north-south and one east-west. The specimen stage should be free to rotate coaxially with the optic axis. A fixed substage condensing lens is necessary, and diaphragms should be mounted on both light sources and immediately substage. A Bertrand lens is optional but advisable.

A binocular microscope can be used primarily to augment hand-lens information. It allows a limited amount of work on individual mineral grains in a rock sample; such work includes physical characteristics of minerals and some microchemical work. As on the polarizing microscope, optic train of the binocular microscope should be built into the LM.

The microscope should have a total magnification power of 5 to 100, variable in fixed increments. The suggested power increments are 5, 25, 50 to 60, and 100. The microscope should have a sample stage to accommodate 4-inch-diameter specimens and a movable light source in order to illuminate any area of the sample. The microscope should be combined in design with the petrographic microscope.

Other instruments. - Little-emphasized instruments that will probably find use in advanced lunar exploration are the gas chromatograph and the solids mass spectrometer. Either would have selective use; for example, the gas chromatograph might be used to study the possibility of gaseous volcanic emanations from Alphonsus.

Sample-preparation equipment. - To obtain reliable and accurate data from the analytical equipment proposed, several types of sample preparations should be obtained for coarse rock fragments. To date, this area of instrument support has received less emphasis than any other.

Samples for diffraction and spectrometry should be finely comminuted (50μ to 100μ). Diffraction analysis requires only fine grinding, but the spectrometer sample should be finely ground and the particles kept within as narrow a particle size range as possible.

The recommendation is for a ball or rodmill type of apparatus that can be timed. Earth-based laboratories commonly use a shaking vial approximately 2 inches in diameter and 3 inches long for the mill. The sample and the ceramic balls or rods are placed in the vial and shaken for 2 to 4 minutes and the sample poured out. The

arrangement could be encapsulated or operated outside the LM to prevent life-support-system problems arising from the grinding dust.

Fine lunar material such as dust can be handled in three ways, depending on the technique of study: (1) the particles can be impregnated with plastic on a glass slide for petrographic analysis; (2) the particles can be packed directly into sample cups for the diffractometer and spectrometer; and (3) should the material'be abundant, a sieving or size-fractionation method yielding size-distribution information might be of use. With this last technique, life-support-system problems must be studied thoroughly.

To use the petrographic microscope most efficiently, a thin section of the sample must be prepared. A feasibility study should be undertaken into the problems of miniaturizing the equipment and automating the thin-sectioning method used for rocks. The thin sections should be at least 1 by 1 centimeter in size, and the thickness of the specimen should be between 0.02 and 0.05 millimeter (preferably 0.03 mm).

Geophysical Instruments

The use of exploration geophysics will depend largely on the mobility and range of the mission. Although investigation of a particular feature requires precise planning derived from computed anomalies, some general guidelines can be based on the mobilit and range capacity. The three principal modes are: (1) short-range walking traverses; (2) longer range point-to-point mobility provided by the flying unit; and (3) longer range continuous traverses provided by the surface vehicle.

On short-range traverses, three-dimensional gradient determinations can be made of both the gravity and magnetic fields. The gradients provide data on local and regional structures, and they are particularly useful in gravity. Short seismic spreads can yield near-surface velocity structure as well as indications of general subsurface conditions (homogeneous, uniformly changing, distinctly layered, or heterogeneous). From a long-range point of view, consideration should be given to compiling a progressive log of velocities measured at various lunar sites.

On longer range, point-to-point traverses, gravity and magnetic measurements can be planned which will give the anomaly amplitudes related to a specific geological structure. For example, five measurements suitably spaced across a rill, crater, or dome will provide enough data to define the associated anomaly amplitude. In seismology, large depths can be sounded by using a centrally located detector spread in combination with explosive charges placed at distant points by the LFU.

The continuous traverse capability will allow continuous profiling to be accomplished in gravity, magnetics, and seismology at a scale commensurate with the features that are being investigated. Gravity profiles can be used at spacings as small as 100 meters; the spacing of magnetic measurements can be even less. Seismic profiling is a more complex operation, and details depend on the particular information that is being sought.

Surveying control. - Surveying control for seismic and magnetic measurements is similar to that required for general geological purposes. For gravity, the data

reduction will require vertical control to precisions which depend upon the purpose of the measurements. For 0.1-milligal accuracy along traverses, an elevation accuracy of 1 meter relative to a datum common to the traverse is sufficient. If control of the vertical should vary progressively over some long-time interval (as may happen with use of inertial devices), it would still be possible to use the data for local structure since the error will appear as a bias which can be removed in the same manner as regional gradients. For short-spread gradient measurements, a vertical control which is accurate to 5 centimeters along the array is required.

Data analysis. - Data acquired and analyzed on gradient spreads, short seismic spreads, and continuous profiling, provide information about the immediate subsurface and can be used to change or modify exploration plans. For example, an extremely high magnetic gradient might indicate a subsurface structure warranting further exploration. The data should be transmitted and analyzed in real time. However, amplitude data and deep seismic sounding will be acquired on a fixed-plan basis, and analysis can be postponed to postmission time.

Transmission of gravity and magnetic data can be done at low bit rates and present no special problem for real-time analysis. Seismic requirements, however, saturate the bit-rate capacity of the proposed transmission system. To alleviate the problem, it may be possible to return the seismic data in two stages by separating the record into two parts. First-break data in the form of time intervals could be transmitted in real time since they are the most immediately useful in determining subsurface structure. The complex of data in the remainder of the record could be recorded on tape and played back at a slower rate. However, the real-time analysis of all seismic data may prove to be desirable, especially in later missions.

Time consumption. - Gradient spreads, short seismic traverses, amplitude measurements, and deep seismic sounding can probably be accomplished in about 20 percent of the available surface excursion time. The most time-consuming procedures are the deployment of the seismic detectors and the measurement of gradients. Amplitude measurements can probably be accomplished (with automatic instruments) with little extra time on any flight of the LFU. On continuous traversing, the time consumption is probably similar, although it is difficult to anticipate the seismic time expenditure without considering the operation in detail.

Equipment. - Gravity and magnetic instruments which operate in completely automatic modes are essential to efficient operation. Precision requirements are 0.1γ for magnetometers and 0.01 milligal for gravimeters (0.1 milligal is suitable for amplitude measurements and continuous traverses). A seismic system of standard detectors, cables, recorders, and energy sources should be developed for lunar operation, perhaps as an outgrowth of the early Apollo seismic system. For short traverses, a thumper might be a desirable energy source; when combined with data stacking, it reduces energy requirements and the dynamic range requirement of the recording system.

Planning. - A major effort should be made at an early stage to derive optimum field methods. Planning based on computed anomalies and the field checkout of systems should be used in close coordination with parallel geological planning and mapping. This approach will insure the most efficient use of the available time on the lunar surface. In seismology, the analytical features of various spread configurations

and nonstandard phenomena such as attenuation, frequency spectrum, and short-period surface waves should be known.

Geotechnical Instruments

A number of geotechnical engineering problems related to lunar exploration were previously listed in this report. Satisfactory solutions to these problems will require knowledge of the following soil and rock properties: grain size, shape, and size distribution; penetration resistance; compressibility; strength density; relative density; elastic constants; adhesion characteristics; porosity; thermal properties (temperature, heat capacity, thermal conductivity); permeability; stress-strain characteristics; and composition. Three basic approaches may be used for qualitative and quantitative determination of these properties:

1. Visual and tactile observational methods

2. Direct soil tests

3. Spacecraft and vehicle-surface interaction studies

At the present time, only limited study has been made of the various approaches. Detailed studies are recommended for selecting the most promising test methods and instrumentation concepts within the constraints of the lunar environment, weight limitations, astronaut capability, and data systems. Only after this has been done can detailed specifications for the proposed systems be prepared. Unmanned Lunar Orbiters and Surveyors provide data from which properties of lunar surface materials can be derived in an approximate way. Useful information can be derived from the following:

1. Determination of slope angles, ground surface roughness, boulder size distribution and frequency, and other features which serve to place constraints on landing-site and traverse-area selection

2. Identification of potentially unstable ground areas by recognition of slump features, boulder tracks, and other features

3. Approximate determination of physical properties by studying crater geometry and the analyzing of throwout boulders as surface penetrators

The preliminary study of all AAP sites should include careful analyses based on these data sources. The resolution of the stereophotographs should be of the same order as the footprint of the traversing vehicle to enable a meaningful trafficability analysis, accurate mission-time estimates, and lower-bound estimates of the bearing capacity of a given terrain.

Useful qualitative and semiquantitative soil engineering data can be derived from verbal description of the soil characteristics, including such features as texture, looseness or denseness, hardness or softness, approximate particle sizes and shapes, color, variability, the effects of disturbance, and any other pertinent feature. Simple digging, scraping, and probing tests made with the aid of Apollo-type handtools can add significantly to the value of the data returned. Even such a simple observation by

the astronaut as the depth of his footprints can be used to derive semiquantitative data of value. The success of the direct observational approach for acquisition of physical-property data will depend greatly on the adoption of a systematic and efficient procedure for describing the materials encountered.

Apparatus and data-acquisition systems should be considered for determining soil properties in situ of surface and subsurface formations during manned and unmanned missions. Careful consideration should be given to the following techniques.

1. In static and dynamic penetration tests, cone penetrometers, vane-shear devices, and modification of the LSS so that the base of the staff can be used as a penetrometer are possible fruitful approaches to pursue. Data from tests of this type can be used to derive strength, bearing capacity, compressibility, and trafficability properties. Also, a modified version of the penetrometer should be attached onto the surface vehicle to determine the penetration resistance from subsurface material to several feet below the surface. Such data can also be correlated with data obtained from active seismic geophysical tests.

2. Integrated borehole probes may provide means for in situ determination of unit weight, thermal properties, porosity, permeability, stress, and load/deformation behavior. A borehole camera would be useful for study of the in situ fracture pattern and texture of lunar rocks.

3. Direct shear and consolidation tests require the investigation of the development of a miniaturized direct shear test device for use at the LM site. Of the usual types of more sophisticated shear test devices, the direct shear test will probably offer the fewest problems in development, and it has the additional capability of permitting determination of the compressibility characteristics of the soil. A test of this type will be needed if separation of strength into its frictional and cohesive components is to be obtained.

A detailed study of the engineering properties and compositional characteristics of the lunar soil can best be made on Earth-returned samples. Thus, sampling techniques must be developed and perfected which will permit the acquisition of samples to depths of several feet in as nearly an undisturbed state as possible since meaningful quantitative measurements of porosity, unit weight, permeability, compressibility, and strength can be made only if the in situ soil structure is preserved. Surveyor results indicate the lunar soil possesses some small amount of cohesion; undisturbed sampling can thus be considered a realistic objective. If cohesionless soil masses are encountered on the Moon, undisturbed sampling will be extremely difficult (if not impossible) unless chemical impregnation of the soil is used. In such cases, in situ measurements of undisturbed soils will be the most significant sources of engineering data. However, disturbed samples can be used for studies of more scientific interest such as composition-property interrelationships and the general stress-strain characteristics.

One of the most fruitful sources of useful engineering property data will come from instrumentation placed on the LM shelter, LFU, and surface vehicles. This has been well demonstrated by the data acquired from the Surveyor I and III landing dynamics records. Measurements of this type require little in the way of apparatus design

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and special test methods; they do require appropriate instrumentation of the vehicles and development of suitable procedures for analysis of the soil and vehicle interaction problem.

In the case of traversing vehicles, measurements of wheel-load distribution, sinkage, wheel slip, and power consumption should be made and correlated with the surface-materials and local-ground profile. Data acquired in this way can be used to back calculate some of the stress-deformation and compressibility characteristics of the soil.

A procedure for sensing ground conditions ahead of surface vehicles to prevent the possibility of driving into unstable areas should be a definite requirement for traverses into areas for which detailed and reliable trafficability data are not available.

LM vehicles act as dynamic and static penetrometers and when properly instrumented can provide data on the static and dynamic stress-deformation properties of the soil. Periodic observation of any settlement of the LM during its staytime on the Moon yields data on time-dependent soil compression.

The possibility of using LM and surface vehicles as reactions for drilling and sampling operations should not be overlooked. Drill rate metering and temperature sensing during drilling operations on the Moon will provide useful information on physical properties.

Instrumentation for Unmanned Vehicles

Unmanned roving vehicles are under consideration for lunar use in three modes: (1) reconnaissance with and without eventual connection with a manned landing, (2) support during a manned mission, and (3) use in a post-manned mission mode. The instrumentation carried on a rover will largely be a function of which of the modes is used, although several items will be common to all instruments. The following paragraphs list the desired instruments in functional categories and briefly discuss how each might contribute to the rover missions. A detailed specification for the instruments is avoided for two reasons: first, specifications of some instrumentation can readily be found in Jet Propulsion Laboratory (JPL) reports and other contractor reports; and second, anticipated further study of the utility of unmanned roving vehicles will lead to clearer definition of instrument specifications. Analysis of lunar samples returned by Apollo will affect the specifics of the instrumentation. Also to be considered in an unmanned rover study is the trade-off between sample analysis and storage; that is, samples might be taken of all the interesting material seen on a mission, considering that 1000 to 2000 small samples can be obtained at the same weight penalty (50 lb) as several analytical instruments.

Imaging. - All forms of roving vehicles will require an imaging system for purposes of navigation and terrain or for sample examination. The system, probably television, should have stereo capability and detented lens combinations to allow a close look at features with minimum travel. Although not known to be required at this time, the imaging system should be capable of incorporating polarizing and color filters which might prove useful in distinguishing among terrain or geological units.

Sample acquisition. - A rover used in the reconnaissance and support role will be required to obtain samples from the lunar surface and carry them to a collecting point, A scoop will suffice for the numerous soil samples, and a claw mechanism will pick up pieces of solid material. For rocks or rock outcrops too large to carry, a device must be provided to obtain a small piece. A chipping mechanism seems preferable for this mode. A coring tool was considered, but the tool was viewed as having a short life and high power requirements.

Sample storage. - Obtaining a sample is the first step. Then each sample must be stored separately to avoid contamination and must be labeled so that it may be keyed to the sample location. This procedure has not been treated in any known study. It is suggested that the problem of sample labeling and storage be studied in the near future.

Sample preparation. - Rovers used in all three modes, but particularly in the reconnaissance and post-manned-mission modes, must have the capability to conduct some basic sample analysis (section entitled "Analytical Instruments"). Many of the analytical techniques available depend upon good sample preparation for success. Lunar soils may already be partially prepared since they are already comminuted. Solid samples will have to be comminuted on the vehicle, possibly sieved, transported, and presented on a suitable mount to the analytical equipment. The techniques developed to do this for Surveyor (based on 1950 technology) proved to be complex, unreliable, and heavy. It is possible to devise a system (based on late 1960 technology) which would accomplish the task satisfactorily.

Analytical instruments. - The imaging system discussed previously is an analytical tool in several respects. However, there are several additional instruments which have more unique roles. Based upon terrestrial experience, and subject to change when lunar experience is obtained, it is believed that a distinction can be made between samples (that is, whether to collect or discard a given sample) on the basis of sample mineralogy and chemistry. The analyses can be accomplished simultaneously by a combined X-ray diffractometer-spectrometer. Also, it appears valuable to obtain textural information about the lunar soil which will probably constitute most of the material analyzed. Some sort of grain mount and microscopic system appears desirable for this analysis.

Several other instruments could be useful in lunar sample examination including the gas chromatograph, mass spectrometer, γ-spectrometer, and neutron activation device. The specific requirement for these instruments cannot be established until further knowledge is gained about what properties of the lunar surface material are diagnostic. In anticipation of use of the instruments, however, it is recommended that development work proceed.

Other. - The unmanned rovers will be able to conduct other functions besides sample analysis and acquisition. Most of those will be geophysical in nature such as active seismometry, gravimetry, and magnetometry (section entitled "Geophysical Instruments").

Instrumentation for Orbital Systems

There are four basic experiment recommendations for the geology experiments: (1) additional orbital photography for AAP mission sites and traverses; (2) an IR radiometry experiment; (3) a lower priority radar and microwave experiment; and (4) a suggested mode for multispectral UV, visible, and IR checkout flights.

Orbital photography. - It is recommended that the present Unmanned Lunar Orbiter (ULO) program be continued for at least two additional flights including a zero-phase-angle, medium-resolution, high-inclination orbit and a flight for high-resolution coverage of the AAP missions.

IR radiometry. - It is recommended that the present ULO system be modified for a thermal emission experiment with the following characteristics:

1. The scientific objective is to measure the nighttime lunar emission (within a few degrees of the morning terminator) to determine the types and geographical distribution of thermal property anomalies as an aid in the regional geological mapping program and in the more detailed AAP sites. Also, the thermal emission measured at high latitudes will provide information on the internal heat flow of the Moon and on the gross properties of the breccia lenses below the craters.

2. The engineering requirements are a scientific payload of at least 50 pounds; polar orbits, preferably circular; ground-based resolution of 100 meters at a wavelength of 100 microns; radiation filtered for cutoff at 5 microns on the short-wavelength side and 500 microns on the long-wavelength side; lifetimes of 30 days desirable to get total geographical coverage; and bit-rate accumulations of between 10^3/sec and 10^4/sec which probably imply a modest amount of data storage before transmission back to Earth.

Radar and microwave studies. - Lower priority is assigned to active radar and passive microwave measurements in terms of their geological content (rather than in terms of an inherent problem in making the measurements). Imaging radar will, however, provide the only topographical information in the regions of permanent shade at high latitudes and will be required for site certification before the AAP polar landing can be performed. Low-frequency radar observations which may provide information at depths to 1 kilometer will be especially valuable as an exploration geophysics experiment. The orbital requirements have already been examined in the Geophysics Working Group report and will not be discussed here.

Multispectral UV, visible, and IR. - Earth-based observations suggest that multispectral, UV, visible, and IR measurements have relatively limited information content because of the lack of a lunar atmosphere, vegetation, and ground water and the presence of a finely particulate surface. It is strongly recommended that NASA investigate the feasibility of simple multiband experiments to be operated from the CSM of a manned orbiting spacecraft. The experiments could be regarded as tests of 'multispectral component mappers on specific sites using scan lines rather than imagers and operating either at specific bands or with limited spectral sweeps over wavelength regions which laboratory studies suggest have the most significant information. The instruments should be relatively simple and modular in construction so that they can be

interchanged on different flights. The amounts of data for the scans over the most promising AAP sites will be relatively low. Also, field observations made during the manned surface exploration phase will prove to be useful criteria for evaluating the multispectral data.

Communications

This discussion presents the requirements for communications during a lunar mission and includes the pertinent science-oriented audio, video, and instrument data links. The discussion is task oriented, and specific characteristics of various transmission links (aside from those specifically tabulated in table VIII of this report and in the NASA Falmouth report) must be taken from the task descriptions.

Data flow during a mission will include all or parts of the following: (1) observations and descriptive commentary, (2) video for imagery and photogrammetry and as an aid to vehicle control, and (3) digital or analog data from scientific instruments and for instrument control. The Earth-based interface between this system and a data storage facility should be an SDC which, under the control of Mission Control Center, Houston (MCCH), will extend the automatic part of the data-transmission link to a first pass through computerized data-analysis programs. Voice communication between the following points during a manned mission should be provided.

1. Astronaut (on excursion) to the LM and MCCH

2. Astronaut (in the LM) to the astronaut on excursion and to MCCH

3. Science communicator in the SDC to the LM and to the astronaut on excursion

Video should be provided during manned and unmanned missions. The video from the TV camera mounted on the LM and surface vehicle must be transmitted to the MCCH TV camera. The video from the LSS TV camera must also be transmitted to MCCH. When the shelter-based microscope is used, the microscope-mounted TV camera video must also be transmitted to MCCH. (This will presumably occur when the LSS is not in operation.) During the unmanned roving missions, two television cameras should transmit imagery from immediately in front of the vehicle to MCCH.

During the mission, a two-way data flow between Earth and the astronauts will be necessary. On the Earth-to-Moon link, MCCH will telemeter the control for remote-operating vehicles, a variety of instruments, and the surveillance camera. MCCH will receive monitoring parameters from the equipment, which will represent the status of operation. Navigation and orientation information will be transmitted from the vehicles and the LSS.

With the exception of seismic data, all instruments involved in the geological and geophysical traverses will provide a few hundred bits of information per second throughout the mission. Seismic experiments will generate about the same total volume of data as from other instruments, but the data will be generated in bursts that may require special preliminary recording techniques on the Moon before Earth transmission. Rock and mineral analyses in the LM shelter will produce a data rate of a few hundred bits per second.

TABLE VIII. - TELEMETRY DATA SOURCES, BIT RATE, AND TOTAL BIT VOLUME PER 2-DAY EXPERIMENT, INCLUDING ONE FIELD AND ONE LABORATORY CYCLE, EACH OF 2-HOUR DURATION

Data source	Field							
	Bit rate, bits/sec	Analysis time, sec	Bits/ analysis	Analyses/ day	Analysis time	Bits/ analysis	Analyses/ day	Total bits/ 6-hr day
Downlink								
Lunar surveying system								
Tracking and orientation	39	1	39		--	--		8.5×10^{5}
TV	2 to 5×10^{6}	2	2 to 5×10^{6}	7	--	--		2×10^{10}
Surface vehicle								
Navigation	39	1	39	--	--	--	--	8.5×10^{5}
Magnetometer	17	1	17	-	--	--	--	3.7×10^{5}
Gravimeter	17	1	17	.2	--	--	--	204
Seismic	9.6×10^{4}	10	9.6×10^{5}	6	--	--	--	6×10^{6}
Surveillance TV[a]	2 to 5×10^{6}	2	2 to 5×10^{6}	7 1	--	--	--	2×10^{10}
Spectrometer[a]	66	--	--	-	2 min	$\leq \times 10^{3}$	20	1.6×10^{5}
Shelter								
Diffractometer	107	--	--		20 min	8×10^{3}		8×10^{5}
Microscope TV	2 to 5×10^{6}	--	--		2 sec	2 to 5×10^{5}	1 . . --	3×10^{9}
Verbal								
[illegible]								
Surveillance TV control	17	1	18	--	--	--	--	--
Facsimile recorder	--	--	--	--	On demand	--	--	--
Verbal								

[a]Will be used on LM during single-launch missions.

NOTE:

Total storage, bits/2 days . . . . ∆ 3×10^{10}

Total excluding video, bits/2 days . . . . 9×10^{6}

Total video, bits/2 days . . . . ∆ 3×10^{10}

Total field/day, excluding video, bits . . . . 8×10^{6}

Total laboratory/day, excluding video, bits . . . . 1×10^{6}

SCIENTIFIC MISSION SUPPORT

The key role of the astronaut in exercising scientific judgment during the course of a lunar surface operation has been repeatedly and properly emphasized, On this judgment rests the effectiveness of such critical enterprises as direct observation, selection of sample sites, collection of samples, and emplacement of instruments. at sites of maximum promise. In a scientific context, the astronaut should be viewed as a Principal Investigator (PI) whose prior training, transportation to and from the area of study, and accompanying equipment are fortified by Earth-based support during his mission.

For greatest net return of useful data from a scientific mission, the only tasks which should be accomplished on the Moon are those that must be done in situ. In manned surface operations, many of the tasks will involve that which can be performed only by the astronaut, or more effectively by the astronaut than by any machine. It follows that the astronaut should receive the support that can be supplied by an Earth-based SDC organized as a part of the MCCH., Unmanned surface operations will require similar support for Earth-based scientists directing unmanned missions. Such a data center, with all the advantages permitted by its location, would be manned and equipped for the following functions:

1. Effective two-way verbal communication with the astronaut

2. Reported data reception and storage on location, physical features, materials encountered and/or tested, and relationships among elements of the terrain

3. Reported data analyses, adjustment or correction when necessary, and (upon request by the astronaut), pertinent information return to the astronaut during the course of an excursion

4. Recorded data compilation; translation into maps, diagrams, and models; and transmission of significance of results to the astronaut if and when appropriate

5. Interpretation (promptly and to sophisticated levels) of analytical data, images, and descriptions provided by the astronaut and report of these interpretations to the astronaut while he is on the mission

6. Advice and guidance provision to the astronaut when necessary, with special reference to unexpected features and to possible modifications of traverse and sampling plans

Data Sources

From post-Apollo exploration, it will be necessary to telemeter and store on Earth TV imagery and digital output from instrumentation and to transmit and store a large amount of verbal descriptive information and commentary. Data deriving from the surface activities of the astronauts will be received by (1) tracking and orientation devices mounted on surface vehicles and the LSS; (2) TV imagery from the staff and surveillance camera mounted on each LM and surface vehicle; (3) geophysical

equipment such as the magnetometer, gravimeter, and seismic instruments; and (4) verbal descriptions. With respect to samples collected and examined during the mission, data will be received from one or more spectrometers, a diffractometer, and verbal and video commentary on materials examined directly and under a petrographic microscope.

Also, transfer of the following kinds of data from Earth to the astronaut will be necessary: (1) special instructions for monitoring and operating various instruments, (2) scientific advice accompanied by sketches and cross sections, (3) requests for further observational information or comment, and (4) transmission of changes in maps and lists of information. If unmanned surface vehicles are employed, it will also be necessary to transmit commands for control of the vehicles, control of onboard instruments, and video monitoring of their movements.

During periods when the astronaut is on the lunar surface and near the LM, Earth-based scientists should be able to control the surveillance TV. At greater distances from the LM, the TV should be slaved to the navigational equipment for nominal operation, with an Earth-based manual override for horizon scanning and other viewing.

If the exploration period can be thought of as comprising field and laboratory configurations that will be alternated as the investigation requires, the process of transmitting, monitoring, and storing of the return data becomes somewhat simpler because the number of data sources that must be handled at any one time is reduced. If the mission is performed by an unmanned probe, only video and limited instrumental data return will require handling.

Concept of an Earth-Based Scientific Data Center

During a post-Apollo mission, a great body of scientific information will accumulate in relatively short periods of time. The information must be properly received, classified, stored, analyzed, and correlated if it is to be used effectively as a base for characterizing and explaining lunar surface phenomena. Such data handling is regarded as the prime function of an SDC established as a part of the MCCH and staffed by a specially qualified team of scientists, engineers, and technicians.

In effect, the role of SDC personnel during a mission is complementary to that of the astronauts. Thus, the SDC will (1) serve as field assistant and scientific advisor to the astronauts, (2) make certain that all pertinent and available information has been received, (3) be responsible for expeditious handling of all data received and for converting data into forms useful for planning traverses and studies on subsequent days during the mission.

Equipment Requirements and Organization

The SDC must provide the environment for receiving and analyzing the various forms of data and for displaying them in forms most suitable for comparison, correlation, and interpretation. Moreover, the data-reduction system must also provide for easy access to information that will be used after completion of the mission in more

refined analyses. For most kinds of information, data sets can be retrieved from telemetry in a straightforward manner and automatically reduced to a preliminary form for scientific use.

Navigation and orientation parameters from the lunar vehicles and staff must be displayed in real time on a plotting board capable of showing the activities for an entire mission. Verbal information should be recorded in real time and available for display. Instrument parameters must be monitored in real time to insure the return of valid data, but analysis of most of the data can be done off-line with the turnaround time varying according to investigator requirements and constraints on the total system.

TV imagery should be displayed as received. Owing to the volume of the data sets, some preliminary screening for electronic quality and uniqueness of coverage should be made prior to permanent data storage.

Verbal data, such as descriptions of geological features and microscopic observations, present special problems in data storage and correlation. The information is voluminous and includes the most important elements of direct geological evidence; hence, it must be gathered and stored in an orderly fashion. The data can be recorded in the following ways: (1) by magnetic tape as a continuous record of conversation, (2) by shorthand typewriter as a continuous record, and (3) by a team of people, each of whom works on an assigned data category to store the complete record.

All the methods should be employed simultaneously, but only by the third method can the data be collected into usable sets. The work could be implemented through structuring of the expected information in a manner sensitive to the most frequently recalled categories, assigning each individual to a specific data category and registering the data by pressing punchboard keys that correspond to a particular information matrix (fig. 6). The keyboard matrix would contain all probable data types for a particular category of information. Registry would occur by pressing an enter key after each topic of conversation had changed, thereby eliminating errors due to incorrect first impressions and operator carelessness. The system must also provide the flexibility for storing data not easily categorized (that is, judgments made by the astronaut and a means for correcting original information). If the English-language equivalent of the shorthand-typed record were displayed on a monitor for each preceding 2 minutes of transcription, the data recorders probably would have ample time to store all incoming information.

The SDC should include a display facility capable of showing the location of the astronaut. It should also be capable of superimposing the photogeological and topographical maps, either separately or simultaneously, on the trace of the traverse of the astronaut. Traverse information such as sample and photograph numbers, time, elevations, geological descriptions, and sample analyses should be keyed to locations so that information can be retrieved by field position as well as by category.

Auxiliary plotting devices should be available for preparing geophysical and surface-composition trend maps; in addition, they should provide for the display of all stored mappable information.

Geological cross sections and three-dimensional geological diagrams can be best displayed by CRT. Each unit should include a light-pen capability for altering and

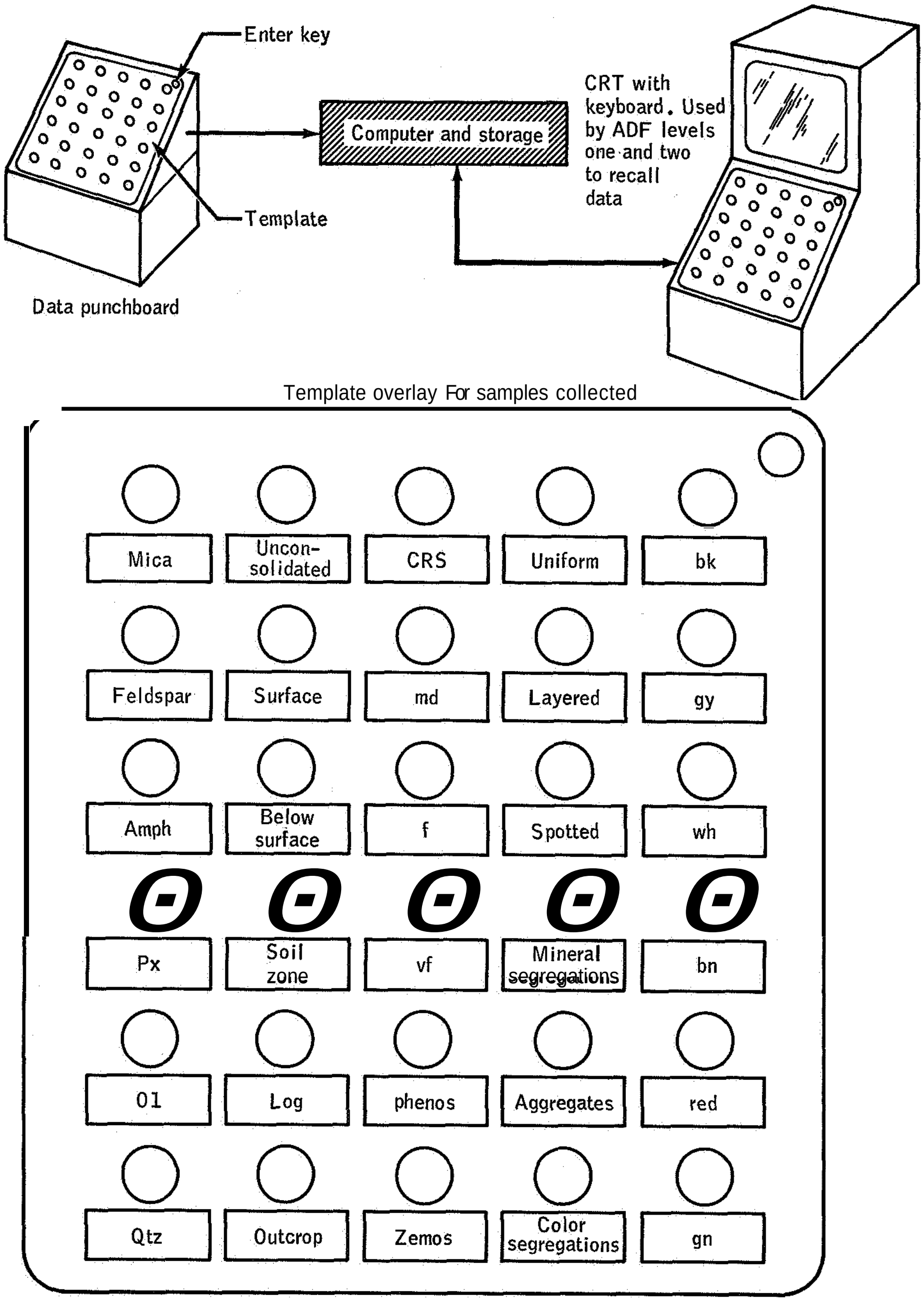


Figure 6. - Punchboard data registry.

updating the information matrix. Data sets derived from verbal descriptions also are best displayed by CRT. When coupled with a typewriter, the unit would enable the operator to recall information and to interrogate the store of verbal description.

Data Storage and Retrieval

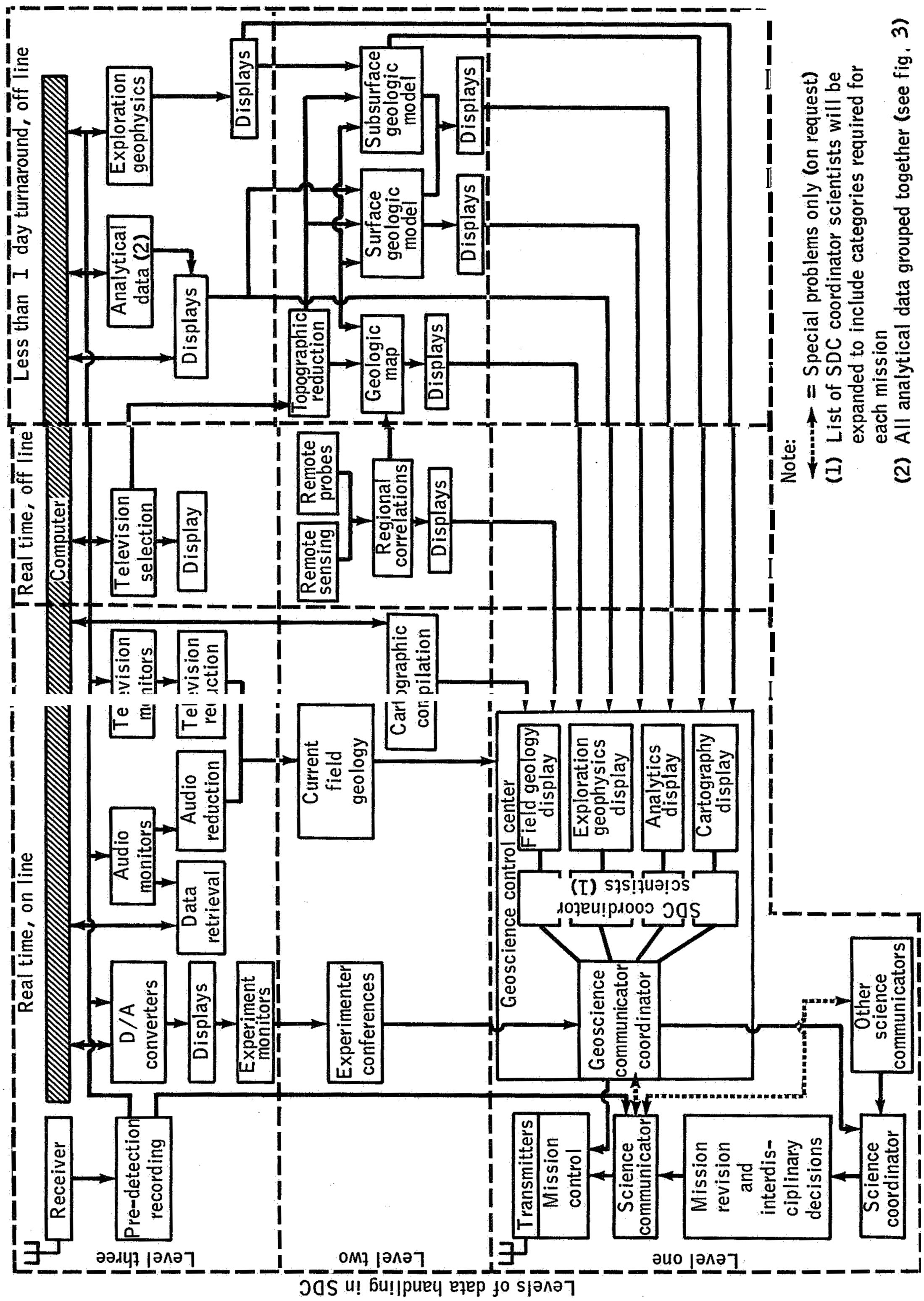
Extended missions of 1- to 2-week duration will create a serious problem of data storage. Some data, such as navigational information, must be displayed in real time and will be recalled repeatedly during the course of a mission. Other data, such as data recorded from TV imagery, will be used sparingly during the mission but extensively in postmission photogrammetric studies. For effective exploration, most of the information returned should be available for recall during the mission, and storage techniques should provide for this. The most critical storage problem is that for verbal information, which must be held for frequent and rapid recall during the entire mission and which will require either a large computer disk or tape storage facility. Refer to the paragraph entitled "Communications" for a summary of total storage requirements for field and laboratory operations. Although TV imagery requires the largest data storage volume for data, recall demands during the mission will be substantially less for TV than for verbal data. For this reason a computer tape storage system with an index of locational parameters should be effective.

Organization of Scientific Data Center Personnel

A major object of SDC is rapid analysis of data to assist the astronauts in obtaining information necessary for solving scientific problems. SDC personnel will receive data from telemetry, TV, and audio transmissions; analyze the information; and assist the astronauts in the scientific portion of the mission. Three levels of coordination within the group are necessary (fig. 7).

Level 3 personnel. - Level 3 personnel will be responsible for initially receiving, storing (if necessary), and displaying the data. Two subgroups will be required to store verbal descriptions by punchboard matrix and magnetic tape and to receive all other data. The verbal data group will consist of at least six punchboard operators, an operator for magnetic tape recording, and a shorthand machine operator. The group should be isolated from other SDC activities because of the exacting nature of the task and the need for a quiet environment.

The subgroup receiving the telemetry and TV data will be responsible for monitoring the receiving and storage equipment, that is, keeping the equipment running and changing the data flow from one device to another. For data sets that require initial massaging before scientific analysis, the first step of computer analysis will be started immediately upon completion of the transmission. For example, output from the spectrometer must be refined before any usable information can be obtained. This will consist of pushing a button to enter the data-analysis program and data into the computer when main-frame time and core storage are next available. Output from the programs will be stored and displayed to level 2 personnel upon completion of analysis.



Note: ←---→ = Special problems only (on request)
(1) List of SDC coordinator scientists will be expanded to include categories required for each mission
(2) All analytical data grouped together (see fig. 3)

Figure 7. - Flow chart for a Scientific Data Center during a lunar surface mission

Initial data analysis of this type will be necessary for all analytical instruments. Video selection, based on freedom from electronic noise and uniqueness of coverage, will also be accomplished automatically at this point.

Level 2 personnel. - Level 2 personnel will undertake much of the sophisticated or professional geoscience data analysis and will consider categories of information that can result in recommendations to an SDC coordinator-scientist. Information categories in level 2 might include cartography, analytical instruments, geophysical instruments, physical-property measurements, TV-image reduction, verbal-geological descriptions, and surveying. Within a group such as that responsible for output from analytical instruments, the following activities might be typical:

1. The diffractometer determines the major mineralogical constituents of surface samples in the initial data analysis. The following questions require answers: Do the analyses help in defining the nature of the geological units from where the samples came? Do any two units represented by several samples appear the same? Do the minerals from a particular sample represent an equilibrium assemblage?

2. The spectrometer determines several chemical compositions in the initial data analysis. The following are typical questions: If these analyses are almost identical, are the two specimens of common origin? What origin might such a chemical combination indicate? What is the nominal chemical composition of the geological units sampled? Is this sample with a significant Ni content a meteorite, or is it indigenous on the lunar surface?

The level 2 coordinator, by integrating the information from several instruments, probably would be able to answer some of the questions posed by his data team. By recalling information compiled by the teams responsible for cartography, geophysics, and physical properties, the coordinator might be able to answer still more questions; he could also pose other questions and might seek further information from the astronauts. His comments, questions, and analysis of information would be displayed and stored for the use of level 1 personnel as it becomes available.

Level 1 personnel. - Level 1 personnel will be a group of professionals coordinated by a communicator in direct radio contact with the astronauts through mission control and science control. The group will be assigned specific scientific areas of responsibility. Each member will be on-line to all stored verbal data and will receive, directly, audio and video transmission to and from the astronauts. Each member will maintain an updated compilation of data pertinent to his responsibility and will receive information and comments from level 2 analysis teams.

The tasks of level 1 geoscience personnel are to (1) help answer completely specific geological questions posed during premission planning; (2) advise the astronauts, through the geoscience communicator, on collection of critical data; (3) construct a geological history for the area under study, including the geological processes and the physicochemical regime(s) involved; and (4) compile a geological map and, if possible, prepare structure sections.

Principal Investigators and coinvestigators should work at appropriate levels within the SDC. If the subject of investigation involves a series of measurements or other well-defined activities, the PI should work with coordination levels 2 and 3. If

the activities of an experiment require that the PI analyze and interpret data before the next experimental step is performed, the PI should work with levels 1 and 2. Members of the level 1 group should be as free as possible to attend to scientific problems presented during the mission. A PI working with level 1 personnel should be a member of this coordination team.

The geoscience communicator will also act as a coordinator of level 1 geoscientists; and his work, along with that of communicators for other sciences, will clear through a science coordinator to the science communicator. Some of the comments, requests, and suggestions of the level 1 geoscientists may be too complex to relate to the astronauts through intermediate parties; hence, the science communicator should allow some flexibility in the form of direct access; The principal function of the science coordinator is to provide a level of interdisciplinary control among the geoscience communicator and his counterparts from other science areas.

An example of the activities of data-analysis personnel from levels 2 and 3 is given in figure 8 where the analytical measurements and topographic reduction boxes have been expanded to show the data flow from receiving the telemetry through preliminary analysis and display devices to a final product displayed for scientists in the geoscience control center. General operating characteristics at different levels for the data-analysis team will be as follows:

1. Level 1 data plotters should each have CRT display devices with direct or indirect keyboard access to all stored data from the computer. This group will be exclusively on conversational computer mode.

2. Level 1 plotters will be responsible to level plotters for data bits and trends and for setting up displays for correlation; they will receive information from all pertinent level 3 data sources. Level 2 will be on conversational and quick-time turnaround computer modes.

3. Level 3 will require quick-time to daylong turnaround time on the computer, depending on the specific data flow.

The training of SDC personnel is as critical as that of the astronauts in terms of the scientific objectives of the mission and the techniques to be used in attaining them. Astronaut scientists and scientists in the SDC levels 1 and 2 of communications and data analysis should have worked together in geological mission simulations for a minimum of 80 hours during the year preceding the first extended mission (14-day type). SDC personnel at all three data-analysis levels should be trained as teams individually and then together. Particular emphasis should be placed on'effective transfer of verbal information because of the great importance of this form of data in the scientific conduct of the mission. Personnel at the three levels of SDC activities should have the following characteristics:

1. Level 1 personnel should consist of mature scientists who are experts in their specific fields of responsibility and who are intimately familiar with the problems of manned lunar exploration. They should have demonstrated the ability to work effectively under mission-control conditions.

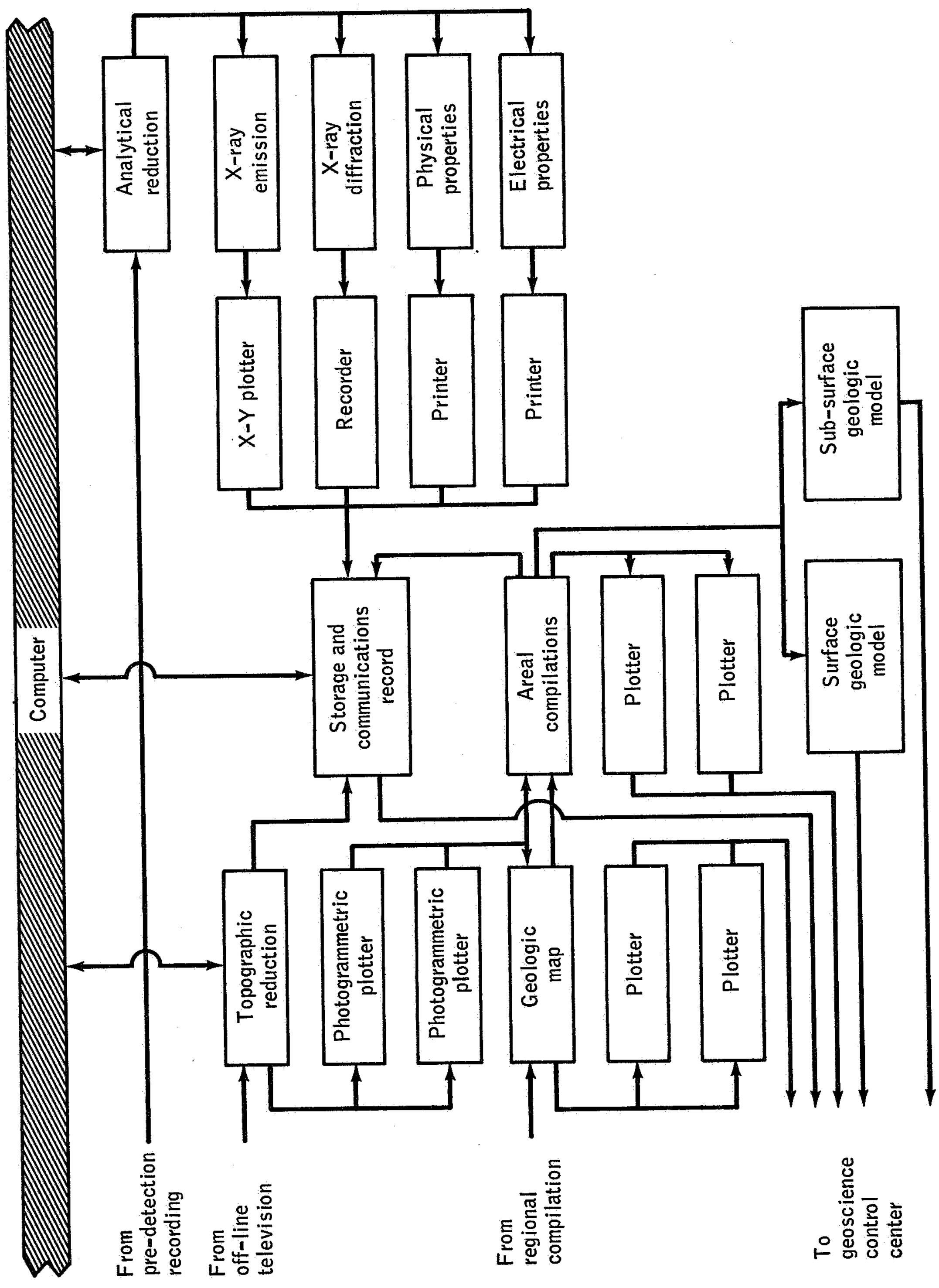


Figure 8. - Off-line analytical data flow chart.

2. Level 2 personnel should be professionally competent in their respective fields of responsibility and should have an intimate knowledge of the data systems with which they are working.

3. Level 3 personnel should be capable of monitoring incoming data, should be familiar with the electronic and telemetry system, and should be trained in recording verbal data.

Because data analysis will be a continuous activity during the mission, it will be necessary to train backup teams for each level of personnel. As an aid to spontaneous problem solving and to minor changes in the data-analysis system, a group of computer programers should be available to personnel of levels 2 and 3 during each mission.,

Computer Requirements

The SDC must provide the Earth-based, rapid data analysis for effective use of the astronaut's time during the course of a scientific mission. To accomplish this, a computer facility is an essential part of the SDC equipment. The facility must be capable of multiphase operation and must receive, monitor, and store incoming information in a retrievable fashion. The SDC must monitor and control on-line real-time and off-line display devices (such as plotting boards and CRT displays with light-pen and typewriter attachments) in the scientific control room and peripheral facilities. The facility must also provide enough core and auxiliary storage for manipulating large data sets in conversational and batch-processing modes and must also be capable of handling a large number of these operations simultaneously.

Principal investigators on specific phases of each mission should be located near the SDC facility, but they may or may not be a part of the integrated SDC teams. Each PI will require computer-driven display devices which will vary with the nature of the experiment and will probably require some computational facilities, at least in the quick-time turnaround mode.

Some data sets, stored in the computer before the actual mission, must be available during the mission for use with all incoming data. Examples of such are the photogeological and topographical maps from Orbiter photography of the landing area and critical data characterizing the models of terrestrial geological processes and lunar analogs. One of the approaches to remote exploration will be to list the minimum information necessary to define uniquely a geological feature or process. Return data will be compared with the models of Earth geology and a statistical fit obtained if necessary. The model will then serve as a guide to determine the amount of data collected before considering another problem.

Several of the analytical instruments might share the use of a lunar-based compact computing device like that now in use for orbital and rendezvous calculations. The equipment can be specialized for different types of computational problems by inserting an appropriate punched- or printed-circuit board. The device can be updated by telemetry from the main Earth-based computer facility and can reduce the telemetry load to some extent. The principal use of the device would probably be in monitoring equipment and in troubleshooting electronic circuitry.

Recommendations for Scientific Mission Support

Emphasis has been placed throughout this report on the need for highly competent, Earth-based scientific support during the course of a lunar mission. If, in the words of J. Hoover Mackin: "the highest and best use of astronauts — the only use that is defensible — is to observe, develop hypotheses, analyze them on the spot, and intelligently seek out the diagnostic evidence needed to test them," it follows that these key people must have all possible assistance in accomplishing such a task under extremely difficult conditions. Not only should they be spared from all but the absolutely unavoidable mechanical elements of observation, recording, and data handling; but they should also be provided, whenever the need arises, with prompt return from the data they transmit. Perhaps of most importance, they should have immediate advice and guidance available to them if and when they encounter the unexpected.

To best serve these purposes and to most effectively handle data transmitted between Earth and the Moon, an SDC should be established as a part of the MCCH. The SDC should be staffed by a specially qualified team of scientists, engineers, and technicians organized at three contrasting levels of operation. The equipment and functions of the SDC have been outlined in some detail on the foregoing pages, and a schematic flow chart for computerized operations during the surface portion of a lunar mission has been included as a start toward planning of SDC activities within the context of the MCCH organization.

For the vital role of scientific ground support, the SDC team should include experts in pertinent media of communication and scientists and engineers unusually competent in the fields of geology, geophysics, geochemistry, biology, topographical and photogrammetrical mapping, and computer science. Adequate backup personnel should be provided. Some members of the team should have had longtime experience with the space program, and all members should have had full-time experience with the program for at least 1 year before the initial mission.

No member of the team is likely to need special training in his own field, but he will require intensive training in the application of his knowledge and abilities to the proper functioning of an Earth-based support facility. Much of this can be accomplished only through repeated tests under conditions closely simulating those of an actual mission; and as often as possible, the tests should involve communications with astronauts scheduled for the earliest missions. If the astronauts' time away from Earth is to be spent wisely for returning a maximum of useful scientific information, appropriate training of Earth-based supporting personnel should begin immediately.

The following specific conclusions and recommendations are based largely upon field tests of procedures and equipment under conditions simulating those of a lunar mission:

1. Geological and topographical maps constructed from photographs should be stored in the computer for recall during the mission. Planning for SDC activities should reflect an awareness that the constructed map may be radically altered during the mission, and the map will be the base upon which virtually all mission data are plotted. A preliminary estimate for the compilation map scale is 1:25,000.

2. Remote note recording and map compilation are vital and require training for the astronaut and SDC personnel. The formal: for the descriptive data at the initiating and compiling ends of the transmission must be developed.

3. The development of devices for the automatic plotting of navigational information is strongly recommended.

4. Analysis of magnetic, gravity, and seismic data should be as automated as possible, and a telemetry capability and computer routines should be developed.

5. The development of computer programs for diffractometer, spectrometer, and microscope analyses and appropriate display systems are required.

6. An LM facsimile copy device to receive Earth-generated data is desirable and the feasibility of such a system should be explored.

7. A data-compilation facility with complete telemetry, computer, and plotting devices for testing and simulation should be developed as soon as possible. The success of display devices in the field-test facility consisting of TV monitors, manual data plotting boards, and several types of instrument recorders suggests the use of computer-driven plotting boards, a CRT display with light-pen or keyboard attachments, TV monitors, and a few special display devices.

POSTMISSION ANALYSIS

Each AAP mission will have specific scientific objectives which are closely integrated in three major stages of the mission. The first stage will include photogeological mapping of alternative landing sites and advance analysis of the problems peculiar to each site. The second and central stage will be the astronaut's studies on the lunar surface. Postmission analysis, the third stage, should maximize the scientific accomplishments of each mission by assuring thorough study by competent investigators of every facet of the returned data. Exactly how this is to be accomplished cannot be stated at this time because the type and amount of data that will be obtained in AAP missions is not known, the different objectives of the several missions will call for different analytic procedures, and all postmission operations (including treatment of samples) will evolve on the basis of experience gained in Apollo and prior AAP missions. The recommendations in this report, therefore, deal chiefly with matters of principle and are stated in general terms.

It is recommended that one or two of the astronauts on each mission be charged with the primary responsibility for surface scientific studies during the mission. The astronaut(s) should be involved in the preflight formulation of the scientific objectives of the mission and should thus be familiar with the geologists who performed the photogeology of the site and the Principal Investigators concerned with specific experiments. In addition to the astronauts, personnel of the SDC, the Lunar Sample Preliminary Examination Team, and other scientists should monitor the operations of the astronaut on the site and should thus be prepared for the first basic step in postmission

analysis, that is, the debriefing of the astronauts. The efficiency of the debriefing process will be increased and there will be timesaving by all involved if some of the sessions are devoted entirely to scientific, as contrasted with technological, matters.

One major function of the monitoring and debriefing is to develop a map of the site showing such modifications of the photogeology as may be required, lines of traverse, and the locations of geological features, photographs, and samples. The map and a text detailing the observations and interpretations of the astronaut, based on the debriefing and including the results of preliminary examination of the samples, are intended primarily to provide the Principal Investigators with the geological field relations and all other significant information about the samples to be studied by the Principal Investigators.

The documents need not be in final form until a week or so after the close of the quarantine period, estimated at about 30 days for Apollo samples, but the map and text will begin to take form during the monitoring and will continue to develop throughout the quarantine period., The compilation of the map and text should be the responsibility of one man, or a team of two men who will synthesize information into the map of various kinds as it becomes available and who will be prepared at any time to assist the public-relations staff in preparing up-to-date press releases.

Preliminary examination of the samples to obtain the data mentioned previously is the responsibility of the Lunar Sample Preliminary Examination Team. During the quarantine period, most operations, including all that are time-dependent, and various types of photometric studies will necessarily be performed within the biological barrier and subject to the restraints imposed by the barrier; the appropriate Principal Investigators should be involved in this work. It is anticipated that certain specimens of special interest will be sterilized and withdrawn from quarantine for petrographical and other preliminary studies essential to planning the lunar sample analysis program.

It is recommended that 1 to 2 months after the samples are distributed, preliminary reports by all the Principal Investigators be published as a group in a journal, or be published directly by NASA. This implies that there be no earlier publication of what would almost certainly be bits and pieces of data, out of context, by individual Principal Investigators or others in the Lunar Receiving Laboratory (LRL) Working Group without authorization by NASA. A meeting of the Principal Investigators prior to preparation of the preliminary reports would be useful but not essential, since work pressures will be severe during this period. Interchange of ideas and data will be chiefly between Principal Investigators working on closely related problems, and this can be effected in most cases by phone conferences with a saving of energy and travel-time if those involved are far apart geographically.

It is recommended that about 1 year after sample distribution, a symposium be devoted to advanced and final reports of the Principal Investigators, for each mission. The reports and extracts of the discussion, if published in a single volume or set of volumes, would provide a unified record of the mission. In any case, publication of articles in scientific journals before and after the symposium should be encouraged. Of particular concern are several closely related matters in the followup stage of each mission study.

1. The investigations should be continued with generous support after publication of the preliminary results and well down along the slope of diminishing returns on the investment. The point is that this investment (that is, the cost of thorough analysis of the returned data) is an exceedingly small fraction of the cost of obtaining the data. Therefore, economies in this stage of the investigation do not make sense. Or to rephrase the same thought, it is not reasonable to spend hundreds of millions of dollars on a mission to get additional data while the data obtained in earlier missions remain unanalyzed or without adequate analysis for lack of hundreds of thousands of dollars.

2. Published reports do not and should not include a full statement of all of the steps in an investigation; for example, a record of exploration of what appear to be blind alleys and data on side issues which do not bear directly on the conclusions. But this unpublished data, generated by the Principal Investigators in a study of lunar Samples, may be irreplaceable and may be of critical importance to later investigators. It is therefore recommended that a record of laboratory procedures and raw data, as complete as practicable, be preserved in a NASA depository.

3. Every practicable measure should be taken to draw on the competence of the scientific community outside of NASA employees, contractors, grantees, and consultants. This is essential to take advantage of that competence and to broaden the overall base of support in the scientific community for lunar and planetary studies. An antidote is needed for the impression that scientific investigations in these fields are limited to a privileged few and that outsiders could not hope to compete with those who are familiar with the vast and bourgeoning mass of data bearing on a given problem. One antidote suggested would be an invitation in the introduction to the group of preliminary reports to qualified investigators interested in extensions of problems discussed in the reports or in other problems suggested by them to apply to NASA for information about the availability of samples, data, and support needed for independent studies. The policy of encouraging outstanding individuals in special fields where work is needed to submit proposals should be continued,

4. It is understood that the planning of each mission will take into account the results of earlier missions. This feedback is so important that methods should be developed to assure its maximum efficiency. For example, continuity is provided by using the same PI on a number of missions; if this advantage is outweighed by the need for bringing new blood into the program, key persons from earlier missions will be needed as consultants in the planning process.

RESEARCH AND TRAINING

To insure the development of an orderly and scientifically sound lunar exploration program, a broad research program is required covering the many facets of geological exploration. This includes research into the experimental techniques to be used during such exploration and study of the equipment, supporting systems, and data requirements which the experiments bring about. Also, continued broad mission planning should be carried out to facilitate the integration of recommended techniques and experiments into an overall exploration program.

The research programs should commence 3 or more years before the flight program which it is anticipated could support a certain type of experimentation and should continue at some level throughout the lifetime of the program. For advanced exploration concepts (those concepts requiring sophisticated supporting equipment), a head-start of 5 or more years may be necessary to fully develop a concept and prove its operational compatibility with a proposed exploration phase.

Research

Several specific areas of needed research can now be identified. As the lunar exploration program continues, other critical areas will be added to those listed.

Instrumentation. - The basic instruments of field geology have undergone, and will continue to undergo, significant modifications for the lunar program. Nonstandard instruments, those which are not normally associated with fieldwork on Earth, must continue to be studied to insure that timesaving and unique measurement equipment is available in the inventory from which the astronaut can choose if he so desires; in particular, instrumentation which will permit rapid, gross analysis of lunar rocks, surveying equipment, and engineering-properties experiments specially designed for the lunar condition should be studied. Other instrumentation which requires further development are sensors of various kinds to be used in lunar orbit. These sensors will aid in analysis of the properties of the lunar surface and subsurface. Requirements for this type of instrumentation have already been proposed (NASA SP-88) and undoubtedly will be refined after the first Apollo landing.

Field methods and procedures. - The selection and development of field methods and procedures uniquely suited to lunar exploration requires a continuing and vigorous research program. The methods and procedures adopted will depend in part upon the new (previously mentioned) equipment developed. Field methods should be devised, reviewed, and tested by experienced field geologists. Early in their development the methods should be inserted into the astronaut training program to insure that time is available for suitable modification and practice. An important method for developing field procedures will be simulations of varying reality culminating with detailed mission simulations prior to the actual mission. Many scientific disciplines will be competing for astronaut time. It is recommended that other lunar surface scientific operations involving astronaut participation be coordinated with the geoscience simulations since, for most missions, the geosciences will be the largest user of astronaut time.

Mission planning for science. - The selection of field procedures and the development of a detailed plan for each mission must proceed simultaneously. Mission planning requires the repetitive fitting of the various pieces of the mission as they are developed and as they become better refined. Constraints which appear, or seem likely to appear during such planning, must be made known as soon as possible to those groups or individuals who are contributing to the scientific operations. Good mission planning for the scientific activities which will be carried out on the Moon requires continual system inputs (that is, operational characteristics of selected mobility devices, PLSS characteristics, and LM characteristics) and the latest information on potential landing sites such as updated geological maps and trafficability characteristics.

Data handling. - The ultimate success of the lunar scientific program will be measured by the amount and quality of information returned. Astronaut observations, transmitted in real time and black-box telemetry, should be analyzed during the mission and postmission. The goal of immediate data reduction is the development of the capability to supply such real-time mission advice as appears necessary for successful mission accomplishment. Although contingency plans should be developed for the scientific activities and for the normal flight activities, the greatest return will be gained from allowing the astronaut freedom of choice in scientific investigation as the mission proceeds. To aid him in making intelligent choices, he should be assisted in reducing the data coming back from the mission since much of it will be collected in a form which would be impractical to reduce on the lunar surface. Continued study of the types and amounts of data which will be of use to him during the mission and an overall study of all of the anticipated data requirements is needed.

Terrestrial analog studies. - The investigations which NASA is currently supporting, the field study of impact and volcanic structures and processes, are essential for mission planning and postmission analysis. It is recommended that a vigorous program be pursued in this area in the future and that added emphasis be placed on the contributions that the studies can make to mission planning in addition to the traditional scientific knowledge that is developed.

Training

Though often said, it needs repeating: The maximum scientific results from placing a man on the Moon require the fullest possible use of his knowledge and scientific judgment. Discrimination in deciding what to sample, the best place to set up a scientific instrument, the recognition of what to describe and photograph in order to document either an expected or unexpected time-space relationship are beyond the capabilities of the most sophisticated instrument. Furthermore, intelligent placing and monitoring (or programing) may increase the scientific return of an instrument by several magnitudes. Highest of all in scientific value is the ability of the astronaut to recognize and analyze the unexpected and then to formulate tests and additional observations that place on record a new and unforeseen contribution to knowledge. If these points are granted, two corollaries are obvious:

1. Astronauts must be freed from all but absolutely essential tasks while on the lunar surface.

2. Astronauts must have sufficient training to recognize significant geological, geophysical, and geotechnical relationships, report what they observe, seek additional evidence, and reach logical conclusions within the operational constraints of a given mission.

Present Training Program

The United States Geological Survey (USGS) and the Manned Spacecraft Center (MSC) conduct courses in geological training for the astronauts. These courses have consisted of 12 field trips of 3- to 7-day duration. Approximately 112 hours of classroom lectures have been divided between the principles of geology and elementary

mineralogy-petrology. The course work has emphasized, but not been limited to, volcanic and impact geology and exploration geophysics.

The training program was not started until 1964; and, with one or two exceptions, only the last three groups of astronauts have completed a large part of it. Of these, because of other assignments — particularly because of being selected on the early missions — about 25 astronauts have essentially completed the classroom and fieldwork. Although the astronauts are apt and intelligent students, more time must be found for additional training.

A review of past training practices in the astronaut scientific training program and of the future requirements for progressively increasing the scientific capability of all astronauts indicates that considerable reorientation of training practices is required. The training program should insure that crew training after selection for a specific mission can concentrate on the conduct of specific experiments and investigations rather than on instruction in the fundamentals of the scientific discipline represented by the experiment.

Also, major new science training requirements have been imposed by lunar- and Earth-orbital programs. The major reason for the inclusion of one or more trained observers as crewmen on orbital missions is the need for the human eye as a scanning and data-selection system. It appears safe to assume at this point in time that there will continue to be limitations on the quantity of high-resolution remote-sensing data that can be obtained by electronic sensors during an Earth-resources mission and on the amount of the data that can be usefully analyzed.

Future Classroom Training

The importance and cost of space exploration and experimentation make it imperative that astronauts receive the best possible classroom instruction. This fact, plus the difficulty in maintaining continuous classroom attendance at MSC because of the temptation to pursue other duties, suggests that classroom training should be on a field trip or tutorial basis whenever possible. Several days of continuous instruction in a particular field or fields should be conducted by people at institutions and Government installations whose particular competence for instruction in this field or fields is widely recognized. This approach would increase the efficiency and quality of instruction. Future classroom instruction should also recognize and capitalize on the high level of basic science and technical competence that is characteristic of astronaut trainees. This is particularly true in the physical sciences where the mathematical, physical, chemical, and geometrical foundations of the sciences should be emphasized rather than the nuances of nomenclature and classification.

Classroom training should be divided into three general curricula; a general science curriculum, a lunar and planetary surface curriculum, and a planetary orbit curriculum. All astronauts would participate in the general science curriculum which should contain introductory, space-oriented courses in geology, geophysics, astronomy, planetology, particles and fields, biology, and meteorology. A more specialized lunar and planetary curriculum should be directed toward astronauts slated for selection

for lunar and planetary surface missions and experiments. Likewise, the planetary orbit curriculum should be oriented toward astronauts slated for orbital and flyby missions.

Future Field Training

Astronaut field training should consist of two phases: (1) an introduction to field geological, geophysical, and biological principles and methods and (2) a course in advanced surface exploration methods. Although field training is primarily in support of the lunar and planetary classroom curriculum, the first phase should be included as a necessary part of the orbital curriculum.

The introductory phase of the field training should be organized along the lines of the current field training program, but should last for only three or four field trips, The second phase of the field training should aim toward developing a systematic method of attacking a new field problem much the same as developing a systematic method of attacking an unfamiliar approach to an airfield. As this phase of training progresses, the general methods of sampling, photography, and verbal description which will be common to all lunar and planetary exploration should be utilized.

Proficiency Training

An area of major importance in astronaut science training is the maintenance and advancement of scientific proficiency by astronauts of piloting and scientific backgrounds subsequent to their basic training and prior to their selection for a mission. As currently authorized, but little realized in practice, astronauts with geoscience backgrounds should spend at least 30 percent of their time in field-oriented research. This, plus their involvement in development and planning for lunar exploration, should insure their scientific progress.

The problem of advancing the proficiency of astronauts without geoscience backgrounds has no clear solution when examined in the light of their other duties and in the light of training requirements. Our recommendation is to establish a faculty of astronaut science advisors. Each advisor would be responsible for the proficiency training of one or two astronauts in the particular discipline of the advisor. Also, each advisor would spend about 50 percent of his time in scientific research, at least part of which should be integrated with the proficiency training of the astronaut. Although much of their time will be spent on research, these men must schedule their activities so that they will be available for spur-of-the-moment training activities, depending on the changing schedule of each astronaut. In the case of the geosciences, the advisors could compose at least part of the instructor core in the basic field training. *Also,* the advisors should participate actively in lunar mission development programs such as those of the USGS.

Upon the assignment of the astronaut advisee to a lunar mission area, the advisor would become an integral part of the experimenter and science support team at the MCCH. The experience of the advisor with the abilities of the crewmen, their techniques, and training will make the advisor invaluable in the premission training and simulations and in the conduct of the actual mission. The use of the crewman-advisor

team during discipline-oriented experiments should increase the scientific return of the experiments.

Mission Training

Mission-oriented training will have to be designed to fit the particular needs of given missions, However, it is essential that science training take an increasingly greater role in crew training. Of particular importance is an intensive program of simulation and rehearsal of activities scheduled during the mission and the review and planning of communication with personnel selected to occupy the SDC during the mission.

It is understood that training in those areas for which Principal Investigators for the flight experiments have been selected will be organized in conjunction with these experimenters. Training related to the more general conduct of lunar sampling should be organized in conjunction with the Principal Investigators for the analysis of returned lunar samples and with the Principal Investigators for the lunar geological, geophysical, and biological experiments.

Crew Selection

Finally, flight operations ability is the primary criterion of selection for a specific mission. It is strongly recommended that ability in field geology be the next most important factor in the selection of the astronauts who will actually land on the Moon. Certain of the more complicated geological missions planned for the later part of the AAP program urgently need the experience of an astronaut who is also a professional geologist.

CONCLUSIONS AND RECOMMENDATIONS

The exploration plan and its requirements in instruments, supporting systems, Earth-based facilities, research, and training discussed in the foregoing section clearly indicate the need for careful planning and coordination of the scientific elements of the lunar exploration program. The scientific elements, in turn, must be planned and carried out in careful coordination with the engineering elements and with complete awareness of the capabilities and limitations of the diverse components of the evolutionary engineering systems.

The following sections summarize the principal recommendations related to planning and to research and development activities discussed more fully in earlier sections of this report.

Instrument Systems

It is recommended that development continue or begin as indicated here on the following systems and instruments.

Field instruments. - The following field instruments are recommended.

1. Lunar surveying system (LSS). Development of the LSS should continue on the engineering model as rapidly as possible in view of the LSS being one of the most versatile of all the geological instruments. Components of the LSS should also be studied for their application to other systems. The surveillance TV camera and an uplink Earth control for the camera should receive more attention than in the past. Detailed feasibility studies leading directly to hardware development as appropriate should be started on modular components for the base of the staff.

2. LFU navigation system. Studies should begin immediately on the types of navigation systems required for the small and intermediate lunar flying units. The accuracy requirements can generally be stated as "the more accurate the better." Trade-off studies between what is desired and what is realistic must begin at once.

3. LSSM navigation system. The LSSM also requires a navigation system. Again the accuracy requirements can be stated as the more accurate the better. Studies on the navigation system and its ultimate requirements must begin at once. In addition, interface studies between the navigation system and the LSS tracker must begin.

4. Electromechanical line tracer. An electromechanical line tracer is necessary because all data should be compiled and analyzed on Earth, and, where feasible during the mission, the astronaut should have the capability of sketching geometric information, especially when interpretive in nature, and of having the sketch transmitted to Earth rather than to have the cumbersome task of attempting to verbally describe geometric data. This will especially enhance the basic mapping capability provided by the LSS and navigation system. It is recommended that an engineering model of the electromechanical line tracer be developed as soon as possible.

5. Orbiter geological photomaps. The photomaps are essential to planning and conducting successful geological missions. Because of the time involved in preparing the maps (that is, producing geological photomaps of the highest quality), it is essential that the USGS lunar mapping program be strongly supported. It is also essential that a much stronger effort toward lunar mapping be applied by other institutions, especially universities.

6. Electromechanical scanner. The electromechanical scanner would be invaluable for providing highly accurate and detailed base maps upon which to place data from the detailed observations of the astronaut in the vicinity of the LSSM. Development should be started on a device of this type for inclusion on the LSSM.

7. Stereometric film camera. Unless the stereometric film camera is developed and used in lunar missions, one of the largest gaps in knowledge about the sites investigated by the astronaut will be in the features whose sizes range between those seen on

the returned samples and those at the limit of resolution of the Orbiter photographs. It is recommended that development begin immediately and that the camera be flown (in place of the Hasselblad) on the earliest possible missions.

8. Stick camera. The stick camera would be a useful adjunct to the stereometric camera and it would provide much information on fragile textural features which will be destroyed on samples returned to Earth. It is recommended that development of this camera begin as soon as possible.

9. Apollo lunar handtools. Testing and development of the Apollo lunar handtools must continue. Testing on a wide variety of materials and test beds must be developed which most nearly fit current lunar models. The tools and the models must be kept current with the most up-to-date information and technology.

10. Drills. It is important that studies of potential mission sites be conducted with the drill in mind; that is, is it needed, where is it needed, and what are the requirements for its need? In the meantime, development of prototype drills which are as automated as present technology permits should be continued. This recommendation is based on the past consideration of what is required for lunar exploration and on terrestrial experience that advises that many fundamental problems can be explored only by drilling.

Analytical instruments. - The following analytical instruments are recommended.

1. Chemical analysis. It is recommended that development continue on a spectrometer for chemical analysis which will give unambiguous information concerning the major rock-forming elements. The goal is not simply to tell granite from basalt, but to be able to quantitatively distinguish the differences in the elemental composition of the rocks. The instrument should be considered for use on the manned and unmanned LSSM outside the LM, and inside the shelter.

2. Mineral analysis. The X-ray diffractometer developed for Surveyor should be modified for use in mineral analysis on manned missions. The present instrument works well, and negligible development remains. The instrument should be considered for the LSSM in the unmanned mode and for the shelter.

3. Textural analysis. The microscope is a time-proven necessity for textural analysis in geological investigation. It is recommended that further study be given to its potential use in the LM shelter, especially to the value of adapting a TV camera for transmission of the microscope image to Earth. Design of the microscope for lunar exploration should await development of sample-preparation devices.

4. Combined and new devices. Other instruments should be studied which might have specific application for specific missions, or that might better serve the function of the previously discussed instruments. The possibility of combining the X-ray diffractometer with an X-ray spectrometer should be thoroughly investigated.

5. Sample-preparation devices. Automated sample-preparation devices must be developed for the instruments discussed previously. No serious effort has been made to develop a miniature device to automatically prepare small, usable (not necessarily commercial quality) thin sections. The practicability of the instruments for

their use on the lunar surface is governed to a large extent by the practical aspects of sample preparation. A program to develop the devices must begin immediately.

Geophysical instruments. - Geophysical studies at the scale of geological investigations should be made on the Moon as a part of the geological investigations. The following instruments should be investigated, developed, or development continued:

1. Active seismic devices which will allow the astronauts to quickly and easily deploy geophone arrays from the LSSM or LFU

2. An LSSM-mounted gravimeter that will allow gravity profiling without dismounting from the vehicle

3. If remnant magnetic fields are present on the Moon, an LSSM-mounted magnetometer which will continuously record a magnetic profile while the vehicle is in motion

Geotechnical Support

The following functions should be established to give geotechnical support to the program.

1. A coordinated program in lunar soil and rock engineering should be initiated and developed, including the establishment of a fully equipped in-house soil and rock mechanics laboratory. The primary function of this laboratory should be to attack the long- and short-range problems related to all lunar missions. Long-term support should be provided to two or three universities or other research agencies for basic research on lunar soil and rock properties, for development of new methods for solution of lunar surface materials problems, for assistance in the definition and solution of unforeseen but inevitable problems, and for training students for positions in the space program.

2. Increased resolution of orbital photography (of the order of 20 cm) is needed for identification of surface features important in assessment of area trafficability.

3. Samples and sampling methods should be developed for obtaining disturbed and undisturbed samples of unconsolidated lunar soils.

4. Simple penetrometers for probing unconsolidated surface materials should be developed from which semiquantitative physical property data can be derived. The possibility of adapting the LSS for this purpose should not be overlooked.

5. Instrumentation should be provided for use on the LM, LM shelter, LSSM, lunar roving vehicles, and lunar drills so that their physical interaction with the lunar surface can be determined.

6. Apparatus and procedures for use at the LM site should be developed that will permit quantitative evaluation of engineering properties of lunar soils and rocks.

Unmanned Systems

The following unmanned systems are recommended.

Roving vehicles. - There are at least three functions for an unmanned roving vehicle:

1. Supporting role in manned lunar exploration

2. Unmanned lunar exploration

3. Planetary exploration

It is recommended that one system be developed to meet the needs of all three programs. Unmanned roving vehicles should be employed in the following basic roles:

1. Reconnaisance in advance of manned landings

2. Long traverses (up to 1000 miles) for exploration of remote areas inaccessible to the astronauts and to provide continuity of geological data between manned landing sites

3. Support mission in conjunction with manned missions

4. Emplacement of a widely spaced instrument network on the Moon, chiefly for geophysical data

It is, therefore, recommended that an unmanned roving vehicle, capable of Earth launch by Atlas-Centaur or Titan IIIC and capable of transport in dual-launch AAP missions, be designed and developed as soon as possible and that this vehicle be closely integrated with the manned AAP program as soon as available. The vehicle should have the following capabilities and systems, in order of priority:

1. An imaging system

2. A communications-to-Earth system

3. Instrument packages for physical, chemical, and mineralogical analyses

4. A range of 1000 miles

5. A traversing lifetime of 6 to 12 months

6. Geophysical instrument packages and the capability of automatic deployment

The roving vehicles should be available for launch in the ratio of at least 1 to 1 and preferably 2 to 1 with respect to the manned missions.

Instrumentation and systems. - The most effective use for the roving vehicle is the acquisition and analysis of lunar samples. The following samples for analytical surveying should be included and ordered according to priority:

1. An imaging system consisting of a high-resolution stereo TV with polarizing and color filters .

2. A system for obtaining samples (claw and scoop) and storing them, a chipping facility, and a storing and labeling facility (An automated 3-meter drill would be of value if it can be developed in time, but it is of low priority.)

3. A sample analysis system consisting of

   a. Mineralogical X-ray diffractometer (first priority)

   b. Bulk-chemical X-ray spectrometer of α back-scattering (second priority)

4. A gas-analysis gas chromatograph

5. A radioisotope, γ-ray spectrometer

6. A bulk-density γ-γ back-scattering device

7. Geophysical systems; passive seismic and an active seismic system, a magnetometer, and a gravimeter as required by the geophysicists

Hard- and soft-landed stationary probes. - Because of their lack of mobility and limited target accuracy, the probes are considered to have low priority in geological exploration. Their utility in deploying a grid net of geophysical instrument packages is in the domain of the geophysicists, but the data obtained would certainly be of value in geological interpretation.

Orbital systems. - Orbital systems would encompass the following considerations:

1. The present ULO program should be revised to include the following experiments:

   a. High-resolution photographic coverage of the proposed Apollo and AAP sites which have not been covered in previous missions (Davy Rille, Sabine and Ritter, Posidonius, and the unmanned traverses) is imperative.

   b. An IR radiometry package on the existing spacecraft (5μ to 300μ) for lunar nighttime coverage of the Moon (thermal anomalies: (1) thermal properties and (2) internal heat flow from permanently shaded areas) is desirable.

   c. Zero-phase-angle photoelectric, photometry of the Moon at 100-meter resolution is highly desirable, if feasible, with filters. It would be relatively simple to use filters (corresponding roughly to U, B, and V) to provide additional information at relatively low cost.

   d. A microwave emission package on present ULO spacecraft is feasible.

2. Strong support must be given for fundamental laboratory, theoretical, and field studies on multispectral UV, visible, and IR before proposing a space-flight program incorporating them.

3. The feasibility of adapting the present ULO system with the modifications proposed for the program for transport to lunar orbit in the CSM during the AAP missions should be investigated.

4. The feasibility of using the CSM for active radar and return film photographic missions should be investigated.

Scientific Mission Support

Astronauts must have all possible assistance in accomplishing their tasks in surface investigations under extremely difficult conditions. They should be spared from all but the absolutely unavoidable mechanical elements of observation, recording, and data handling; and they should also be provided, whenever the need arises, with prompt return from the data they transmit. Perhaps of most importance, the astronauts should have immediate advice and guidance available to them if and when they encounter the unexpected.

An SDC should be established as a part of the MCCH. It should be staffed by a specially qualified team of scientists, engineers, and technicians organized at three levels of operation. Equipment and functions of the SDC have been previously outlined in this report in some detail, and a schematic flow chart for computerized operations during the surface portion of a lunar mission has been included as a start toward planning of SDC activities within the context of the MCCH organization.

For the vital role of scientific ground support, the SDC team should include experts in pertinent media of communication and with scientists and engineers unusually competent in the fields of geology, geophysics, geochemistry, biology, topographic and photogrammetric mapping, and computer science.

The SDC team will require intensive training in the application of its knowledge and abilities to the proper functioning of an Earth-based support facility. Much of this can be accomplished only through repeated tests under conditions closely simulating those of an actual mission, and as often as possible the tests should involve communications with astronauts scheduled for the initial missions. Appropriate training of Earth-based supporting personnel should begin immediately.

The following specific conclusions and recommendations are based upon field tests of procedures and equipment under conditions simulating those of a lunar mission:

1. Geological and topographical maps constructed from photographs should be stored in the computer for recall during the mission. Planning for SDC activities should reflect an awareness that the map may be radically altered during the mission. A preliminary estimate for the compilation map scale is 1:25,000.

2. Formats for remote note recording and map compilation at both the initiating and compiling ends of transmission must be developed.

3. The development of devices for automatic plotting of navigational information is strongly recommended.

4. Computer routines for geophysical data must be developed.

5. Development of computer programs for diffractometer, spectrometer, and microscope analyses and appropriate display systems are required.

6. An LM facsimile copy device to receive Earth-generated data is desirable, and the feasibility of such a system should be explored.

7. A data compilation facility with complete telemetry, computer, and plotting devices for testing and simulation should be developed as soon as possible.

Postmission Analysis

The following considerations for postmission analysis are recommended:

1. On the basis of monitoring during the mission, a site map should be developed showing such modification of the photogeology as may be required and showing lines of traverses, and location of the Apollo lunar surface experiments package (ALSEP), geologic features, samples, and photographs.

2. Debriefing of the astronauts on scientific aspects of the mission should be directed by scientists directly concerned with experiments on the mission. The debriefing should in effect fill out the site map with all available data relevant to interpretation of scientific relations at the site.

3. Preliminary reports should be prepared about 1 month after sample distribution for publication in a single issue of a journal or by NASA, and a symposium consisting of advanced or final reports should be published about 1 year later. The papers are to be published together as a unified record of the mission.

4. Thorough studies of the data should be supported as long as such study is useful.

5. Preservation of the astronaut field notes, a record of laboratory procedures, unpublished data, and available sample materials should be placed in a NASA depository for use by later investigators.

6. Every effort should be made to bring competent investigators, not now involved, into the lunar study program.

7. All aspects of data analyses should be accomplished as rapidly as practicable to assure that information obtained in each mission be used in planning the next mission.

Research and Training

Recommended research and training considerations would include the following:

Instruments. - The development of time-saving instruments with unique capabilities for use in the lunar environment should be continued. Examples of such instruments are tracking and surveillance systems, sensors of various kinds to be used in lunar orbit or on automated surface vehicles, and instruments that can obtain rapid gross analyses or diagnostic physical properties of rocks and unconsolidated materials.

Field methods and procedures. - A vigorous research program on selection, development, and simulation of field procedures particularly suited to lunar exploration is essential, Since all scientific disciplines are competing for astronaut time, the studies must evaluate methods of integrating the diverse needs into a time-saving package.

Data handling. - Study is needed of the kinds and amounts of data that can be compiled within the SDC for immediate use by the astronaut during the mission and for its intrinsic value in later scientific studies. The aim is to allow the astronaut freedom of choice in scientific investigation during the mission, and to assist him by collating, analyzing, and plotting the data coming from the mission into usable feedback form.

Terrestrial analog studies, - A vigorous and expanding program of the field studies currently supported by NASA on impact and volcanic structures and on the processes that may modify the lunar surface is essential both for mission planning and for postmission analysis.

Astronaut training and crew selection. - After basic classroom work and tutorials, the astronaut should be provided the time and opportunity to participate directly in the research and planning activities of the particular mission for which he is selected. This may require one or more thorough refresher tutorials covering the specific topics of prime geological importance for the mission.

In crew selection for any mission, flight-operations ability is the primary criterion. For the Apollo missions, it is strongly recommended that ability in field geology be the second most important factor in the selection of the crewmembers who will actually land on the Moon. For some of the complicated scientific missions in the later part of the AAP, the knowledge and experience of an astronaut who is also a professional field geologist is essential.

Maintaining scientific career proficiency. - In the interests of maintaining career proficiency, astronauts should be provided time to engage in some form of research activity within their professional field.

Mission planning. - It is recommended that an immediate and intensive program of detailed mission analyses be undertaken for all of the prime lunar landing sites and traverses that have been listed by the Geology Working Group. With the rapid development of suitable launch capability and the growth of an extensive body of photogeological maps of the lunar surface and because of the leadtimes required for the development of selected systems, such detailed analyses are urgent and must be planned on an iterative

basis to test the applicability of planning and development for the achievement of the general scientific objectives of lunar exploration. The objectives of the studies would be the following:

1. Determination of tentative astronaut time lines for each lunar surface mission to compare the actual time available with the time required of the astronauts to achieve the scientific objectives of each mission

2. Establishment of the mobility requirements for the effective performance of each mission, which will provide a basis for the recommendation of a practical, adequate, and flexible combination of mobility systems from among those proposed for development for the AAP

3. Analysis of each scientific mission within the context of astronaut safety constraints

4. Establishment of a comprehensive list of the technical capabilities of lunar surface vehicles and communications, navigation, and other instrumentation systems from which a more refined order of specific mission site priorities may be formulated

5. An assessment of the scientific yield to be derived from the mission profile

The performance of the mission analyses requires the closest integration of scientific considerations with the basic technological capabilities and planning. It is recommended that a mission analysis group be selected from among the several lunar surface working groups of the Santa Cruz Conference and the planning, engineering, and astronaut offices of NASA. It is recommended that the size of the group be restricted to about 10 members. The group should undertake the analyses immediately for the purpose of recommending, at the earliest possible time, the development of all essential systems to assure availability for the proposed launch schedule, Such a program is essential to making any final decisions on the selection of systems.

RECOMMENDATIONS FOR POTENTIAL LATE APOLLO FLIGHTS

Since the major relaxation of the present Apollo constraints is in the landing site requirements, additional sites have been discussed. Two general categories of missions for the late Apollo flights have been agreed upon: missions which would visit the AAP sites listed in the general report of the Geology Working Group and missions which would visit sites of interest other than those selected by the working group as AAP sites.

The first category of missions would obtain preliminary information about the scientific nature and characteristics of the sites. Sample collection and geological study would have the highest priority to provide a better understanding of the kinds of scientific problems which the later AAP missions could attack or solve. The emplacement of automated instruments would be the second type of activity scheduled within

this category, but of lower priority. The following are sites identified for this category, with a tentative priority:

1. Flamsteed Ring
2. Marius Hills
3. Hyginus Rille
4. Sabine and Ritter
5. Copernicus
6. Alphonsus

The second category of missions would schedule the same types of activities in most cases, but would attempt to answer specific questions suggested by the nature of the site. The following are sites selected for this category, also with tentative priorities:

1. The eastern flank of Dionysius
2. Gambart
3. Mosting C
4. Hipparchus
5. The dome near Apollo Site II-P-2
6. The flank features of Copernicus
7. Surveyor and Ranger sites

It should be emphasized that the priorities shown are only tentative and will undoubtedly change as additional information is obtained. It should also be clearly understood that the actual accomplishment of Apollo-type missions at any or all of the sites listed will not provide the data nor depth of observations required to answer the major questions which have been posed. These missions would be extremely useful but must be followed by missions of greater capability such as those listed and discussed elsewhere in this report.

CHAPTER 4

REPORT OF
GEOPHYSICS WORKING GROUP

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a

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INTRODUCTION

Scientific Objectives and Background

The study of the interior of the Earth has provided many important clues to the understanding of the origin and evolution of the Earth and the solar system. Elucidation of these problems is one of the ultimate goals of Earth science and of the study of the Moon and planets.

Broadly speaking, there are three important aspects to the study of a planetary interior. One is the study of the internal structure, such as layering and lateral variation, and is essentially three-dimensional mapping. In the Earth, the mere presence of such radial subdivisions as the crust, mantle, core, and such lateral subdivisions as ocean basins and continents, has important implications regarding the differentiation and evolution of the planet and the initial conditions of formation. Any physical property of the interior that can be measured at the surface of the planet is potentially useful in mapping the internal structure.

The second aspect concerns the determination of the physical conditions and composition of the interior, which in turn requires knowledge of the effects of composition, temperature, and pressure on physical properties. The temperature and physical state (that is, solid or fluid) of the interior are involved here.

The third aspect can be called the dynamics of the interior and involves such things as the energy budget (mechanical and thermal) and response of the body to internal and external stresses. In general, this aspect would include heat flow, creep, movement of magma, seismicity, the magnetic field, tidal deceleration, and damping of the various free and forced motions.

Some properties of the interior are important in their own right. For example, the elasticity and anelasticity of the body are involved in orbital evolution and, therefore, have direct bearing on the ultimate question of origin. The presence of an internal magnetic field is important quite apart from the possible use of a magnetic field or of the magnetic properties of rocks in determining structure, composition, and temperature of the interior.

Once the broad features of the interior are established, more specific questions can be asked. These questions should, however, be placed in the context of the overall framework of planetary exploration. For example, is it more important to embark on a detailed geophysical mapping program of the Moon or to land a single geophysical observatory on Mars at a comparable cost? The Geophysics Working Group supports the concept of a shifting emphasis from lunar exploration to planetary exploration, with the crossover point occurring in about the year 1975.

The Geophysics Working Group takes the important geophysical problems regarding the Moon to be the nature of the internal structure, composition, temperature, and energy budget. Attention is restricted in this report primarily to broad-scale geophysics aimed at the central problems of the origin, evolution, and constitution of the Moon. Also of concern is the explanation of the main features on the lunar surface, such as mare, uplands, craters, ridges, rills, scarps, surface debris layers, et cetera. Traverse geophysics will provide three-dimensional control for geological observations. Remote sensing of the properties of the surface will be used to extend the in situ geological and geophysical measurements.

Strategy of Geophysical Experiments on the Moon

The overall Apollo Applications Program (AAP) exploration plan calls for (1) sophisticated scientific stations emplaced by astronauts, (2) simple and rugged geophysical modules delivered with surface probes from orbiters or off loaded from unmanned traverse vehicles, (3) automated soft landers (ASL), (4) subsatellites ejected from orbiters, (5) long geophysical traverses accomplished with unmanned vehicles, and (6) short manned traverses.

The Emplaced Scientific Stations evolve from Apollo Lunar Surface Experiments Package (ALSEP) type systems in the early AAP period to more sophisticated systems for use on dual launches. The stations will contain a mixture of experiments for studying the lunar interior, the lunar atmosphere, the solar wind, et cetera. The stations, along with remote geophysical monitors, and automated soft landers, provide a Moon-wide array for detecting seismic waves from moonquakes and impacts of spent Saturn IVB (S-IVB) stages. The stations can also contain small absolute gravity meters, transponders, total pressure gages, and mass spectrometers. The long traverses, made with the Lunar Surface Survey Module (LSSM) operating in unmanned mode. will be used to characterize the outermost 100 kilometers of the Moon beneath mare, uplands, and transition regions. Seismic, gravity, and magnetic profiles will be made along with electromagnetic or acoustic profiling to map the outer layers. The seismometers will be dropped automatically in linear arrays several hundred kilometers long in preparation for one or two S-IVB impacts. After the impacts, the remote geophysical monitors would revert to passive monitors.

In conjunction with the short, manned traverses motivated primarily by geological considerations, short active seismic traverses, gravity and electromagnetic/sonic profiling would be carried using the LSSM or the Lunar Flying Unit (LFU). In this way, small-scale features such as rills, scarps, hills, craters, cones, and local variations in the debris layer can be studied with both geological and geophysical methods.

Orbital missions are proposed which include photography and more meaningful coverage of the electromagnetic spectrum with passive monitoring and radiometric mapping. Active electromagnetic mapping over a wide band of frequencies is also proposed. The use of subsatellite systems to map the magnetic field of the Moon and the interaction of the magnetic field with the solar wind is a key feature. Orbiters used in union with transponders deployed with the remote geophysical monitors can increase the resolution with which the selenoid can be mapped.

RATIONALE OF GEOPHYSICAL EXPLORATION OF THE MOON

Statement of the Problem

The problem of geophysical exploration of the Moon is to study the present state, structure, and composition of the Moon and, from observational data, to infer the history and origin of the Moon.

Experiments conducted both on the surface and from orbiting satellites are required to determine the physical state, structure, and composition of the Moon at the present time. From the data obtained, it is hoped that the origin and evolution of the Moon may be inferred. Interpretation of these data provides a crucial test of the predictions of hypotheses previously formulated in the study of the Earth and solar system. The derived information contributes to the basis of theoretical ideas and experimental techniques for the exploration of other planets, including the Earth.

The key questions to be resolved in the physics of the Moon are the following:

The figure of the Moon. - The determination of the overall physical shape and external gravitational field of the Moon enables the determination of the departure from an equilibrium configuration to be specified. The present lunar orbiter program will provide data from which it is possible to determine the harmonics of the lunar gravitational potential through the fifth degree. Anomalies of corresponding size (thousands of kilometers) will give information about the stresses and the large-scale physical processes which cause anomalies in the deep interior. Refinement of harmonic coefficients will require additional orbiters. Extension of the work through the 10th or 15th harmonics will be necessary to test the hypothesis of isostasy. An exact determination of the moment of inertia factor is the key parameter in determining the radial variation of density within the Moon.

The dynamics of the Earth-Moon system. - The use of corner reflectors on the Moon, could greatly improve the knowledge of the motion of the Moon. Of great interest is the determination of whether the Moon has a forced libration in longitude, as has been deduced from telescopic observations, and if so, the examination by a long series of observations the nature of the excitation and decay of this free libration. The improved measurement of the forced physical libration in longitude would enable a more accurate determination of the mechanical ellipticity of the Moon and would be an independent check of the second harmonic of the lunar gravitational field, as determined from orbital satellites. The method could conceivably be sensitive enough to detect a forced libration in latitude, analogous to the Chandlerian nutation of the Earth.

The present and past magnetic fields and the current state of magnetization of near-surface lunar materials. - Lunar-orbital magnetic measurements reveal that any lunar magnetic field associated with low-order spherical harmonics does not exceed a few gammas. However, this observation does not preclude the presence of local magnetic fields of significantly greater magnitude. Such local fields could arise from electrodynamic processes or from magnetic material of lunar or extralunar origin. The possibility also exists that the Moon had or was exposed to a much larger magnetic field in the past and that this fact is recorded in lunar rocks. Therefore, studies of time and space variations of the lunar magnetic field from tight orbits, at

emplaced scientific stations, and along traverses are important. Studies of the magnetization of lunar rock samples are also important. Finally, a long series of measurements would enable the existence of a small dipole field to be tested, and this is of key importance in connection with the difficult theory of planetary dynamics and the possible existence of a small lunar core.

The structure and composition of the lunar interior. - Unlike the gravitational and magnetic fields, no information presently exists on the seismicity of the Moon or on the propagation of elastic waves through the Moon, The acquisition of seismic data is of the very highest priority, because these data are the most effective bases for inferences concerning the structure and composition of the interior. For this purpose, a global network of short-period stations capable of locating natural events, such as moonquakes and meteor impacts over the whole of the surface of the Moon, is necessary. The network should be extended to the back side of the Moon when the communication problem has been solved. Impacts of S-IVB shells are desired to provide the near-surface information which is fundamental for the interpretation of the data on the deep interior and for the study of regional variations of traveltimes.

The installation of a network of long-period seismographs is of equal importance to that of the installation of a short-period network. Study of the dispersion of surface waves provides information on the velocity and structure in the interior which is complementary to that provided by body-wave studies. In addition, study of the amplitude of surface waves will probably provide more information on the anelastic properties of the Moon than any other kind of observation.

The energy budget of the lunar interior. - The energy budget includes problems of heat flow, seismicity, and tectonic activity. Information relevant to the temperature of the interior will be obtained from the seismic and electrical experiments. Measurements of the heat flow at the surface will also be required.

The geophysicist wishes to know whether seismicity shows a global pattern and whether this is related to the selenoid and to the distribution on the lunar surface of the various classes of features recognized as of possible internal origin. Deployment of the lunar net of seismometers and geophysical investigations on traverses are desirable, with the geological and geochemical investigations to decide the significance of each. These studies and those discussed previously will possibly lead to a theory of the internal energy of the Moon. Observable secular strains and moonquakes may be associated with some lunar features, such as long sharp-walled structures, if they are currently active.

The gross elasticity and anelasticity of the Moon. - The amplitude and phase lag of the terrestrially induced tides are measures of the gross elasticity and anelasticity of the Moon. The theoretical tidal amplitudes on a reasonable model differ by only 0.5 percent from those of a wholly rigid Moon; although the tilts are 2 percent different, the interpretation of this measurement is difficult in the presence of the large thermal effects. Thus, the tidal experiment involving a sensitivity of 1 microgal and long-term stability requires further preparatory investigation although measurements of anelasticity at seismic and tidal periods would throw light on the physical processes of dissipation in the solid Moon. Long-period horizontal seismometers or tiltmeters and strainmeters should be designed to respond to tidal periods with sufficient precision to be useful in these studies.

The geophysical differences between such large-scale features as maria and uplands. - Investigations can be expected to reveal the cause of geophysical differences between large-scale features such as maria and uplands.

The previously mentioned list includes the first-generation questions pertinent to the Moon as a planet and, except for the heat-flow experiment, involve basically the interpretation of orbital data and the installation and monitoring of packaged observations on the Moon. These problems can be attacked on many different scales. Initially, understanding of the planet as a whole is desired. Subsequently, variations on the order of thousands of kilometers for correlation with features of the lunar surface and the selenoid can be studied.

Other detailed questions. - A second group of questions involves the lateral variation of physical properties, composition, and structure in the Moon on the scale of tens of kilometers. Solution of these problems requires additional orbital missions, the installation of many more observatories in selected sites, and the running of many traverses. Typical questions at this level are the following:

1. Are the smaller surface features on the Moon in isostatic equilibrium?

2. How does the subsurface (for example, layering and depth of crust) differ in the major regions of the Moon?

3. Are there large buried dense masses on the Moon?

4. How deep is the debris layer, and how does the thickness vary?

5. What is the meteorite influx on the Moon?

6. What is the distribution of water and ice on the Moon?

Many of these questions will be motivated by geological considerations, but must be considered in this report because they involve geophysical techniques. In addition to the physical analysis of well-chosen samples of lunar material, either from surface outcrops or from boreholes, the classical geophysical methods of seismology and gravimetry (plus satellite selenodesy) are most likely to be highly productive in lunar exploration. However, certain known, or likely, differences between the Moon and the Earth indicate that the relative efficiencies of various geophysical techniques may be quite different:

1. The surface gravity of one-sixth that of the Earth permits gravity anomalies much greater, relative to the total field, than those observed on Earth.

2. The absence of a strong internally produced magnetic field may reduce the effectiveness of standard magnetic exploration techniques and increase the importance of studies of time variations of the magnetic and the electromagnetic fields; the relative importance of remanent magnetization of anomalous bodies might be greater.

3. The absence of free, liquid water might increase the efficiency of electromagnetic methods (active and passive) of depth sounding relative to seismic reflection methods.

4. The existence of a weak, anelastic, "gardened" layer, perhaps **1** kilometer or more in depth, might reduce the efficiency of active seismic techniques.

5. The absence of an atmosphere will permit much higher precision from electromagnetic (optical laser or radiofrequency (RF)) distance-measuring devices; long (of the order of **1** km) laser strainmeters for seismic, tidal, and secular strain observations are feasible.

6. Great physical heterogeneity of near-surface materials may make it difficult to obtain meaningful measurements of average lunar heat flow and, using standard seismic refraction and reflection methods, of near-surface (0 to 10 km) elastic properties.

Operational Considerations

The primary advantage of a manned scientific mission over an unmanned mission is the mental and mechanical flexibility of the astronaut. The astronaut is able to install, adjust, and repair complex equipment; to carefully select lunar samples using stratigraphic and other criteria; and to modify mission plans during execution to obtain optimum results. Although many of these functions could be accomplished remotely (from Earth) or with the aid of automated equipment, it is unlikely that the same degree of flexibility could be achieved with an equivalent amount of effort and technical capability.

The primary disadvantage of a manned scientific mission is probably the large basic cost of transporting a man to the Moon, maintaining him on the Moon or in orbit around the Moon, and returning him safely to Earth after a relatively short period of time. Additional related,disadvantages are limitations in the lunar areas sufficiently safe for manned exploration, limitations in the range (in space and in time) of a given manned exploration mission, and the relatively high noise level (mechanical, electrical magnetic, thermal, etc.) produced by the astronaut and by the life support system.

Two advantages of unmanned missions are the long staytime capability and the low noise level. For surface missions, instruments can be emplaced in and samples collected from poorly accessible or dangerous regions, such as the far side, the highlands, recent craters, et cetera. Detailed mapping of specified areas (topographical, geological, and geophysical) might be efficiently conducted by a remotely operated, unmanned rover capable of long-term operation. But, rapid traverse reconnaissance across two-dimensional structures, provided the topography is not too rough, could be most effectively conducted by a manned mission. A lunar flying vehicle would also be useful for such purposes.

The following program of lunar missions has been separated into four categories: manned, orbital and surface; and unmanned, orbital and surface. The items in each category, some of which are fairly general, are listed essentially in order of priority.

The surface mission tasks (manned and unmanned) can be subdivided into those missions associated with traverses and mapping expeditions and those missions associated with instrument installation. The two groups require rather different capabilities **(1)** for the astronaut and the associated support equipment for the manned missions

and (2) for the automated support equipment for the unmanned missions. It is difficult to estimate the relative efficiency of manned or unmanned accomplishment of a given task or combination of tasks without a detailed examination of the instrumentation presently under development or feasible.

Relationship to Other Disciplines

The study of the present state and origin of the Moon is a multidisciplinary problem involving geophysics, geology, geochemistry, and geodesy. Although this section is concerned with geophysical questions as well as those questions which can be answered with geophysical techniques, the importance and, in some cases, the priority of certain programs being undertaken by other groups is acknowledged. In particular, the Geophysics Working Group considers the following investigations to be especially pertinent:

1. The return of samples from a variety of lunar locations for detailed geochemical, geological, and geophysical examination

2. Accurate petrological and stratigraphic descriptions by a geologically trained astronaut of the rock units at each landing site

3. The radioactivity of the various parts of the Moon

4. Age dating of rocks from selected locations

5. Cosmic-ray exposure ages of surface and near-surface material

6. Detailed mapping of the gravitational and magnetic force fields of the Moon and accurate determination of the physical libration

7. Detailed mapping of the figure of the Moon to ± 100 meters

Introductory Recommendations

The concurrent emplacement of long-lived experimental packages at many places on the Moon is of highest priority. Questions which require experiments involving extensive activity or extended traverses by the astronaut are few. Such experiments are required mainly to support the geological investigations conducted by the astronaut.

Because of the importance of the seismic program and the emphasis placed upon it, the Geophysics Working Group considers it a matter of utmost urgency to send at least one seismometer to the Moon as soon as possible, hopefully on the next Surveyor. The importance of placing a seismometer on the Moon stems not only from the fact that seismicity and seismic noise level must be known to design the optimum AAP seismic experiment, but because of all the elements in the environment to which the astronaut will be exposed (namely, particles and fields, meteorites, soil bearing strength, surface roughness, and seismic activity), only the seismic activity is completely unknown.

EMPLACED SCIENTIFIC STATIONS

Scientific Uses for Emplaced Stations

The primary purpose of emplaced stations in the AAP is to carry out observations on the lunar surface over extended periods of time. Four basic types of emplaced stations are useful in implementing the recommended experimental programs. The intent is to utilize existing instruments wherever possible and to evolve *a* new generation of instruments which more fully exploit the **AAP** capability. One conceptually new system is specified: a means for delivering eight to 12 lightweight geophysical stations to the lunar surface from an orbiting command and service module (CSM) or from an automated LSSM, with impact loading of 25g or less. These are called Remote Geophysical Monitors. These methods of deployment appear to be particularly convenient methods to achieve a widely spaced network of simultaneously operating geophysical sensors on the lunar surface. Each station would weigh approximately 100 pounds, not including the descent vehicle. The other types of stations are either under development at the present time or are modifications of present systems.

Types of Emplaced Stations Required

Emplaced Scientific Station (ESS). - The ESS is the present ALSEP upgraded for longer life and improved performance with the provision for new experiments when available. The ESS serves as a central observatory. It is clear that maximum use of the ALSEP development program must be made in AAP and that the science which can be supported by an ESS should not be frozen within the present ALSEP design. For AAP purposes, ESS (ALSEP) should properly be regarded as a major support system which can provide power and telemetry for any experiment meeting the interface specifications.

The present ALSEP has a gross weight of 300 pounds with a scientific payload of 131 pounds (66 lb for experiments and 65 lb for geological equipment). The total available power from the radioisotope thermoelectric generator (RTG) is 56 watts with 29 watts available for experiments. The following are provided by ALSEP: (1) mounting tabs and electrical terminals for five experiments, (2) storage for geological equipment, (3) a power supply (RTG) for 1 year of continuous operation, (4) a multiplexer and transmitter (60-dB dynamic range), (5) a command receiver and decoder capable of receiving and routing 100 separate commands, (6) a scanner and analog-to-digital (A/D) converter to sample 90 separate engineering data points, and (7) a telemetry capability of 10 600 bps with an 80-foot receiving antenna and 1060 bps with a 30-foot antenna. The ALSEP is carried 300 feet from the lunar module and erected by the astronaut in approximately 90 minutes.

The following experiments are under development for ALSEP:

1. Passive Seismic Experiment (PSE)

2. Active Seismic Experiment (ASE)

3. Heat-Flow Experiment (HFE) (includes the Apollo Lunar Surface Drill)

4. Cold-Cathode Gage Experiment

5. Suprathermal Ion Detector Experiment

6. Lunar Surface Magnetometer

7. Charged-Particle Lunar Environment Experiment

8. Solar-Wind Spectrometer

The primary improvement recommended for ALSEP is aimed toward accommodation of any experiment which falls within a specified weight, power, and volume limit. Although major redesign to produce ESS is not recommended, arrangements should be made possible for investigators to propose modifications, improvements, and new experiments consistent with the weight, power, and volume constraints. The operational lifetime of the ALSEP should be extended to 3 years if possible.

The candidate experiments for ESS include the following:

1. Passive seismic/tidal gravimeter/tiltmeter (three long-period components and one to three short-period components)

2. Surface triaxial magnetometer (three components)

3. Heat flow

4. Active seismic (without mortar)

5. Dust transport monitor

6. Corner reflector

7. Micrometeoroid detector

8. Doppler transponder for use with orbital satellites

9. Surface electrical field

10. Total pressure gage

11. Mass spectrometer

Expanded Emplaced Scientific Station (ExESS). - The ExESS represents the most sophisticated instrument system recommended by the Geophysics Working Group. The total weight is approximately 400 pounds with a scientific payload of 250 pounds. The station would be erected on the lunar surface near the landing site by an astronaut. The ExESS would serve as a long-lived observatory just as the ESS; however, the greater

payload, power, and telemetry capability would permit a larger number of experiments to operate simultaneously throughout the lifetime of the station. The ExESS will also serve as the central station for array experiments. It is recommended that outlying array stations telemeter directly to Earth rather than back through the ExESS.

The ExESS should provide the following items: **(1)** mounting tabs and electrical terminals for nine experiments, **(2)** storage for geological equipment, **(3)** a power supply (RTG) for a minimum of 1 year of continuous operation with a design goal of 5 years (~**100** W), **(4)** a multiplexer and transmitter (60-dB dynamic range), **(5)** a receiver and command decoder capable of receiving and routing **115** to **120** separate commands, **(6)** a scanner and A/D converter to sample **130** separate engineering data points, and (7) a telemetry capability of **1300** to **1400** bps with a 30-foot receiving antenna.

The experiments for ExESS should be completely modular with standard electrical (plug-in) and mechanical interfaces where possible.

ExESS candidate experiments include the following:

1. Passive seismic/tidal gravimeter/tiltmeter (three long-period components and one to three short-period components)

2. Surface triaxial magnetometer (three components)

3. Heat flow

4. Active seismic (without mortar)

5. Strain meter

6. Surface electrical field

7. Corner reflector

8. Dust-transport monitor

9. Deep drill (**100** ft)

10. Doppler transponder

11. Micrometeoroid detector

12. Total pressure gage

13. Mass spectrometer

Remote Geophysical Monitor (RGM). - The RGM should be as light as possible. Present considerations suggest that 100 pounds including scientific instruments, a power supply, a transmitter and reciever, a command decoder, and a data subsystem is a realistic goal. The RGM should be fully automated, compact, and rugged with a power supply sufficient for continuous operation over a minimum span of 2 years with a design goal of 5 years. The instrument system should be designed to withstand a 25g maximum (over a frequency range of 0 to 100 Hz). A softer landing is desirable if it can be achieved without an excessive weight penalty. The anticipated power source is the system for nuclear auxiliary power (SNAP) 19 RTG, although a lighter unit would be preferable. The SNAP 19 in a flight qualified version will weigh approximately 30 pounds and will deliver 15 watts. The power level may be marginal, particularly if an omnidirectional antenna is used. Approximately 25 watts should be considered as a design goal. An alternate power supply could be a solar-cell battery system with long-term survival. The RGM could be deployed by LSSM or LFU or directly from orbit by a suitable descent vehicle. The primary purposes of the RGM are (1) to provide a widely spaced net of seismometers, gravimeters, and transponders over the face of-the Moon (by orbital deployment); (2) to serve as outlying stations in triangular-array configurations in conjunction with an ESS or ExESS central station (manned deployment by LSSM); and (3) to be deployed along unmanned LSSM traverses at approximately 50-kilometer intervals.

The RGM candidate experiments include the following:

1. Passive/active seismic

2. Gravimeter (geodetic)

3. Doppler transponder

4. Total pressure gage

5. Mass spectrometer

Automated Soft Lander (Augmented Surveyor). - It is recommended that the present Surveyor system be upgraded for use in conjunction with the manned exploration of the Moon. Use of an RTG in place of the solar panels and batteries presently used should permit greatly extended lifetimes on the lunar surface. A total of eight missions is proposed. These missions should be to locations not feasible or desirable for manned missions, for example, the South Polar region, the Far Eastern region, the highland areas, and the far side (if possible), to produce a more complete lunar network than would be otherwise possible.

If the Atlas-Centaur launch system cannot be used to carry the scientific payload of 125 pounds (in addition to power source), consideration should be given to use of the Titan IIIC or Saturn IB.

To some extent, the complement of scientific experiments will depend upon the specific mission contemplated. However, it is anticipated that the instruments used will be similar to those used in the ESS and ExESS. The operational lifetime of this station should be at least 2 years with a design goal of 5 years.

The Automated Soft Lander (ASL) candidate experiments include the following:

1. Passive seismic/tidal gravimeter/tiltmeter (three long-period components and one to three short-period components)

2. Corner reflector

3. Gravimeter (geodetic)

4. Doppler transponder

5. Surface triaxial magnetometer

6. Total pressure gage

7. Mass spectrometer

Experiment Descriptions

The following are descriptions of the experiments summarized in table I.

Passive Seismic Experiment. - For AAP, the primary objectives of the seismic experiment will be (1) to achieve a wider distribution of detectors, (2) to lower the minimum detectable signal of an individual detector, and (3) to improve the performance of the ALSEP-type long-period seismometer system at the ultralong-period end of the spectrum (free oscillations, tides, secular strains, and tilts).

It is recommended that a four-component passive seismic/tidal gravimeter/tiltmeter (three long-period seismometers and one short-period seismometer) and preferably a complete six-component instrument (two additional horizontal short-period seismometers) be installed at each manned exploration site. The instrument would weigh approximately 25 to 30 pounds. In addition, at least two, preferably three, outlying RGM stations should be installed at the ends of traverses during each dual-launch manned exploration site. These sites will probably be at distances of 8 to 10 kilometers from the central station (ESS or ExESS). The dimensions of the triangular array would ideally be about 30 kilometers on a side, but mobility constraints will likely limit the largest separations to between 8 and 15 kilometers.

Lighter versions of the RGM (~80 lb) will be dropped off by an unmanned LSSM at approximately 50-kilometer intervals to form long linear seismic arrays for use in the Lunar Deep Seismic Sounding (LDSS) Experiment. It is recommended that the impacts of the spent S-IVB stages be considered for use as the energy sources for the LDSS Experiment. The RGM could become a passive monitor after the impact.

A widely spaced network of seismic stations will be achieved by the Automated Soft Landers and by the orbital deployment of eight to 12 Remote Geophysical Monitors on the lunar surface from the CSM. The seismometers contained in the network Remote Geophysical Monitors should be triaxial, intermediate in period (2 to 5 sec), and

TABLE I. - CHARACTERISTICS OF EMPLACED SCIENTIFIC STATION EXPERIMENTS

Experimental equipment	Weight, lb	Power, W	Telemetry requirements, bps	Other parameters
Passive seismic/tidal gravimeter/tiltmeter (including 1 to 3 short-period components)	25 (for 3 long-period components); 5 (for 3 short-period components)	10 (for 3 long-period components); 1 (per short-period component)	120 (for 3 long-period components); 200 (per short-period component)	T_o = 15 to 30 sec for long-period component; T_o = 1 sec for short-period component
Intermediate-period triaxial seismometers for RGM stations	[illegible]	[illegible]	500 (for 3 components)	T_o = 2 to 5 sec for network stations; T_o = 1 sec for lunar-array stations
Gravimeter, geodetic or traverse	5 to 10	10	10 (short term)	
Triaxial surface magnetometer	15	10	90	
Active seismic (8 geophones, no mortars)	10			[illegible]
Heat flow, 2 down-hole probes and electronics	10	9	20	
Corner reflector	17	None (passive)	None	
Strainmeter (3 components)	15 to 25	10 to 20	120	
Doppler transponder			Analog to Orbiter	
Micrometeoroid detector	10	1	5	
Dust transport monitor	1	1	0.2	
Surface electrical field	10	3	50	

rugged enough to withstand the RGM landing (25g maximum). The three-component assembly will weigh between 5 and 10 pounds. The minimum detectable signal should be the smallest value attainable with present techniques approaching 1 angstrom at 1 hertz. The same seismometers will be used in the outlying triangular-array and linear-array stations, although the natural periods may be changed to 1 hertz for the linear array. The network (RGM and ASL) stations will be deployed over the entire near side of the Moon. Each station should have sufficient power supply for continuous operation for a minimum of 1 to 2 years. If a means for data retrieval from the far side is available, several stations should be located on the far side.

The combination of a widely spaced net, triangular arrays, and long linear arrays of seismic stations recommended by the Geophysics Working Group will provide the means for an extremely useful experiment. Of course, the utility of the net depends upon concurrent operation of all stations in the net and emphasizes the requirement for long-term operation.

Gravity, Tilt, and Strain Variometer Experiments. - The experiments can be divided into three types in terms of decreasing characteristic frequencies: (1) low-order free oscillations with periods of about 15 min/cycle or less, (2) tidal oscillations with periods of about 28 days/cycle, and (3) secular deformations.

Free oscillations (if excited with sufficient amplitude by large moonquakes, meteorite impacts, or artificial sources) can provide a relatively unambiguous picture of the elastic and anelastic properties of the interior of the Moon (provided the Moon has a fair degree of radial symmetry).

The gravity variometer (vertical seismograph) responds only tu spheroidal oscillations; whereas the tilt variometer (horizontal seismograph) and the strain variometer respond to both spheroidal and torsional oscillations. The largest earthquakes have produced free oscillations with amplitudes of the order of 1 millimeter and strains of the order of 10^{-9}. Instrumental sensitivities for lunar experiments should be of this order or better.

Tidally induced, forced deformations of the Moon also reflect the elastic and anelastic properties of the interior. In the absence of detectable free oscillations, these deformations may be the only source of such information. The integrated elastic properties of a radially symmetric body can be expressed by the three Love numbers. Tidal gravity and tilt data define two independent combinations of two of these numbers; strain data are required to define the third number. Tidal amplitudes expected on the Moon are approximately 1 milligal, 0.1 second of arc, and 10^{-8}, respectively, for the three types of measurement. To be useful in differentiating among various lunar models, these amplitudes should be measured to rather high precision, for example, $1:10^4$ for gravity, $1:10^3$ for tilt, and $1:10^2$ for strain.

Secular strains and tilts will be associated with any tectonic activity on the Moon. Strain rates of about 10^{-6} per year and tilt rates of about 1 second of arc per year have

been observed in active regions on Earth. Although it is difficult to estimate lunar rates, it is reasonable to expect that instruments with long-term stability one or two orders of magnitude better than the rates mentioned will be required to observe tectonic activity on the Moon.

Gravity (vertical seismograph) and tilt (horizontal seismograph) variometers with sensitivities and stabilities approaching those suggested here are presently under development; however, more development work is required. Also, to obtain useful tidal and secular data (especially for tilt), it may be necessary to place the instruments a few feet below the surface to reduce thermal effects to acceptable levels.

At this time no strainmeters or long-baseline tiltmeters are under development for lunar use. The absence of a lunar atmosphere makes the use of a laser beam for a linear strainmeter an attractive possibility. It appears that a single continuous laser source used in conjunction with four mirrors to establish four baselines of the order of 1 kilometer in length could provide the sensitivity and stability required for the three types of observations discussed.

Surface Vector Magnetometer Experiment. - The following are primary scientific objectives of a three-component magnetometer in an Emplaced Scientific Station.

1. To characterize the time variations of the direction and magnitude of the surface magnetic field and thus to establish the existence and location of a bow shock, magnetosheath, and stagnation region

2. To distinguish between a remanent lunar field, if extant, and the field caused by diffusion of the interplanetary field into the Moon

The ESS should include a triaxial magnetometer measuring the vector magnetic field from 0 to 1 hertz or higher with an accuracy of ±0.1 gamma over a dynamic range of 0 to 100 gamma. The orientation of the sensors must be known to within a few degrees, relative to lunar coordinates. Consecutive landing missions should include a magnetometer so that eventually simultaneous measurements with a net of instruments is achieved. The initial net need include only three or four instruments which are located (ideally) at widely separated sites. A correlative study of these data and those obtained with simultaneous lunar orbiting spacecraft carrying similar magnetometers is important to determine uniquely the electrical and magnetic fields of the Moon. The magnetometers presently and successfully employed in the Eccentric Geophysical Observatory (EGO), interplanetary monitoring platform (IMP), Pioneer, Explorer, and Mariner series of spacecraft demonstrate that no new development is necessary for detector systems at the present time. Typical weight, power, and size of these packages are:

Weight, lb	5 to 15
Power, W	0.8 to 5
Size, in^3	150 to 500

The problem of thermal control and magnetic isolation of these instruments on the lunar surface may require some increase in these figures (generally by a modest amount) and development of specific package configurations.

Heat Flow and Deep Drill Experiments. - The **HFE** on the lunar surface consists of measuring the vertical thermal gradient in a drilled hole and subsequently determining the local thermal conductivity by an in situ method. In the ALSEP concept, a hole 3 meters deep is drilled by a handheld percussive drill. A thermal probe 1 meter long is then emplaced in the bottom of the hole. The probe is equipped with four platinum resistance thermometers arranged in two bridges on a 50-centimeter spacing, and the cable extending to the surface is equipped with thermocouples. Thermal conductivity is determined by heating the surface of a cylindrical ring and monitoring the temperature rise of the rings as a function of time. The values obtained in this way are backed up by independent measurement of the conductivity of returned samples in the laboratory and by an analysis of the decay in the amplitude of the diurnal thermal wave with the depth as detected by the thermocouple chain.

The success of the gradient measurement depends on finding a poorly conducting layer near the lunar surface. The temperature cycle observed during a lunation is consistent with a value of $Kpc = 5 \times 10^{-6}$. Thus, with a conductivity of 15×10^{-6} cal/cm sec°C and a diffusivity of 50×10^{-6} cm^2/sec (corresponding to $p = 1.6$ gm/ cm^3 and $c = 0.2$ cal/gm°C), the surface amplitude is attenuated by a factor of e^{-32} at a depth of 2 meters. A thermal gradient is expected of about 10' C/m in such poorly conducting material (corresponding to a heat flow of 10^{-7} cal/cm^2 sec), and the gradient measurement clearly presents no difficulty. If the conductivity is 50×10^{-6} cal/ cm sec°C and the diffusivity is 500×10^{-6} cm^2/sec (corresponding to $p = 0.5$ gm/cm^3 and $c = 0.2$ cal/gm°C), the attenuation of the thermal wave in 2 meters is only by a factor of $e^{-10} = 5 \times 10^{-5}$. Thus, a fluctuation of about 0.015' C persists to this depth. The thermal gradient is still about 0.2" C/m for the above value of the flux, however, so that a satisfactorily accurate value can be obtained with a sensor resolution of 0.001" C. Higher values of diffusivity would make the experiment more marginal, and if solid rock ($K \approx 0.005$ cal/cm sec°C, $\alpha \approx 0.008$ cm^2/sec) is encountered near the surface, no measurement could be made in a 3-meter hole.

The in situ conductivity experiment yields a heating curve which depends on the thermal conductivity and diffusivity of the lurar material and on the thermal contact resistance between the heater and the lunar material. Study has shown that it is possible to disentangle the effects of these three parameters and to determine the conductivity uniquely by analyzing the data from more than one sensor suitably spaced along the axis of the thermal probe. The analysis is simpler and more accurate if the contact resistance is previously known, for example, by assuring that thermal coupling between the heater and the wall of the hole is by radiation only and incorporating this feature in the design. The precision of the heat flow measurement is estimated to be better than 20 percent.

A number of factors may cause the heat flow at a particular site to differ from the regional mean value in its vicinity. The principal factors are thermal refraction

caused by variations in thickness of the surface rubble and by variations in mean surface temperature from variable albedo. It is virtually impossible to anticipate the resulting anomalies; hence, a sizable number of measurements is required for a meaningful average. Therefore, several measurements are specified at central stations, and additional measurements must be made at neighboring satellite stations to detect long-wavelength disturbances. It is important that heat flow be measured at as many lunar stations as possible to reveal and eliminate the effects of local anomalies and to determine such large-scale variations as may exist over the lunar surface.

For the AAP, development of a means for deploying the heat flow probe beneath the lunar surface should continue, with an attempt made to reduce the weight or extend the capability of the ALSEP system. Drills mounted on the LM or LSSM, which are capable of drilling to depths of 10 to 100 meters, will enable the probe to be placed at greater depths where temperature fluctuations are less pronounced and near-surface disturbances are less important. It may be feasible to penetrate the lunar surface material to a depth of 3 meters with vibratory drilling equipment which is much simpler, lighter, and easier to use than the ALSEP drill. The development of a vibrodrill for the HFE should have high priority. Automation of the various drilling modes should be stressed so that emplacement of the HFE from unmanned vehicles becomes feasible.

The platinum sensors used with ALSEP suffer from relatively low sensitivity and require individual calibration. Great care in manufacture is required to assure that the calibration of the sensors is held at 0.001" C through the rigors of launch, touchdown, and emplacement. The search for sensors with higher sensitivity and greater inherent stability should continue. Nuclear quadruple resonance (NQR) thermometers, which were not ready for ALSEP, show some promise of replacing platinum thermometers; and systems superior even to NQR may appear in the future. Improved sensors should be incorporated during AAP as they are made available.

Even if heat-flow stations can be deployed without the help of man, only a very small proportion of the lunar surface can be covered by emplaced measurements. To increase surface coverage, the feasibility of measuring heat flow from orbit and from a traversing vehicle while in motion should be considered. Some possibilities include the following concepts:

1. Determination from orbiters of the amount of heat radiated by permanently shadowed areas. This is a direct measure of the heat flow from the interior of the Moon in large craters.

2. A combination of infrared (IR) and passive microwave emission measured from orbiters. The IR energy comes from the surface; the microwave energy comes from depth, and the mean depth depends on the wavelength. By judicious combination of IR and microwave data, perhaps at more than one wavelength, the thermal gradient can be determined. If the thermal conductivity can be estimated with adequate precision, the heat flow can be determined.

3. The depth to an ice-water interface. If the interface exists, it might be measurable electromagnetically. The thermal gradient could be extracted from the result of this measurement, and the heat flow could be extracted from an estimate of conductivity.

4. Magnetic surveys might reveal the depth to the Curie-point isotherm, which would give another estimate of the thermal gradient.

Of these methods, only the first can give absolute values; the others must be calibrated at places where the heat flow has been measured with emplaced probes, The low accuracy expected from these techniques is offset by the wide geographic coverage; and the Geophysics Working Group therefore strongly recommends further feasibility studies.

Large-Scale Passive and Active Seismic Experiments. - The following are objectives of the Passive Seismic Experiment.

1. To determine the seismically active areas of the Moon

2. To use moonquakes and meteor impacts to establish the traveltimes of body waves and the dispersion of surface waves on the Moon to infer the seismic velocity distribution within the Moon

3. To infer the anelasticity of the Moon from the study of surface and body waves

It is recommended that a four-to-six component (one to three short-period and three long-period components) station should be installed at each manned exploration site (MES). In addition, at least two outlier stations should be installed at each MES at distances of at least 8 kilometers from the central station, that is, at the ends of the traverses. The other stations should have three short-period components. The purpose of the outlier stations is to permit determination of $dT/d\Delta$ at the MES stations.

The manned exploration sites will be occupied over a 5-year interval and may have a lifetime of only 1 year. It is important in this experiment that several widely separated stations should be in operation at the same time. We recommend, therefore, that at least six remote geophysical monitors containing seismographs should be emplaced from orbit from a large-scale network. The unmanned stations should be long lived, hopefully for 5 years. The minimum requirement is a single short-period component, but a complete six-component station would be preferred. A study should be made of the possibility of deploying remote geophysical monitors from the CM.

In addition to the observation of natural events, such as moonquakes or meteor impacts, it is suggested that a controlled impact (or impacts) should be used to establish seismic velocity distribution down to a depth determined by the available impact energy and instrument sensitivity. The time and position of impact should be determined. It is suggested that an S-IVB shell should be used. The mass of this shell is 1600 kilograms, and the impact velocity is 2.6 km/sec, so that the impact energy is 5.4×10^{17} ergs. It is expected that the efficiency of conversion of the impact energy into seismic energy will be on the order of 1 percent so that the impact may be confidently observed at a distance of about 200 kilometers and, hopefully, at greater distances. It is planned that one MES and two unmanned stations should be at distances of 100 to 200 kilometers from the impact point.

The Active Seismic Experiment is detailed in a subsequent section of this report entitled "Traverse Geophysics."

Corner Reflector Experiment. - Laser ranging to passive reflectors on the Moon will provide accurate determinations of lunar librations, C/Ma^2, variations in the rate of rotation of the Earth, and possible secular (.monotonic) variations in Earth-Moon separation. The instrumentation required on the Moon is a corner-cube reflector of about 100 in^2. Manned delivery, for purposes of optimum site selection, is preferred but not absolutely necessary. The instrument, as currently designed, weighs about 17 pounds; alternate lightweight designs should be developed.

Dust Transport Measurement. - The Orbiter and Surveyor photographs have demonstrated that processes are occurring on the lunar surface which cause the movement of material from higher to lower ground. However, the nature of the transporting process is presently unknown. Possible mechanisms include shaking of the ground (caused by moonquakes and large impacts), electrostatic levitation, and thermal creep. Experiments on the lunar surface to elucidate the nature and measure the rate of the process are urgently needed and should be solicited from interested scientists. One possible experiment would be to use photodetectors, placing one flush with the lunar surface and one a meter or so above the surface, to monitor the difference in output as a function of time. Both detectors would be equally affected by solar radiation degradation; however, the lower detector would be preferentially covered by transported dust or very low-velocity tertiary meteoroid ejecta.

Doppler Transponder Experiment. - Accurate and well distributed satellite tracking data will greatly improve the resolution and accuracy of gravitational field determinations. Such data can be provided by a widely distributed net of Doppler transponders. These instruments should weigh less than 5 pounds and could be deployed with each emplaced station (RGM, ASL, ESS, ExESS).

Surface Electric-Field Experiment. - It is the view of the Geophysics Working Group that measurement of electric-field strength (three components) just above the lunar surface is an important measurement; however, the present state of our understanding of the interaction between the plasma field and the Moon is such that a meaningful Electric-Field Experiment cannot be defined. The Geophysics Working Group recommends that a theoretical and experimental study be undertaken to define a meaningful Electric-Field Experiment.

Micrometeoroid Detector Experiment. - The major erosive and morphological agent acting in the lunar surface is probably meteorite impacts. Thus, the impacts of large and small bodies and the accompanying redistribution of material are the lunar equivalent of water and air erosion on the surface of the Earth; therefore, the determination of the meteoroid flux is an important geophysical measurement. Equipment for monitoring the flux of primary meteoroids and secondary ejecta as a function of both mass and density in the range of 10^{-11} to 10^{-6} grams should be included in early emplaced scientific stations. The detector can be similar to those flown in Earth-satellite missions. Primary objects can be distinguished from secondary ejecta by their velocities. However, if the detector records spurious events caused by thermal transients or other causes, the system should also incorporate an appropriate control detector which is shielded from the meteorite flux but subject to all other environmental effects. The flux of larger particles (above 1 μg) can be evaluated by using the lunar surface as an impact counter. An area of several hundred square

kilometers should be photographed at 1-meter resolution from orbiters at intervals of several years, and the rate of generation of new small craters should be measured, possibly by blink-microscope methods. The impacts of larger meteoroids will be detected by the seismic sensors.

Electromagnetic Sounding and Profiling Experiment. - Continuous radar reflectivity soundings can be made from both unmanned and manned LSSM vehicles. These soundings will provide detailed measurement of the vertical and horizontal variations of €he electrical parameters, the dielectric constant, and the electrical conductivity, which will indicate the geological structure and composition and the depth of the debris layer and will serve as a direct indicator of the presence of water or ice at shallow depths. An FM–CW Sounder adapted from the Allouette Topside Sounder operating below 10^7 hertz may be suited to this task. Exploration to depths as great as several kilometers may be possible.

Supporting Research and Technology

Very-low-noise amplifiers. - These amplifiers should have a band pass of 0.01 to 20 hertz for use with seismometers to achieve the highest possible sensitivity to seismic energy on the lunar surface. If background noise on the Moon is very low, seismic sensitivity must be increased to the maximum.

Long-period seismometer/tidal gravimeter/tiltmeters .- Long-period vertical seismometers and gravimeters have the same basic design, as do long-period horizontal seismometers and tiltmeters. Thus, with appropriate design, a triaxial set of long-period seismometers can also function as a gravimeter and as a two-axis tiltmeter. The triaxial approach is presently being followed for the ALSEP PSE, but performance can be improved at the long-range-period end of the spectrum (free oscillations and tides). The improvements will consist mainly of increasing the thermal and mechanical stability of the pendulums and the supporting structure. Burying the instruments within the lunar surface material should be considered. New approaches for this type of instrumentation, such as long-baseline tiltmeters, should be examined.

Remote-station seismometers. - These instruments are a three-component set of intermediate-period seismometers (2 to 5 sec) for use in the RGM. These instruments will be used in (1) a widely spaced network of detectors placed over the entire surface of the Moon by an orbiting CSM; (2) a long, linear array of detectors deployed from the LSSM as part of an unmanned traverse; and (3) a triangular array deployed at the ends of short traverses (8 to 10 km) during the manned LSSM exercises. These seismometers must have very high ultimate sensitivity and must be rugged enough to withstand the environmental extremes imposed on the RGM. For the linear array, it may be desirable to have **natural** periods as short as 1 second.

Strainmeters. - Strainmeters have been of great value on Earth for measurements of secular strain across faults, free oscillations, tides, and long-period surface waves. These measurements would also be of great value as a complement to the seismic and gravity measurements and as a means for determining secular strain, if made across major tectonic features on the lunar surface. Development of a strainmeter suitable

for the **AAP** may be a difficult engineering problem; however, the possible return in understanding of the major stress patterns on the lunar crustal layer is very great. A feasibility study should be conducted; and if feasible, such instruments should be used in lunar exploration.

Lightweight corner reflectors. - The corner reflector, as presently designed, weighs 17 pounds. Lighter designs should be possible.

Dust-transport monitors. - The use of photocells which gradually decrease in output as they are covered with transported fragmental material has been suggested to measure the rate of transport of particles on the lunar surface. Better approaches to this measurement may be possible — approaches which would yield a more complete understanding of the overall transport process. The problem should be investigated.

Gravimeters for geodetic and traverse measurements. - An automatic, lightweight, rugged, and highly stable gravimeter is needed with an accuracy of approximately 1 milligal and a precision of 0.1 milligal.

Electric-Field Experiment definition. - A theoretical (and possibly an experimental) study should be undertaken to define a meaningful and feasible electric-field experiment for the lunar surface.

Data-acquisition system. - At some point in the AAP, the multiplicity of operational stations on the Moon may very likely exceed the capability of the receiving network on Earth. The Geophysics Working Group recommends that, if this is the case, a sequential sampling and storage system be devised which could interrogate a network of stations sequentially. Data from each station would be stored in a small solid-state memory with sufficient capacity to hold data for one scan interval. Immediate development of a system for acquiring data from the far side of the Moon should also be undertaken.

Priority List for Augmented Surveyors

The Augmented Surveyor (AS) is conceived to be a means of emplacing instruments similar to those used in the ESS and ExESS in regions not accessible to manned landings, such as the far side or the highlands, to obtain a more complete lunar network than would be possible otherwise.

The following list of priorities includes those experiments considered for ESS and ExESS:

1. Passive Seismic Package (ALSEP type)
2. Vector Magnetometer
3. Two Horizontal Short-Period Seismometers
4. Tidal and Secular Tiltmeter
5. Vector Electric-Field Meter

6. Micrometeorite Detector

7. Corner Reflector and/or Transponder

8. Active Seismic Experiment

Priorities of Experiments on Emplaced Scientific Stations

The ESS experiments are listed in order of priority for individual missions in table II. Only instruments of geophysical interest have been noted in table II and no comparison with other experiments is attempted. The list is not a priority list of all geophysical experiments, but only of those that require long-time monitoring from a lunar observatory and/or use of the ESS power supply and telemetering system. The priority ranking in table II is based on scientific importance, success probability, and supposed previous missions. These priorities should be reevaluated after each mission, and subsequent ESS packages should be modified, when possible, to reflect the new priorities.

Table 111 is a list of the proposed AAP missions with the experiment priorities listed which will require astronaut time.

Development Required for Smaller Emplaced Stations

The Remote Geophysical Monitor is intended for deployment along traverses and from orbiting vehicles. The following instruments and systems need development:

1. Two geophysical instruments are anticipated and both need development: (a) the Passive Seismic (maximum use should be made of Ranger and Surveyor programs and a new effort should be made in the direction of smaller size and weight for maximum utility of the RGM concept) and (b) the absolute gravimeter (sensitivity 1 milligal).

2. Data-Acquisition Systems (including studies of information compression) must be developed. The Geophysics Working Group emphasizes that studies related to information compression and onboard storage techniques must involve the scientist as well as the communication engineer.

3. A system (or systems) for locating remote emplaced stations needs development.

4. Development of the basic RGM power system, framework, data transmission, antennas, et cetera, is necessary.

The requirements are needed whether the Remote Geophysical Monitors are surface or orbit deployed. For orbit-deployed remote geophysical monitors it will also be necessary to develop a descent vehicle (25g). Maximum use should be made of the entire Surveyor System or, at a minimum, the Surveyor subsystems.

TABLE II. - EXPERIMENTS AS A FUNCTION OF PRIORITY AND MISSION

Priority	Mission[a]						
	AAP-1	AAP-2	AAP-3	AAP-4	AAP-6	AAP-7	AAP-8
1	Passive seismic package[b]	Passive seismic package[b]	Passive seismic package[b]	Passive seismic package[b]	Passive seismic package[b]	Passive seismic package[b]	Passive seismic package[b]
2	Vector magnetometer	Passive seismic package'	Corner reflector, laser ranging experiment, and/or Doppler transponder	Corner reflector, laser ranging experiment, and/or Doppler transponder	Vector magnetometer	Vector magnetometer	Passive seismic package'
3	Passive seismic package[c]	Active seismic experiment	Heat flow experiment	Vector magnetometer	Vector electric-field meter[d]	Vector electric-field meter[d]	Corner reflector, laser ranging experiment, and/or Doppler transponder
4	Heat flow experiment	Tidal and secular tiltmeter/gravity meter/strain-meter	Vector magnetometer	Tidal and secular tiltmeter/gravity meter/strain-meter[d]	Active seismic experiment	Long-period strainmeter (2 cps, dc)[d]	Active seismic experiment
5	Active seismic experiment	Heat flow experiment	Vector electric-field meter[d]	Long-period strainmeter (2 cps, dc)[d]	Tidal and secular tiltmeter/gravity meter/strain-meter[d]	Heat flow experiment	Heat flow experiment
6	Vector electric-field meter[d]	Vector magnetometer	Passive seismic package'	Passive seismic package[c]	Long-period strainmeter (2 cps, dc)[d]	Passive seismic package[c]	Long-period strainmeter (2 cps, dc)[d]
7	Tidal and secular tiltmeter/gravity meter/strain-meter[d]	Vector electric-field meter[d]	Corner reflector, laser ranging experiment, and/or Doppler transponder	Heat flow experiment	Passive seismic package'	Tidal and secular tiltmeter/gravity meter/strain-meter[d]	Vector magnetometer
8	Micrometeorite detector[d]	Micrometeorite detector[d]	Time-varying ground truth experiment[d]	Active seismic experiment	Heat flow experiment	Time-varying ground truth experiment[d]	Vector electric-field meter[d]
9	Time-varying ground truth experiment[d]	Time-varying ground truth experimentd	Active seismic experiment	Time-varying ground truth experiment[d]	Corner reflector, laser ranging experiment, and/or Doppler transponder	Active seismic experiment	Tidal and secular tiltmeter/gravity meter/strain-meter[d]
10	Corner reflector, laser ranging experiment, and/or Doppler transponder	Corner reflector, laser ranging experiment, and/or Doppler transponder	Tidal and tiltmeter/gravity meter/strain-meter[d]	Vector electric-field meter[d]	Time-varying ground truth experiment[d]	Corner reflector, laser ranging experiment, and/or Doppler transponder	Time-varying ground truth experiment[d]
11	Long-period strainmeter (2 cps, dc)[d]	Long-period strainmeter (2 cps, dc)[d]	Long-period strainmeter (2 cps, dc)[d]	Micrometeoritt detector[d]	Micrometeorite detector[d]	Micrometeorite detector[d]	Micrometeorite detector[d]

[a]AAP-5 is taken as an orbiting mission.

[b]The passive seismic package includes a three-component, long-period seismometer/gravity/tiltmeter variometer (2 cps, dc) and a short-period vertical seismometer.

[c]The passive seismic package includes a three-component, long-period seismometer/gravity/tiltmeter variometer (2 cps, dc) a short-period vertical seismometer, and two short-period horizontal seismometers.

[d]Experiments which need development or feasibility studies.

TABLE III. - PRIORITIES FOR GEOPHYSICAL OBSERVATIONS WHICH REQUIRE ASTRONAUT TIME

Mission[a]	Location	Priorities[b] 1	2	3	4	5	6	7	8
AAP-1 (single launch)	Copernicus	Emplace ESS	Gravity at the central station	Gravity at the ends of the LFU traverses	Heat flow at the central station	Local active seismic experiment	Heat flow at the end of the LFU traverses	--	--
AAP-2	Hyginus Rille	Emplace ESS	Gravity at the central station	Gravity at points in rill and on walls using LFU	Local active seismic experiment	Heat flow at the central station	Heat flow at the end of the LFU traverses	--	--
AAP-3	North Pole	Emplace ESS	Corner reflector emplacement	Heat flow in a permenantly shaded site	Heat flow at the central station	Gravity at the ends of the LFU traverses	Local active seismic experiment	--	--
AAP-4 (Dual launch)[c]	Marius Hills	Emplace ESS	Emplace corner reflector	Gravity at the central station	Gravity and radar or sonic soundings on traverses	Heat flow at the central station	Deploy 2 RGM Saturn IVB impact profile	Local active seismic experiment	Heat flow at the end of the traverses
AAP-6[c]	Aristarchus	Emplace ESS	Gravity at the central station	Local active seismic experiment	Deploy 2 RGM Saturn IVB impact profile	Gravity and radar or sonic soundings on traverse through rill region and into Cobra Head	Heat flow at the central station	Heat flow at the end of traverses	--
AAP-7	Apennine Front	Emplace ExESS	Heat flow at the central station (100-ft drill to be used)	Gravity at the central station	Gravity and radar or sonic measurements on traverse	Emplace 2 RGM Saturn IVB impact profile	Local active seismic experiment	Emplace corner reflector	Heat flow at the end of traverses
AAP-8	Sabine and Ritter	Emplace ExESS	Heat flow at the central station (100-ft drill to be used)	Gravity at the central station	Gravity and radar or sonic measurements on traverse	Emplace 2 RGM Saturn IVB impact profile	Local active seismic experiment	Emplace corner reflector	Heat flow at the end of traverses
AAP-9	Alphonsus	Emplace ExESS	Heat flow at the central station (100-ft drill to be used)	Gravity at the central station	Gravity and radar or sonic measurements on traverse	Emplace 2 RGM Saturn IVB impact profile	Local active seismic experiment	Emplace corner reflector	Heat flow at the end of traverses

[a]The AAP-5 mission is an orbital mission.

[b]The priority for each mission may be revised in the light of the curtailment of objectives in earlier missions and the success or failure of experiments on the earlier missions.

[c]All seismic instruments must be operating during the Saturn IVB impact period.

The RGM concept was developed for the deployment of instruments for experiments that require a more widespread spatial coverage than will be supplied by the landings and traverses. The PSE and the large-scale ASE, which uses the passive array, have the greatest need for wide deployment. Consequently, the RGM is much less complex and requires much less integration than the ALSEP.

TRAVERSE GEOPHYSICS

The development of vehicles of the LSSM type that can be operated in either a manned or unmanned mode opens the opportunity for long geophysical traverses on profiles 100 to 1000 kilometers in length. These geophysical traverses are important for studying lateral variations on the Moon and form a bridge between the intensive observations that are made in the immediate vicinity of the landing sites and the extensive observations that can be made from orbit. Geophysical experiments that should be conducted on traverses are

1. Deep Seismic Sounding to measure the thickness of any seismic layers present on the Moon and the velocities within these layers and to investigate regional variations in layering and velocity structure

2. Gravity measurements to determine the nature and extent of isostatic balance on the Moon and the deep structure of significant geological features

3. Local active seismic measurements to measure the near-surface properties and the velocity of the basement rocks below this layer; continuous profiling to obtain the thickness of the debris layer by electromagnetic or sonic techniques

4. Magnetic measurements, along with measurements of remanent magnetization of surface samples, to contribute to knowledge of the intensity and direction of the permanent magnetization of parts of the Moon above the Curie-point isotherm'

5. Electromagnetic measurements to detect the presence of water and to determine the conductivity, dielectric constant, and thickness of near-surface layers

6. Heat-flow measurements

The traverse experiments will provide data pertinent to the following questions:

1. Is the Moon radially layered and what is the magnitude of the lateral variations in structure and composition?

2. Does the Moon have a crust?

3. How thick is the crust and what is the gross structure and composition?

4. What is the structure of and origin of geological features, such as craters, rifts, rills, and volcanic cones?

5. What is the depth of the surface debris?

6. Does water occur near the lunar surface?

Gravimeter Experiments

Two classes of gravimeters have been considered for lunar measurements — tidal gravimeters and portable gravimeters. The principal purpose of tidal gravimeters is to measure temporal variation in gravity at fixed points. The total temporal variation in gravity at any point on the Moon is about 1 milligal. A tidal gravimeter, if it is to discriminate between models of different rigidity for the Moon, probably has to have a sensitivity of 1 microgal or better. Such an instrument is considered for installation in the ESS; however, it would not be suitable for use as a portable gravimeter for traverse geophysics.

Portable gravimeters will be lightweight and low in power consumption. They will not be required to have the sensitivity of tidal gravimeters (0.1 or 0.2 milligal adequate) but will have the requirements of a larger operating range (several thousand milligals). An essential requirement for the portable gravimeters will be that the measurements be tied to gravity measurements on Earth.

Purpose of gravity experiments. - On Earth, gravity measurements have been made at three different scales to obtain the figure of the Earth, to obtain information in regional studies conducted over hundreds of kilometers, and to solve structure problems related to geological features a few kilometers in extent.

Since only a limited number of gravity measurements can be made on the Moon, the figure of the Moon is best determined from Lunar Orbiter studies. Gravity measurements at ESS sites and along traverses will provide ground truth checks for orbital gravity determinations, provided harmonics of a high enough degree and order have been determined and provided surface measurements are made in areas of low gravity variability.

Regional gravity studies have a principal use in that they can be used to estimate the state and extent of isostatic equilibrium. Comparison of gravity values in mare and highland areas are of great interest. Single measurements of gravity at mare and highland sites can provide some information, but the value depends on the variability of gravity at these sites. Even two or three measurements within a radius of a few kilometers will be very useful. Regional gravity measurements along long traverses (500 to 1000 km) will provide information about regional isostatic balance. The regional gravity gradients will also provide information about the maximum depth at which lateral density variations can exist. If detailed structure is obtained by seismic refraction, gravity measurements will not only provide a check on the structure but will also indicate whether deeper density variations also exist.

Local gravity studies will provide information about near-surface density variations and will give clues to the structures of features, such as rills, small craters, faults, graben, et cetera, and possibly provide information regarding the depth of lava and debris layers.

Instrument requirements. - Portable gravimeters can probably be constructed by the modification of existing instruments with weights of about 10 pounds and power requirements of about 10 watts. An accuracy of 0.1 milligal is also achievable on the basis of present instrument design. Accuracy of this order is useful for detailed local gravity surveys. A lower accuracy (10 milligals) is sufficient for regional surveys, but it is probably worthwhile to use the same type of instrument on local and regional surveys. Other instrument requirements are the following:

1. The instrument should have very low drift (probably less than 0.1 milligal per day). Any drifts should be linear.

2. The instrument should possess automatic leveling and reading capabilities.

3. It should be possible to check the calibration of the instrument (reading versus gravity) remotely.

4. The instrument should be capable of measuring in the lunar and Earth gravity fields so that direct ties can be made.

Navigation requirements. - For local studies (which will be in the manned mode), the desirable accuracy of gravity measurements is 0.1 to 0.2 milligal. To determine the free-air correction to 0.2 milligal, elevations accurate to 1 meter are required. It will be desirable to have horizontal distance control to ±10 meters. These navigation accuracies are required only with respect to the landing site.

For regional studies (500- to 1000-km traverses in the unmanned mode), the required accuracy of gravity measurements is 10 milligals. Horizontal positioning to an accuracy of several hundred meters and vertical positioning to an accuracy of 50 meters should be adequate. These traverses and landing sites will have to be tied into a Moon-wide reference system.

Mobility requirements. - The small weight of the portable gravimeter will enable it to be carried on any of the mobility devices, such as the LFU or the LSSM (manned and unmanned modes).

Special requirements. - The development of a lightweight navigation system that can be carried on the mobility device would be very useful for gravity studies.

Mapping of the lunar topography from orbital studies to an accuracy of ±100 meters is a necessary requirement for gravity studies.

Lunar Deep Seismic Sounding (LDSS). - The LDSS Experiment has a scale intermediate between the local Active Seismic Experiment and the Passive Seismic network over the entire Moon. As such, the experimental results should provide information about (1) the Moon to depths of several tens of kilometers, (2) the thickness and structure of any lunar crust, and (3) the nature of isostatic compensation, if present.

In the proposed experiments, an array of seismometers is deployed by the astronauts in the vicinity of the landing site using an LSSM; and after the departure of the astronauts, the LSSM would be used in the unmanned mode to deploy seismometers

along a traverse. A source of seismic energy would be provided by the impact of expended space hardware or by a special launch of one of the lower cost delivery systems.

The LDSS Experiment appears to be feasible with minor modifications of hardware developed for the Apollo Program, but attempts should be made to develop hardware specifically designed for this experiment before the flight of the first dual-launch missions in late 1971 or 1972. Although the proposed experiment is primarily an active experiment, the seismic systems will also form a part of the passive lunar seismic network.

A similar experiment on an even larger scale utilizes remote geophysical monitors deployed from orbit which, in conjunction with the ESS and the Saturn IVB impact, constitutes a Moon-wide Active Seismic Experiment.

Seismometers. - An RGM (including triaxial intermediate-period (1 to 5 sec) seismometers capable of recording over a 1- to 20-Hz band) is proposed for deployment. Each RGM will have an individual power supply and telemetry.

A major uncertainty (in 1967) in the design of the RGM experiment is the unknown seismic noise level. If the seismic noise level on the Moon in the 1- to 10-cps band is several orders of magnitude less than on the Earth, the sensitivity of seismic systems should be increased to make optimum use of the available sources. The feasibility of deploying a seismic array which is tied to the RGM by electric wires has not been demonstrated, but this possibility should be evaluated.

Sources. - The expended Saturn IVB stage is an attractive source of seismic energy with a mass of 38 000 pounds and an impact velocity greater than 7500 ft/sec. The seismic waves generated by such an impact could be recorded to a range of at least 200 kilometers in an Earth environment. With a low seismic noise level on the lunar surface this impact could perhaps be recorded to distances of 1000 kilometers or more.

The expended lunar module (LM) offers a second possible energy source. The LM mass of approximately 6000 pounds could be impacted with great precision using the LM guidance system with little added cost to the program.

The Thor-Delta, Atlas-Agena, Atlas-Centaur, or Titan IIIC, could also be used to deliver one or more seismic sources. This approach would involve the added expense of a special launch, but might offer compensating advantages in achieving an optimum mass-to-velocity ratio, multiple impacts from a single launch, and control over the timing of impacts.

Weight. - Because seismic sources are expected to be provided by special launches or by expended space vehicles, the only additional weight on an AAP mission would be that of seismometers, amplifiers, cables, power supply, telemetry, and perhaps the equipment needed for the extra guidance requirements. The weight of each RGM package will not exceed 80 pounds. At least six packages should be deployed along a traverse. Additional RGM packages would be desirable, if the package weight can be reduced.

Data transmission. - Data transmission will be required for 10 minutes during and immediately following the time of impact. A data rate of 1200 bps for each seismometer or 3600 bps for each RGM in operation is required. Data compression and digital data storage systems should be developed to reduce the load on communication facilities.

Astronaut time. - Astronaut time will be required for installing the seismic array at the landing site and for preparing the LSSM for unmanned operations at the end of the manned mission.

Mission schedule. - The full-scale LDSS experiment cannot be scheduled before the first dual-launch mission in 1971 or 1972, because it depends on the presence of the LSSM; but parts of the experiment can be implemented in earlier missions. The impact of the Saturn IVB could be tested in the first AAP missions if the seismometers in the Apollo Lunar Surface Experiments Packages used in the AAP are successful.

Data on the seismic background noise and the efficiency of explosive sources from the ALSEP Passive and Active Seismic Experiments will be used for the final design of the LDSS profile. The first LDSS profile should be short, about 300 kilometers; later profiles can be extended if initial results are favorable.

Local Active Seismic Experiment. - Short seismic profiles should be installed by the astronaut in the vicinity of the landing site and executed after the departure of the manned mission. The type of seismometer arrays developed for the ALSEP are ideal for the experiment, and the arrays can also be used as part of the LDSS profiles described previously.

The local seismic measurements will determine the thickness of the debris layer and the seismic velocities in the deeper material. By comparison with the seismic velocities measured on short refraction profiles with seismic velocities measured in samples of known composition, the composition of the deeper layers might be inferred.

The active seismic measurements conducted near the landing site will provide important calibration for echo- or electromagnetic-bounding experiments that will be carried on long traverses.

During early AAP missions when the mobility is limited to an LFU, the astronaut could deploy a geophone array consisting of three to five detectors over a 500-foot profile. The array would be tied to the ESS package. The astronaut could also deploy explosive charges (2 lb or less) on traverses with the LFU at various distances from either end of the geophone array. The charges would be fired after the astronaut departs.

The amplifiers, data storage, and telemetry electronics can be contained in the ESS. Miniature 4.5- to 7.5-hertz geophones can be used as the detectors. For the active listening mode, the system should have a pass band from 3 to 50 hertz and a minimum capability to detect 1 millimicron of ground motion at 10 hertz with a 19-decibel signal-to-noise ratio. This sensitivity has been achieved in the ALSEP program. The central-station electronics will allow a reduced bandwidth of (<10 to 20 Hz) in the passive listening mode.

During dual missions, the local ASE can be extended in dimension. As the **LSSM** traverses away from the ESS, a cable with detectors will be unreeled behind the moving vehicle. Explosive charges (10- to 15-lb maximum) can be emplaced at distances ranging from 1 to 8 kilometers from the end of the array. The length of the array that can be effectively deployed and the optimum positioning of the charges should be studied. The array, which is tied to the ExESS, can also monitor in a passive mode and be used in eonjunction with the LDSS experiments.

Continuous recording of the thickness of the debris layer will be extremely useful in resolving near-surface structure. This measurement may be very important in defining geological contacts and structures. Methods of continuous profiling by sonic or electromagnetic techniques along the traverse in the manned and unmanned modes should be examined and developed. Feasibility studies should be conducted.

Heat-Flow Experiments

A general discussion of heat-flow measurements is given in the section on Emplaced Scientific Stations.

Heat flow could be measured on manned missions in several slightly different ways. At the central station, two or more drilled (3 m) holes similar to the concept used in the ALSEP could be utilized. As soon as equipment is available, a deeper hole (10 to 100 m) could also be used at the central station. In the early AAP, before the LSSM can be delivered to the lunar surface, single-hole heat-flow measurements will be made at the ends of 500-foot traverses made with the LFU or with the astronaut on foot. After the LSSM becomes available, holes of 3 to 10 meters are proposed (rather than the shallower holes used earlier). The deeper holes are more useful for heat-flow observations, and the availability of the **LSSM** weight to load the drill enhances the feasibility. Stations deployed by the astronaut will make use of cable linkage to the central station for communication and power, which may be shared with the Active Seismic Experiment. Stations deployed by the LSSM will be adjacent to remote geophysical monitors and will rely on the monitors for power and telemetry. The development needs include a vibrodrill, the possibility of measurements in an unmanned mode from the Augmented Surveyor and from vehicles at the ends'of unmanned traverses, and feasibility studies of NQR temperature sensors.

Electromagnetic Experiments

The radar reflectivity experiment is discussed below. The magnetic variation deep sounding experiment is discussed under magnetic experiments. Other possible electromagnetic experiments are considered in the section on Supporting Research and Technology.

Within the radar scattering band (10^5 to 10^{11} Hz), energy is returned from the lunar surface and interior by specular reflection from smooth surfaces, by diffuse reflection from rough surfaces, and by scattering from discrete objects, such as boulders on the lunar surface or buried within the depth of penetration of the electromagnetic

wave. Within the 10^5- to 10^7-hertz band, the scattering from discrete objects is unlikely to be a major contributor to reflected energy, except for objects in the 30- to 300-meter range. Antenna beam widths, from an engineering viewpoint, probably cannot be minimized to the same extent as in the band 10^7 to 10^{11} hertz. Hence, the reflection from rough surfaces may be difficult to separate from the specular reflection from smooth surfaces. However, in the 10^5- to 10^7-hertz band, the product of the dielectric permittivity and frequency is expected to be of the same order as the electrical conductivity for lunar materials which permits measurement of conductivity and dielectric permittivity if measurements are made over a range of frequencies.

The depth of penetration into the lunar interior of electromagnetic waves in the frequency range 10^5 to 10^7 hertz is probably tens of meters and maybe several kilometers. Hence, deep layering (if it exists) can be mapped. The effect of surface roughness decreases in importance relative to specular reflection as an interface is made deeper.

Based upon current knowledge of the dielectric constants and electrical conductivities of Earth materials (as functions of frequency, moisture content, and temperature), dry materials will not exhibit dielectric constants much larger than 10, but values can be much in excess of 10 if moisture is present. Dielectric constants increase inversely with frequency, and values as high as 10^8 have been observed at frequencies of the order of 1 hertz. The conductivities can increase by several orders of magnitude as the frequency increases from 10^2 to 10^7 hertz. If an apparent dielectric constant significantly in excess of 10 (a power reflection coefficient significantly in excess of 0.25) is observed, then it can be stated with some assurance that either water or ice exists within the first tens of meters to several kilometers depth range. The only known conflict with this statement arises if rocks at temperatures in excess of 500° C exist within the same depth range. Such high temperatures at shallow depth will be obvious from the results of other proposed experiments; hence, it seems that the unique detection of the presence of water in the outer kilometer is achievable from lunar traverse.

If the frequency could be lowered to 10^4 or even 10^3 hertz, then the depth of penetration would be greater and the dielectric constants higher. Hence, there is a real need to attempt to expand the frequency range to 10^3 to 10^7 hertz. Unfortunately, the electron plasma frequency of the interplanetary medium at approximately 10^4 hertz could lead to difficulties in making lunar interior studies below about 10^5 hertz.

Continuous mapping of the debris layer along all manned and unmanned traverses and the determination of the presence of any water or ice that may be on the Moon is a principal objective of the radar reflectivity experiment. Weight and power are expected to be about 15 to 30 pounds and 20 to 50 watts, respectively. The presence of an astronaut is not required for the experiment. The possible adaptation of the Allouette CW-FM topside sounder to this task should be investigated. The radar reflectivity unit must be located on the traverse vehicle so that the vehicle does not produce spurious signals.

Magnetometer Experiment

It is desirable to study the permanent magnetization of that part of the outer Moon which is below the Curie point. The induced magnetization by the solar-wind magnetic field is presumably below the detectable limit of the magnetometer now available, except for rocks with high iron content.

It is recommended that a magnetometer be constructed as one module available for inclusion in all traverse missions.

If lunar rocks are magnetized, magnetic surveys on short traverses would chiefly investigate, with other geophysical and geological methods, the subsurface material and would throw light on the origin of those features recognized in photographs of the lunar surface as being possibly tectonic, such as rills, faults, and domes.

The objectives of magnetic surveys on long traverses would be (1) to investigate whether the outer part of the Moon (that is, above the Curie-point isotherm) is permanently magnetized and, if so, whether there is any pattern which might be useful in dating the lunar surface and in the study of the evolution of the Moon; (2) to monitor the magnetic-field time variations at the surface of the Moon to assist in determining the radial variation of electrical conductivity within the Moon; (3) to sample the spatial magnetic-field variations on a long traverse arising from the upper part of the Moon (The depth of the Curie-point isotherm may be obtained from the spectrum. Such spectra obtained over high and low areas of the selenoid or over maria and upland may be different and would clearly give information of the relative depths of the Curie-point isotherm under the provinces and of the size and distribution of the regions of anomaly.); and (4) to perform the magnetic-variation deep-sounding experiment.

If the magnetic-field perturbations arise from a statistically uniform inducing field over a substantial portion of the lunar surface, then measurement of the ratio of the vertical component to the total horizontal component of the perturbation magnetic field, as a function of frequency, yields information on the distribution of the conductivity and permeability within the lunar interior. Traverse missions can define lateral changes in the electrical parameters which might be related to thermal anomalies. The experiment would be conducted with a pair of three-component flux' gate magnetometers of bandwidth 0 to 10 hertz and of sensitivity at least as good as 0.1 gamma. On manned traverses, one of these instruments can be the one at the ESS. The other instrument will be mounted on a long boom attached to an LSSM, or (alternatively) towed behind the vehicles in a magnetically clean environment. The surface vehicle will be required to stop to make an observation, and the length of the stop will dictate the longest period of magnetic fluctuation which can be monitored for this purpose. The longest period of magnetic fluctuation, in turn, dictates the depth of exploration. If gross changes in the inducing fields (the interplanetary field fluctuations) are encountered over distances of the order of the traverse length, then difficulties may be expected in interpreting the resulting data. There is no reason why such measurements could not be extended above 10 hertz, provided adequate magnetic fields are present. In the audiofrequency band, the measurements would be made with induction coils. Previous orbital or ESS measurements of ambient electromagnetic noise levels are required for intelligent selection of the bandwidth for the experiment. The lower the frequency used, the greater the depth of exploration. The anticipated instrument weight is 15 pounds, and the power consumption is approximately 5 watts.

Summary of Candidate Experiments

A summary of the candidate experiments follows:

1. A portable gravimeter on all traverses including LFU traverses on Saturn V single-launch missions

2. A local Active Seismic Experiment on an approximately 500-foot-array scale on Saturn V single-launch missions, with 1- to 8-kilometer arrays on dual-launch missions (deployment by LSSM)

3. An LDSS experiment (deployment of sensors on all dual-launch missions)

4. Continuous electromagnetic/sonic soundings on all LSSM traverses

5. Heat-flow measurements

6. Magnetometer measurements

Supporting Research and Technology for Traverse Experiments

Gravimeter measurements. - Existing instruments can be modified to build a lunar gravimeter with 0.1-milligal sensitivity, several-thousand-milligal measuring range, and the capability of making measurement ties with Earth sites. The instrument will require automatic leveling, calibration, and reading capabilities. The development requirement for making the necessary modifications and tests is strongly recommended.

The development of a lightweight navigation system that can be carried on the mobility device is desirable for gravity studies. The system should provide a navigation accuracy (expressed in meters) of $X = \pm 10$, $Y = \pm 10$, and $Z = \pm 1$ in the manned mode and of $X = \pm 200$, $Y = \pm 200$, and $Z = \pm 50$ in the unmanned mode.

Seismic sources for the long-profile active experiment. - Except for local measurements, the emplacement of explosive sources on the lunar surface does not appear to be advisable. A pound of mass is required to decelerate a pound of mass for soft landing on the lunar surface so that more than one-half of the potential explosive energy is wasted if the explosives are soft landed. In the Earth environment, buried explosives are always a much more efficient source of seismic energy than explosives detonated on the surface. There is some evidence that an impact source may have characteristics similar to those of buried explosive sources. Research is needed on the seismic efficiency of impact sources, particularly to determine the mass-to-velocity ratio that will provide optimum efficiency.

Attractive possibilities for impact sources are listed in table IV. Because the Saturn IVB and the expended LM impacts appear to be the least expensive, they will probably be the first choices for impact sources; but special advantages might be achieved through the additional control on mass, velocity, number of sources, and timing that is provided by a separate launch. The feasibility and the advantages of a separate launch should be evaluated. Systems to determine the time and location of

impacts need to be examined and developed, if not available. Time of impact to 0.1 second and location to ±1 kilometer, or better, are desirable.

TABLE IV. - POSSIBILITIES FOR IMPACT SOURCES

System	Mass, lb	Velocity, ft/sec	Guidance	cost, millions of dollars
Saturn IVB	38 000	7500	Saturn[a]	--
LM	4 700	5000	LM[b]	--
Thor-Delta	150	7500	Missile guidance[a]	≈1
Atlas-Agena	--	7500	Missile guidance[a]	8.0
Atlas-Centaur	5 500	7500	Missile guidance[a]	10.0
Titan IIIC	--	7500	Missile guidance[a]	18.0

[a]The accuracy is ±500 kilometers without midcourse correction. Accuracy can be improved with midcourse correction.

[b]The LM fuel residual is marginal, and additional fuel may be required to impact.

Seismic recording systems. - An RGM containing at least a three-component short-period seismic system with an independent power supply and Moon-to-Earth telemetry system is required. This system must weigh less than 80 pounds so that an adequate number of instruments can be deployed.

Research is needed to reduce the weight of the RGM package. The effectiveness of the LDSS Experiment increases with the number of seismometers that are emplaced along the traverse, and the number that can be emplaced is inversely proportional to the weight of each package.

The following possibilities for weight reduction should be evaluated.

Telemetry requirements: The telemetry requirements might be greatly reduced by limited operation of the RGM package and/or by an onsite data-selection process. This requirement would involve a data-reduction and storage mechanism. Telemetry requirements might be reduced by telemetry to an orbiter.

Seismometer sensitivity and pass band: Weight reduction might be achieved by limiting the pass band of the seismometer, but requirements for high sensitivity which cannot be evaluated before the first successful seismometer is emplaced on the Moon could force an increase in seismometer weight. This trade-off should be evaluated.

Arrays: It may be possible to emplace a number of seismometers along an array 10 kilometers or more in length connected by hard wire to a central telemetry station. This possibility should be evaluated.

Local active seismic measurements. - The ALSEP active seismic electronics package, with minor modifications, is an ideal package for local surveys at the landing site. Local seismic measurements along the unmanned traverses will require the development of a new system. Feasibility studies of this system are required.

Continuous profiler. - Continuous profiling by electromagnetic sounding or sonic means along manned and unmanned traverses will require the development of a new system. Feasibility studies of this system are required.

Heat flow on traverses. - It is desirable to upgrade the drilling capability to extend the depth that is feasible and to simplify the drilling of 3-meter holes. A percussive drill mounted on the LSSM can take advantage of the weight of the vehicle for loading the drill. A 10-meter depth should be a reasonable design goal. The use of vibro-drills for achieving emplacement of the experiment to a depth of 3 meters should be explored in the interests of simplifying emplacement. A very important ultimate goal of this development would be fully automatic drilling so that heat flow could be measured from unmanned vehicles.

A second area of development is improved sensors. The NQR thermometer is an example of a device that offers an attractive possibility to improve the platinum resistance thermometers that are used in ALSEP.

Electromagnetic experiments. - Six passive and seven active electromagnetic methods, spanning the frequency band from dc to 10^{11} hertz, have been considered for lunar traverse missions. These methods are as follows.

Passive systems:

1. Diffusion of interplanetary field lines through the Moon
2. The separation of magnetic fields of origin internal and external to the Earth
3. Natural dc electrical fields
4. Telluric current method
5. Magnetotelluric method
6. Magnetic variation deep sounding

Active systems:

1. Resistivity method
2. Induced electrical polarization method

3. Fixed transmitter, inductive method 1 to 10^5 hertz

4. Mobile transmitter, inductive method 1 to 10^5 hertz

5. Radar reflectivity, 10^7 to 10^{11} hertz

6. Radar reflectivity, 10^5 to 10^7 hertz

7. Capacitive coupling method

Based upon the current knowledge of the lunar environment and of instrumental technology, two of these methods (magnetic variation deep sounding and radar reflectivity, 10^5 to 10^7 hertz) are recommended for use in lunar traverses and three others (fixed transmitter inductive method, 1 to 10^5 hertz; module transmitter inductive method, 1 to 10^5 hertz; and radar reflectivity, 10^7 to 10^{11} hertz) are recommended for feasibility studies. A further feasibility study is recommended to determine whether or not the radar reflectivity (10^5 to 10^7 hertz) may be extended to lower frequencies.

Specific recommendations for traverse experiments. - The recommendations for the traverse experiments are as follows:

Experiment related: The design of alternative antenna designs for the most efficient use of radar depth sounding on lunar surface traverses should be supported.

Laboratory investigations: Laboratory measurements of the dielectric constant and electrical conductivity are required for simulated lunar materials under the following conditions:

1. Frequency variable, 10^{-4} to 10^{11} hertz

2. Moisture variable, vacuum dried to saturation

3. Temperature variable, -150° to 1000° C

Supporting experiments: It is recommended that ambient noise levels be monitored in the frequency range of 10^{-4} to 10^{11} hertz from early Lunar Orbiters or from early lunar landers.

Theoretical analyses: A theoretical analysis is required to determine the relationship between the electric fields and the magnetic fields of the solar wind at the surface of the Moon and the distribution of electrical parameters in the interior of the Moon.

A theoretical analysis is required to determine whether or not the communication link between the Apollo LM and CSM may be used for determining electrical parameters of the lunar interior.

Feasibility studies: The feasibility of electromagnetic mutual coupling induction experiments should be examined.

It is highly desirable that the radar reflectivity measurements be extended below 10^5 hertz, and a feasibility study should be supported to determine whether or not this is possible.

A feasibility study should be initiated on radar sounding of the debris layer using the 10^7- to 10^{11}-hertz frequency band.

Magnetic measurements. - The following magnetic measurements are related to experiments:

1. A three-component, flux gate magnetometer of 0.1 gamma noise level will require mounting on a boom on the roving vehicle or will be towed from the roving vehicle. A study should be undertaken to find the best configuration and means for mounting the magnetometer and compensating for the presence of the vehicle.

2. The development of an automatic orienting and leveling device within the power and weight limitations of the unmanned roving vehicle and of the LSSM should be supported. This task should be correlated with the requirements for the gravity experiment.

3. An investigation should be initiated to determine whether or not stability and sensitivity may be improved beyond 0.1 gamma for relative measurements of three components of the type recommended.

ORBITAL GEOPHYSICS

Rationale

Scientific studies of the Moon from long-lifetime lunar orbiting spacecraft provihe the only feasible method to explore the entire lunar surface and near-surface physical properties and to map the gravitational and magnetic fields of the lunar body. Surface missions for study of the Moon will provide landing and traverse capabilities at many sites, but these complementary studies will cover less than 1 percent of the lunar surface; Programs for orbital studies also represent a prelude to similar studies of the planets. The Space Science and Technology Panels of the President's Scientific Advisory Committee (PSAC) and the Space Science Board of the National Academy of Science (NAS) have recommended the exploration of the planets Mars and Venus as specific objectives of the post-Apollo NASA program. While certain instrumentation needed for the initial phases of lunar orbital studies is available, the entire field of remote sensing devices must be developed so that early orbital missions to Mars and Venus can employ these techniques with maximum confidence for optimum return of scientific results. Thus, while the exploration and study of the Moon progresses, a background of scientific and technical competence will be established that will be available for these long-range goals.

Recommendations

It is recommended that orbital missions be given a very high priority in the NASA program for lunar exploration for the two compelling reasons of an efficient, accurate study of the Moon and a test bed for techniques to be used in future exploration of the solar system. It is noted that the Lunar Orbiter (LO) and Anchored Interplanetary Monitoring Platform (AIMP) programs have just concluded the scheduled series of launches. This fact means that unless a follow-on series of such spacecraft is instituted now, there will be a gap of 4 to 5 years in orbital studies until at least 1971 or 1972, when the AAP will be able to provide the delivery system to place subsatellites in independent orbits.

Thus, it is strongly recommended that NASA include plans for a follow-on LO and AIMP series so that the initial studies may be continued. These studies would phase into the AAP programs so that continuity and a natural evolution of scientific studies could be maintained. Specifically, it is recommended that at least two follow-on AIMP missions in 1970 to 1971 be planned with three or more Lunar Orbiters during the same period, if not before. The instrumentation used should be reviewed and new experiments solicited in disciplinary areas which have yet to be studied. Major modifications to the existing spacecraft systems are not recommended, since this will require an excessive amount of resources of time and money. Each program offers unique capabilities in spacecraft orbit, attitude stabilization, and other technological features essential to each set of experiments.

The use of the subsatellite concept in the AAP is strongly endorsed. Studies prove the feasibility of carrying completely self-contained satellite systems, such as AIMP (or Pioneer), to the Moon in the CSM. Thus, planning of AAP missions in the post-1972 period should include at least two of these spacecraft and the capability of including an advanced Lunar Orbiter for mapping studies.

The scientific need for simultaneous measurements of the same phenomena, such as magnetic and electric fields from orbital missions and lunar surface stations, is strongly supported. The separation of complex lunar environmental and lunar interior physical properties can only be accomplished with such multiple detector systems. An evolving program is recommended. In the AAP, NASA should plan to provide the necessary orbital capability for more advanced measurements of the lunar environment and surface. The follow-on studies by AIMP should evolve also from loose orbits (at heights from 2000 to 7000 km) achieved by direct ascent to tight orbits (at heights of less than 2000 km) in high inclination achieved by subsatellites.

The Geophysics Working Group endorses the measurement of the lunar gravitational field and figure of the Moon recommended by the Geodesy and Cartography Working Group and the measurement of the lunar electric and magnetic fields recommended by the Particles and Fields Working Group.

Lunar Magnetic-Field and Body-Electrical Properties

The study of the lunar magnetic field is of great interest for understanding the present state of the interior of the Moon. It is also of great interest in attempts to understand the past history of the Moon, since the remnant magnetic properties of the

lunar material reflect the origin of the Moon. Study of the flow of the interplanetary medium past the Moon will yield information concerning lunar electrical properties and internal temperature, depending upon the specific radial distribution of electrical parameters (ϵ, μ, and σ). Orbital studies of this type have been initiated by Explorer 35 and demonstrate the potential of these efforts.

Instrumentation for these and related supporting measurements (see the report of the Particles and Fields Working Group) are in advanced states of development, having demonstrated successful performance many times in the IMP, Pioneer, EGO, Explorer, and Mariner series of spacecraft.

Visible. - The entire lunar surface should be photographed in stereo to a resolution of the order of 100 meters, with a large number of interesting sites photographed with 1-meter resolution. There appears to be no great need at present for general coverage at resolutions smaller than 100 meters. Four sets of pictures are required, two each near the sunrise and sunset terminators for best definition. A low-altitude polar orbit is required. Additional high-resolution photographic orbiters in very low altitude and launched from the CSM will have other important uses, including tracking manned and unmanned traverses and observing changes on the Moon. Changes could be natural, such as major seismic events and meteorite impacts, or manmade, such as the impact of a Saturn IVB stage for active seismic experiments.

In addition, the entire surface should be scanned photoelectrically at high Sun angle simultaneously through three narrow-bandwidth filters in the near UV, visible, and near IR ranges. Wavelengths of 2500 and 15 000 Å are provisionally suggested. Such pictures will provide high-quality albedo data and elucidate the small, but real, differences in color which occur from region to region on the Moon. The boundaries between the areas appear to be quite sharp in Earth-based photographs, and the actual widths and correspondence to other provinces will prove interesting.

Infrared radiometry (5μ to 30μ). - The temperature of the entire lunar surface should be mapped by infrared sensing techniques at several phase angles to a ground resolution of 100 meters. Of particular interest is the mapping of thermal anomalies and the correlation of these anomalies with optical and radar features. Continuous mapping of the Moon may give information on transient phenomena which occur on the lunar surface, such as the red spots reported in Earth-based observations: Because the lunar surface is very nearly in radiative equilibrium during the lunar day, thermal anomalies are readily detectable only during eclipses or at lunar night. However, eclipses do not occur on the far side of the Moon; hence, the temperature mapping must be done during the lunar night when temperatures are lower than during eclipses. The greatest variations in temperature distribution would occur just before lunar sunrise. Hence, the highest priority should be to map the Moon a few degrees on the nightside of the sunrise terminator. This will require 1 month of continuous mapping. If longer vehicle lifetimes are available, the mapping should be repeated at other times during the night, close to the sunset terminator.

The proposed mapping program will require a detector with a lifetime of at least 1 month which is capable of measuring the temperatures of surfaces as low as 30° K and of operating from orbit. It would be of great advantage for the detector not to require cryogenic cooling; such a detector does not presently exist. While it is possible to conceive of ways of cryogenic cooling, such as the evaporation of solid H_2, such

methods do not appear particularly attractive. It should also be remembered that it will be necessary to map other planets thermally; and for these missions, evaporative methods will not be possible. It is recommended that the development of a detector with the above requirements be encouraged and supported by NASA. If such a detector can be achieved within a short time, it should be used for the lunar mission; and, if not, then evaporative cooling or a similar system should be used. Nevertheless, the development of a detector which does not require cooling should continue to be supported because of the necessity for its use in planetary missions.

If possible, the IR mapping should be done simultaneously with the passive microwave mapping from the same vehicle. A low-altitude polar orbit is required.

Remote measurement of heat flow. - Measurements of the total heat flux by a radiometer from craters in high latitudes (above about 65°) might give a measure of the lunar heat flow. The higher latitudes contain a large number of craters which have regions in permanent shade; that is, never are exposed to sunlight. These craters, therefore, contain regions where temperatures are determined partially by heat flow from the interior and which never vary far from 30° to 70° K. Adjacent areas have daytime surface temperatures near several hundred degrees Kelvin; and consequently, there is a permanent lateral thermal gradient which produces a lateral heat flow that also contributes to the vertical surface flux. The magnitude of the lateral heat flow depends upon the thermal properties below the crater floor and the radius of the permanently shaded area. The possibility exists, therefore, that by measuring the total flux in high-latitude craters as a function of permanently shaded area, the vertical heat flow of the Moon could be extrapolated; and also some information about the physical properties of the material below the crater floors could be obtained. These measurements can be done at the same time and with the same instruments as the IR mapping program described in the preceding section.

The following are the requirements of the spacecraft to accommodate the experiments:

1. A polar orbit
2. Measurements in the 30μ to 300μ range
3. Resolution to about 100 meters
4. A fraction of 10^9 bps
5. Periodic telemetering of data
6. A weight of 50 to 100 pounds
7. Facilities for cooling the radiometric sensor

The laboratory development program consists of (1) engineering of the overall package, (2) design and development of a satisfactory sensor, and (3) feasibility experiments.

Spectral lines. - Compositional mapping of lunar areas by spectroscopic identification cannot be recommended at the present time for spacecraft missions because of the lack of experimental and theoretical research which is required to interpret the data. When such research is completed, this technique may be more promising. Laboratory work should be strongly supported during the 1967 to 1972 period.

The following items are the specific recommendations for laboratory work:

1. The relative role of emissivity and reflectivity should be determined for silicates at the appropriate temperatures.

2. The effect of the following on the reflectivity of geologically important materials should be extensively analyzed.

a. Surface films

b. Simulated solar-wind bombardment

c. Porosity and grain size

d. Shock metamorphism

3. Theoretical analyses of the reststrahlen for three-atom cells, five-atom cells, and n-atom cells in a lattice should be extended.

4. An infrared multichannel spectrometer or a rapidly sweeping frequency spectrometer should be developed.

Passive radiometric studies. - Radiometric experiments are technically feasible for Lunar Orbiter payloads on any conceivable time scale, because equipment has been and is being developed for Earth orbiting manned and unmanned meteorological satellites. In particular, a microwave imager has been developed and could readily be incorporated into a Lunar Orbiter vehicle. The scientific utilization of the microwave imager would be to provide a map of the thermal emission of the Moon from a depth approximately 0.5 to 2 meters below the surface. When flown in conjunction with an infrared radiometric mapper, the results could provide information on the thermal environment of the near-subsurface lunar material. The observations might reveal regions of thermal activity (if such exist), regions of anomalous emissivity, evidence of near-surface layering of denser materials, and regions having thermal properties different from those of adjacent regions.

The following items are typical experimental parameters:

Weight, lb	20
Power, W	20
Volume, ft^3	3 to 5
Telemetry, bps	50
Spatial resolution, km	5 for 100-km orbital altitude
Temperature resolution, °K	±1 (approximately)
Orbital constraints, altitude (polar orbit), km	50 (or higher)
Pointing accuracy, deg	0.3 (or less)
Utilization of astronaut	None

The above equipment parameters are those typical of the Nimbus microwave imager operating at a wavelength of 1.55 centimeters. Similar values would apply at other wavelengths escept that the antenna dimensions scale directly as the wavelength. At 1.55 Centimeters, the antenna is a flat-plate array with dimensions of 45 by 45 centimeters.

Thermal experiments, both infrared and microwave, are enhanced by sampling radiation from each point on the lunar surface at different times of solar illumination to provide a full interpretation in terms of the heating-cooling curve. This will probably require several missions. Furthermore, observations at several different wavelengths in the microwave range may give a measure of the thermal gradient because of the different depths of penetration of the different wavelengths.

Radar imagery. - A vast radar technology exists today, practically all of it adaptable for aircraft use and, in a few cases, for spacecraft use, Feasibility studies have been, and are being, conducted to determine the use of radar as a research tool for Earth-orbiting satellites. Such studies, and the technology developed, are directly applicable to the lunar exploration program.

The wide variety of possible radar experiments precludes a detailed discussion of each type. but typical objectives and experimental configurations can be indicated. The coherent radar imager and radar altimeter will be considered. The coherent radar imager is capable of producing a map of the lunar surface and/or subsurface at radar wavelengths from 3 meters to 3 centimeters. The longer wavelengths are to be preferred for greater depth penetration, but consideration should be given to dual-frequency observations (which need not be simultaneous) to give some depth resolution. The radar imager may reveal geological phenomena which escape photographic detection because of covering by a dust, or other, layer. Such observations may be extremely important in the site selection of future landing parties to choose those sites of maximum geological and geophysical interest.

Radar maps at frequencies close to those at which the radiometric imager is to be performed are particularly to be desired. Since the radiometric experiments respond to the product of the emissivity and the temperature and the radar observations respond to the reflectivity of the material, the interpretation of the microwave thermal data will be aided appreciably by the radar data.

Typical characteristics of a radar imager are presented; however, it should be noted that wide variations are possible.

Weight, lb	100 to 200
Power, W	100 to 500
Spatial resolution, m	[a]$\sim$100
Antenna size, m	[b]0.75 by 8
Frequency range, MHz	10^2 to 10^4
Orbital constraints altitude	not critical[c]

[a]100-meter resolution easily obtainable, higher resolution possible but does not seem necessary at this time, A swath width of $\sim$50 kilometers is typical.

[b]For 2 GHz (15 cm) in a 100-kilometer orbit.

[c]High inclination provides for greater lunar coverage.

The spacecraft stability is very severe in yaw but dependent upon frequency and desired resolution. The probable value is a few milliradians in both yaw and yaw rate (mrad/sec) and 1 deg and 1 deg/sec in roll and pitch and in roll rate and pitch rate.

If available and feasible, the astronaut will be of value in changing film in the data retrieval system. The large bit rate may preclude telemetry of data since bit rate depends upon resolution and number of polarizations transmitted and received; but, the rate might be approximately 10^8 bits per orbit.

Radar altimetry. - Another important radar experiment is the radar altimeter, an experiment well within current technology. Altitude information, to a resolution of 10 to 100 meters, will be of value to geodetic studies to determine the figure of the Moon. It is understood that radar altimetry will be included in the CSM of early Apollo missions, and this should be included in all Lunar Orbiters until such time that laser altimeters prove to be superior. Radar altimeters can be of the pulse or FM-CW types and are capable of giving the altitude profile of the surface below the spacecraft to an accuracy of 10 to 100 meters, depending to a large extent on the nature of the surface at the subsatellite point. As with radar imagery, altimetry is possible over a wide range of wavelengths.

A typical radar altimeter system might include the following parameters:

Weight, lb	15 to 30
Power, W	20 to 50
Antenna size, m	1 to 5
Altitude resolution, m	10 to 100
Telemetry, bps	$\sim 10^4$
Spatial resolution, km	5
Pointing accuracy, deg.	0.3 (or less)

Radar reflectivity (10^7 to 10^{11} Hz). - Radar scattering measurements are normally conducted in the frequency band 10^7 to 10^{11} hertz (8 mm to 20 m actual). Electromagnetic energy is returned from the lunar surface by specular reflection from smooth surfaces, by diffuse reflection from rough surfaces, and by scattering from discrete objects, such as boulders on the lunar surface or buried within the depth of penetration of the electromagnetic wave. The depth of penetration of electromagnetic waves of such frequencies is probably of the order of 1 to several tens of meters, In the radar scattering band, it is expected that the depth-to-shallow interfaces can be mapped if they exist, the dielectric constant of the material near the surface can be measured, and boulders and voids within the depth of penetration can be detected.

Scattering from discrete objects and reflection from rough surfaces may be separated, to some degree, from specular reflection by several procedures including narrowing the antenna beamwidth, measuring the depolarization, measuring the Doppler shift, and applying the techniques of the statistical communication theory. By these means, it is hoped that the ordered specular reflection may be extracted from the random reflection from rough surfaces and scattering from discrete objects.

Orbital measurements of radar reflectivity could map the distribution of dielectric constant in the near surface, would indicate the surface roughness in the radar sense, and conceivably, could give some indication of layering if it exists within the top several tens of meters, provided the ordered signal from specular reflection could be separated from the random scattering and reflection from other sources,

Radar reflectivity measurements are recommended for early unmanned orbital missions. Typical system parameters are like those for radar altimetry.

Radar reflectivity (10^5 to 10^7 Hz). - Within the band 10^5 to 10^7 hertz, the scattering from discrete objects is unlikely to be a major contributor to Moon return reflections, except for objects in the 30- to 300-meter range. Antenna beamwidth, from an engineering viewpoint, probably cannot be made narrow for longer wavelengths, nor can the side lobes be expected to be minimized to the same extent. Hence, the reflection from rough surfaces is difficult to separate from the specular reflection from smooth surfaces. However, in the 10^5- to 10^7-hertz band, the product of frequency and

dielectric permittivity is expected to be of the same order as electrical conductivity for lunar materials, which permits the measurement of conductivity, as well as dielectric permittivity, provided the measurements are made over a range of frequencies. The depth of penetration into the lunar interior in the 10^5- to 10^7-hertz band probably ranges from tens of meters to possibly several kilometers; hence, deeper layering can be mapped. The effect of surface roughness decreases in importance relative to the specular reflection as an interface is made deeper.

Based upon current knowledge of the dielectric constants and electrical conductivities of Earth materials as functions of frequency, moisture content, and temperature, dry materials will not exhibit dielectric constants much in excess of 10, but values can be much greater than 10 if moisture is present. Dielectric constants vary inversely with frequency, and values as high as 10^8 have been observed at frequencies of the order of 1 hertz. The conductivities can increase by several orders of magnitude as frequency increases, for example, from 10^2 to 10^7 hertz. If an apparent dielectric constant significantly in excess of 10 (a power reflection coefficient significantly in excess of 0.25) is observed, then it can be stated with some assurance that either water or ice exists within the depth range of the first tens of meters to a few kilometers. The only known conflict with this statement arises if rocks at temperatures in excess of 500° C exist within the same depth range. Such high temperatures at shallow depth will be obvious from orbital IR sensing; hence, it seems that the unique detection of the presence of water in the outer kilometer is achievable from lunar orbit.

An adaptation of the Allouette B satellite system should be considered for this task.

The following are typical systems parameters:

Weight, lb	20 to 50
Powers, W	100 to 300
Antenna size, ft	75 to 200
Telemetry	As per the Allouette B satellite system
Spatial resolution	≈altitude
Orbital constraints, maximum altitude (for reasonable resolution), km	150
Utilization of astronaut	None

If the frequency could be lowered to 10^4 or even 10^3 hertz, then the depth of penetration would be greater and the dielectric constants would be higher. Hence, there is a real need to expand the frequency range to 10^3 to 10^7 hertz. Unfortunately, the

electron plasma frequency of the interplanetary medium at 10^4 hertz could lead to difficulties in lunar interior studies at frequencies below approximately 10^5 hertz.

Gravity gradiometer in Lunar Orbiter. - The function of the gravity gradiometer would be primarily to supply information about the gravitational field of the Moon for harmonics of higher order than those obtained by orbital studies. Gradiometer data would be used to determine the isostatic balance between the mare and upland areas, yielding a broad coverage not attainable by traverse experiments.

An instrument of sensitivity 3×10^{-10} gal/cm or better would be required for such studies. Attention will have to be given to the problems arising from the attitude and motion of the orbiter while making the measurements. To define lunar surface gravitational features with wavelengths of the order of 30 to 40 kilometers, a readout time of 5 seconds or less should be attained.

Further considerations concerning the gravity gradient measuring instrument appear in appendix I.

Recommended Orbital Experiments

The AIMP and Lunar Orbiter direct-ascent programs should be extended. These programs would then phase into the AAP programs so that continuity and a natural evolution of scientific studies would be maintained.

Passive and active geophysical experiments should be incorporated into lunar orbiting missions of the AAP. The following are the recommended experiments, ~~of equal~~ priority :

1. Mapping of the lunar gravitational field. For extensive details, see the report of the Geodesy and Cartography Working Group. This experiment includes Doppler and ranging transponders in the orbiting craft for Earth observation and Doppler transponders on the lunar surface. A receiver and transmitter with large power requirements will be required. Corner cube retroreflectors are required in the orbiting spacecraft. A gravity gradient meter should be placed in the orbiting spacecraft.

2. The figure of the Moon. Combined radar and laser altimetry in conjunction with accurate orbit determinations of lunar ephemeris, orientation, and libration are to be used. Further discussion may be found in the report of the Geodesy and Cartography Working Group.

3. The magnetic field of the Moon. A complete description of the interplanetary magnetic field in the vicinity of the Moon is essential to our understanding of the electrical-conductivity distribution in the interior of the Moon and of the interaction of the solar wind with the Moon.

4. Large-scale regional variations of the lunar surface. Radar reflective measurements will indicate surface roughness, electrical parameters, and the structure of the outer portions of the Moon. Microwave and infrared thermal imagery provide a map

of the lunar surface at a resolution consistent with the requirements for geological exploration, geophysical traverse measurements, and selection of samples for return to Earth. Infrared reflectivity measurements are needed, A radar imager is needed to provide a radar map of the surface and subsurface to reveal features hidden by the rubble layer. Photographic coverage obtained simultaneously with the radar imaging is desirable, Visual photography and three-color photometry are needed to provide a visual and colorimetric map of the lunar surface.

Recommendations for Laboratory Feasibility Studies

The following are recommended for laboratory feasibility studies:

1. Laboratory studies of the electrical conductivity and dielectric constants as a function of frequency, temperature, and moisture content for simulated lunar materials should be conducted as soon as possible.

2. A laboratory study of the emission and reflection spectra of geological and possible lunar materials in the W and IR range should be supported.

3. A feasibility study should be conducted to determine whether or not orbital radar reflectivity measurements could be extended below 10^5 hertz.

4. Studies of the feasibility of the development of an instrument to make gravity gradient measurements in an orbiting spacecraft are recommended.

Long Range Possibilities

When the AAP is underway, orbital programs will be possible which will greatly extend the range of scientific payload and volume beyond that possible by using present orbiter spacecraft. At that time, new information will be available from first generation orbiters, geological exploration, and geophysical surface experiments and from returned samples. Orbital experiments probably not feasible for first generation orbiters should then be conducted, especially those with large power and weight requirements and those which require operation by the astronaut.

MISSION PROFILES

A summary of the mission profiles is shown in table V. Although specific missions are indicated for each flight in the AAP (table VI), the Geophysics Working Group considers the later missions to be flexible. As the lunar exploration program proceeds, such details as landing sites, experiments, and location of long unmanned traverses should be reviewed for each mission in the light of available data.

The proposed program leaves an array of geophysical instruments that, with time, extends across the front surface of the Moon. The array is extended with each successive mission. Also, the array provides the wide geographical coverage needed

TABLE V. - SUMMARY OF PROPOSED MISSIONS

Mission	Spacecraft	Date	Site	Mobility device	Geophysics payload, lb	Experiments
Apollo 1, 2, 3	LM, Saturn V	1968 to 1969	At least two mare sites	Foot	--	ALSEP
AAP-1	ELM, Saturn V	1970	Floor of Copernicus	2 LFU	300	1. ESS 2. Heat flow 3. Gravity 4. Local ASE
ASL-1	AS	1970	South Pole	--	125	1. Passive seismic 2. Corner reflector 3. Doppler transponder 4. Magnetometer
AAP-2	ELM, Saturn V	1970	Hyginus Rille	2 LFU	300	Same as AAP-1, plus magnetometer
ASL-2	AS	1970	Eastern Highlands	--	125	Same as ASL-1
AAP-3	ELM, Saturn V	1971	North Pole	2 LFU	300	Same as AAP-1, plus corner reflector
ASL-3	AS	1971	Southeastern Highlands	--	125	Same as ASL-1
AAP-4	2 ALM, dual launch, Saturn V	1971	Marius Hills with unmanned profile through Oceanus Procellarum	2 LFU, LSSM 25-km radius in manned mode, 500- to 1000-km traverse in unmanned mode	--	Manned mode: 1. ESS 2. Radar (or sonic) survey of layer 1 thickness 3. Gravimeter 4. Heat flow 5. Local ASE 6. Deploy 2 RGM, for a Saturn IVB impact profile 7. Corner reflector Unmanned mode: 1. Deploy 5 RGM at 10- to 100-km separation for Saturn IVB impact profile 2. Gravimeter, radar/sonic survey magnetometer (TV and Geological/Geochemical package will be included)
ASL-4	AS	1971	Repsold	--	125	Same as ASL-1
AAP-5	Orbiter, Saturn V	1972	--	--	--	1. Deploy 8 to 12 RGM 2. Orbital geophysics 3. Impact spent Saturn IVB
ASL-5	AS	1972	Far Western Highlands	--	125	Same as ASL-1
AAP-6	2 ALM, dual launch, Saturn V	1972	Aristarchus Region. Study Cobra-Head, Schröter's Valley, and rills in manned mode. Unmanned profile through Mare Imbrium	Same as AAP-4	--	Same as AAP-4
ASL-6	AS	1972	To be determined later	--	125	Same as ASL-1
AAP-7	2 ALM, dual launch, Saturn V	1973	Apennine Front with unmanned traverse toward Sabine and Ritter craters	Same as AAP-4	--	Same as AAP-4 but ExESS replaces ES
ASL-7	AS	1973	To be determined later	--	125	Same as ASL-1
AAP-8	2 ALM, dual launch, Saturn V	1974	Sabine and Ritter with unmanned traverse into Mare Fecunditatis across highlands	Same as AAP-4	--	Same as AAP-7
ASL-8	AS	1974	To be determined later	--	125	Same as ASL-1
UP-9	2 ALM, dual launch, Saturn V	1975	Alphonsus with unmanned traverse due east across highlands	Same as AAP-4	--	Same as AAP-7

TABLE VI. - SUMMARY OF PROPOSED AAP MISSIONS

Mission	Mission location	Location of lunar satellite stations	Length of traverses	Staytime, days	Desired date	Operating period	Hardware	Scientific experiments	Special requirements	Purpose
AAP-1	Floor of Copernicus	None	Short, for active seismic experiment	3	Early 1970	Emplaced station will operate 2 to 5 yr	ELM single-launch Saturn V 2 LFU	ESS gravity, heat flow, and active seismic Orbital geophysics	Manned ELM	Emplace augmented ALSEP-type central station (ESS). Conduct gravity and active seismic experiments on structure and variation of floor toward rim and at central peak of crater. Obtain heat-flow measurements.
AAP-2	Hyginus Rille near Hyginus Crater	Along short traverses	3 to 6 of 25-km radius by way of LFU	14 (or as long as possible)	Late 1970	2 to 5 yr for ESS; less for other experiments	Saturn V ELM LFU	Same as AAP-1, plus magnetometer	Manned	Investigate rills on 25-km to the N-W, to a string of small craters in rill, to the rill to the east, to a crack system W-SW toward Hyginus B, and to the higher land (of a possibly different material) N toward Schneckenberg.[a]
AAP-3	Near North Pole	--	25-km radius	As long as possible, but not less than 3	1971	2 to 5 yr for ESS; less for other experiments	Saturn V ELM LFU	Same as AAP-1, plus corner reflector	Same as AAP-2	Obtain regional geographic coverage for emplaced stations, install corner reflector near North Pole, investigate geographic variations of lunar heat flow and get heat flow in permanently shaded area to verify orbital measurement.
AAP-4	Marius Hills, unmanned traverse through Oceanus Procellarum	Manned mode: 2 RGM within 10 km or less Unmanned mode: 3 RGM with 100-km separation	Manned mode: several of 25 km Unmanned mode: 500 to 1000 km	14 (or as long as possible)	[illegible]	2 to 5 yr	2 LFU LSSM in manned and unmanned modes	Manned mode:[a] Same as AAP-3, plus radar/sonic survey and Saturn IVB impact profile Unmanned mode:[a] Gravity, magnetometer, radar/sonic survey, and TV and geological-geochemical package	--	Study geology of Marius Hills. Unmanned traverses yields typical gravity values for Mare Procellarum for comparision with other mare and highland areas. Traverse terminates at landing site of AAP-6. Examine and select samples for return to Earth.
AAP-5	Lunar orbit: various locations (see satellite stations)	45° N, 60° E 18° N, 18° E 20° N, 26° E 25° N, 20° E 0° N, 0° E 25° S, 35° W 40° S, 70° W 10° S, 10° E 30° S, 10° E 50° S, 10° E	None	None	[illegible]	2 to 5 yr	Semihard landing device Deceleration not to exceed 25g	Gravity meter, radio transponder, short-period seismic system, orbital geophysics	Orbital vehicle capable of deploying RGM	Emplace seismic stations in other sites than where manned landings are planned. Impact spent Saturn IVB stage for seismic source.[a]
AAP-6	Aristarchus region	--	Manned: 25 km per sortie Unmanned: 1000 km	14 (or as long as possible)	Late 1972	2 to 5 yr for ESS	LFU LSSM	ESS, electromagnetic/sonic depth sounder, gravity magnetometer, corner reflector, and heat flow with deep drill	Dual, manned mission	Manned geological investigation near Aristarchus Crater and Schröter's Valley. Deep drill heat flow near landing site. Long geophysical profile across typical maria, Oceanus Procellarum, and southern margin of Mare Imbrium. Local active seismic and gravity profile across Schröter's Valley (sensors deployed by LFU).[a]

TABLE VI. - SUMMARY OF PROPOSED AAP MISSIONS - Concluded

Mission	Mission location	Location of lunar satellite stations	Length of traverses	Staytime, days	Desired date	Operating period	Hardware	Scientific experiments	Special requirements	Purpose
AAP-7	Apennine Front	6 RGM along traverse	Manned: 1000 km Unmanned: 50 km	14 (or as long as possible)	Early 1975	2 to 5 yr	2 ALM 2 LFU LSSM ExESS	ExESS, gravity, magnetometer, electromagnetic/sonic sounder Orbital geophysics, and heat flow	Manned, dual launch, ALM	Examine Apennine Front with long unmanned geophysical traverse extending from the landing site into the Mare Vaporum, passing near Marco Polo, and terminating near Sabine-Ritter area.
AAP-8	Sabine-Ritter area	Form L-shaped array	1000 km in unmanned LSSM	14 (or as long as possible)	Late 1973	2 to 5 yr or longer for emplaced station	2 ALM Dual-launch Saturn V LSSM 2 LFU 1 ExESS 8 RGM	ExESS and 2 RGM radar, gravity, heat flow, active seismic Orbital geophysics	Manned, dual launch	Study structural differences between maria and highlands and mare-upland contact.[a]
[illegible]	Alphonsus area	Form L-shaped array with 25-km legs	1000 km in unmanned LSSM eastward from Alphonsus	14 (or as long as possible)	1974	2 to 5 yr	Same as AAP-8, except ESS used for ExESS	Same as AAP-8	Same as AAP-8	Investigate the deep structure of a lunar highland.[a]
Undefined mission	Lunar orbit	-	-	-	Open[b]	At least 1 month, preferably 1 yr	Equipment bay in CSM	Remote sensors at many wavelengths	Polar orbital capability missions desired, e.g., first mission of a dual mission	Acquire orbital remote sensing data. Because of weight, power, volume, or data retrieval constraints, experiment may exceed spacecraft capability of subsatellites.
Undefined mission	Lunar orbit	--	-	-	Open[c]	At least 1 month, preferably 1 yr	AIMP, Lunar Orbiter and follow-on series Advanced Lunar Orbit for multifrequency electromagnetic mapping	Magnetometer, active and passive electromagnetic (multifrequency) experiments	Dual mission not required, but overlapping and simultaneous operations required for certain experiments with orbiting SC and lunar surface stations	Inject lunar orbiting spacecraft into precise orbits (altitude < 200 km).

[a]Further details are presented in text.
[b]When any manned mission is flown with capability for experiment package.
[c]When any mission is flown with orbital subsatellite capability.

to study the deep internal properties of the Moon, as well as the dense local coverage necessary to study regional features and to reveal finer details. The use of unmanned LSSM traverses on the dual missions, several ending up at the landing site of the next mission, provides a great capacity for sample collection and ultimate return to Earth of some of the samples.

The combined use of orbit-deployed and traverse-deployed remote geophysical monitors provides a seismic network with the valuable capacity to perform both active and passive experiments.

Advantage is taken of each opportunity to obtain additional geophysical coverage of the Moon by means of experiments on orbiting vehicles. The full complement of orbital geophysical instruments including magnetometers; multiband radiometers, spectrometers, and imagers; radar and optical altimeters; and gravity instruments are included in many orbital missions to provide adequate coverage of the Moon. During the AAP, data on the back side of the Moon are obtained only by means of the orbital instruments.

Apollo Applications Missions

Proposed AAP missions are outlined in table VI. Special details and comments are detailed for some of these missions.

AAP-2 mission. - For the AAP-2 mission, heat flow, gravity, and local seismic experiments are executed and deployed on short LFU traverses. Traverses 3 and 4 would comprise a total of 50 kilometers at right angles to the rill. Gravity and magnetic profiles will be of significant help in interpreting the deep structure.

Investigation of Hyginus Rille, the most prominent of the lunar rills, will provide insight and information on the history and structure of the rills.

AAP-4 mission. - In the manned mode, an ESS will be emplaced near the landing site. The LSSM will be used in the manned mode to make a continuous radar (or sonic) survey of layer 1 thickness. Gravimeter and magnetometer readings will be obtained at a few hundred-meter intervals in the manned mode. Several heat flow measurements will be made; a corner reflector will be deployed; and two RGM will be deployed in an L-shaped array with an ECS at the corner.

In the unmanned traverse on the LSSM, six RGM will be linearly deployed with the ESS, and one RGM will be manually deployed. Continuous gravimeter, magnetic, and electromagnetic/sonic depth surveys will be made.

AAP-5 mission. - It is important that there be a period when seismic coverage is widespread and capable of locating seismic events over the greater part of the Moon. This coverage is necessary for studies of seismicity and of the relation of the seismically active areas to the surface features and for travel-time studies where fairly precise locations are necessary.

In 1972, emplaced scientific stations will be operating at the Marius Hills (near the South Pole) and at the North Pole. In 1973, ExESS will be emplaced near craters

Sabine and Ritter and at Mare Fecunditatis. Proposed sites will cover regions unlikely to be visited by other missions. Suggested sites are tentative and dependent on the timing of other programs.

AAP-6 mission. - A long traverse will complement an earlier traverse made during the mission to the Marius Hills. The traverse will terminate near the landing site of the Apennine Front so that samples collected along the route may be selected by the astronauts for return to Earth.

AAP-8 mission. - After an extensive manned geophysical survey and setup of an L-shaped 25-kilometer array (consisting of one ESS and two RGM), a long unmanned traverse will be run well into the highlands. The LSSM, while operating in the unmanned mode, will make gravity readings, radar and magnetometer surveys, and will deploy six RGM packages (three in the mare floor, three in the highlands) which will be used for active refraction and passive seismology.

AAP-9 mission. - After an extensive manned geophysical survey on the L-shaped subsatellite array, 25 kilometers on a leg will be tied to the ESS. The LSSM, unmanned, will deploy six RGM on a 500- to 1000-kilometer traverse. A Saturn IVB impact will be used as the seismic source for the active seismic refraction experiment.

Augmented Surveyor Missions

The Augmented Surveyor missions will provide regional coverage unattainable with manned landings, will permit placing corner reflectors at optimum locations, and will allow the investigation of interesting regions not accessible to manned landings. An operating period of at least 2 years is desired.

The following sequence is recommended for the unmanned missions. It is anticipated that the missions will begin about 1970 and proceed at the rate of 2 per year,

Mission	Region
AS-1	South Polar Region (75° S, 0° E)
AS-2	Far Eastern Highlands (3° S, 70° E)
AS-3	Southeastern Highlands (35° S, 50° E)
AS-4	Northwestern Mare near Repsold (50° N, 70° W)
AS-5	Far 'Western Highlands (10° S, 70° W)
AS-6, AS-7, and As-8	To be decided later, perhaps far side

REQUIREMENTS FOR GEOPHYSICAL EXPERIMENTS

Telemetry Requirements

Three types of geophysical experiments for lunar exploration are planned: (1) ALSEP or RGM type scientific packages placed on the Moon which transmit data continuously for an extended period of time, (2) traverse geophysics which transmit at relatively high rates for limited periods (a few days or months), and (3) orbiting satellites with geophysical experiments which transmit data continuously, when feasible.

Emplaced stations. - The estimated total number of separate emplaced stations transmitting data from the Moon and the total bit rates as a function of time are listed in tables VII and VIII. In preparing these tables the following assumptions and constraints were used

1. In determining the number of stations, only the landed scientific packages have been considered. These packages include the ESS, the RGM, ,and the AS.

2. The following continuous information transmission rates are adopted for computing total bit rates:

Package	bps
ALSEP	1000
ESS	2000
RGM (unmanned)	500
RGM (man deployed)	1000
AS	2000

3. Two sets of tables are presented. The first set is based on an assumed lifetime of 18 months for all emplaced stations (table VII). The second set is based on an average lifetime of 12 months (table VIII).

4. In the tables it is assumed that each dual mission deploys 1 ESS, 2 RGM (manned), and 6 RGM in unmanned mode.

Traverse geophysics. - The manned and unmanned traverses are listed separately in table IX. These traverses operate for relatively short periods of time, and they require a high rate of data transmission capability. Exact data transmission rates are uncertain at present because of still undefined experimental procedures. A definite requirement is continuous TV imagery on each traverse. Another requirement is to transmit at a rate of about 3600 bps for each RGM for 300 seconds by 8 stations on the traverse during an active seismic experiment.

Orbital Geophysics. - The estimated geophysical data transmission from orbiting satellites is summarized in table X. Visible and high resolution infrared imagery require high data rates and may require orbital experiments which are capable of film package return to Earth.

TABLE VII. - NUMBER OF EMPLACED GEOPHYSICAL STATIONS AND ESTIMATED DATA TRANSMISSION RATE[a]

Year	Number of stations						Total bit rate, bps (b)
	ALSEP	ESS	RGM, manned	RGM, unmanned	AS	Total (b)	
1968	1	--	--	--	--	1	1×10^3
	2	--	--	--	--	2	2×10^3
1969	3	--	--	--	--	3	3×10^3
	2	--	--	--	--	2	2×10^3
1970	1	1	--	--	--	2	3×10^3
		2	--	--	1	3	5×10^3
1971		3	--	--	2	5	8×10^3
		3	2	6	3	14	14×10^3
1972		3	4	12	3	22	19×10^3
		2	4	22	3	31	22×10^3
1973		1	2	16	3	22	15×10^3
		1	2	16	3	22	15×10^3
1974		2	4	12	3	21	17×10^3
		2	4	12	2	20	16×10^3
1975		2	4	12	1	19	15×10^3
		1	2	6		9	7×10^3
1976		1	2	6		9	7×10^3

[a]Estimated data transmission rate is based on an average lifetime of **18** months **for** each station.

[b]The total does not include traversing, astronaut communication, and orbiting satellites.

TABLE VIII. - NUMBER OF EMPLACED GEOPHYSICAL STATIONS AND ESTIMATED DATA TRANSMISSION RATES[a]

Year	Number of stations						Total bit rate, bps (b)
	ALSEP	ESS	RGM, manned	RGM, unmanned	AS	Total (b)	
1968	1	--	--	--	--	1	1×10^3
	2	--	--	--	--	2	2×10^3
1969	2	--	--	--	--	2	2×10^3
	1	--	--	--	--	1	1×10^3
1970	--	1	--	--	--	1	2×10^3
	--	2	--	--	1	3	5×10^3
1971	--	2	--	--	2	4	6×10^3
	--	2	2	6	2	12	11×10^3
1972	--	2	4	12	2	20	16×10^3
	--	1	2	16	2	21	14×10^3
1973	--	--	--	10	2	12	7×10^3
	--	1	2	6	2	11	9×10^3
1974	--	2	4	12	2	20	16×10^3
	--	1	2	6	1	10	8×10^3
1975	--	1	2	6	--	9	7×10^3
1976	--	1	2	6	--	9	7×10^3

[a]Estimated data transmission rates are based on an average lifetime of 12 months for each station.

[b]The total does not include traversing, astronaut communications, and orbiting satellites.

TABLE IX. - ESTIMATED GEOPHYSICAL DATA TRANSMISSION FROM LUNAR TRAVERSES

Year	Traverse	Duration	TV imagery	Scientific bit rate, bps
1970	--	--	--	--
1971	--	--	--	
	Manned LSSM	14 days	Yes	2×10^6
	Unmanned LSSM	3 months	Yes	2
1972	Manned LSSM	14 days	Yes	2×10^6
	Unmanned LSSM	3 months	Yes	2
1973	--	--	--	--
	Manned LSSM	14 days	Yes	2×10^6
	Unmanned LSSM	3 months	Yes	2
1974	Manned LSSM	14 days	Yes	2×10^6
	Unmanned LSSM	3 months	Yes	2
1975	Manned LSSM	14 days	Yes	2×10^6
	Unmanned LSSM	3 months	Yes	2

TABLE X. - ESTIMATED GEOPHYSICAL DATA TRANSMISSION FROM LUNAR ORBITERS

Experiment	Estimated duration, months	Bit rate, bps
Visible mapping and high-resolution infrared mapping	--	very high
Lunar magnetic fields and electrical properties	36	10^2
Radar altimetry	3	10^4
Thermal imagery	3	8×10^4
Radar imagery	3	2×10^4

Hardware Priorities and Requirements

The Geophysics Working Group recommends the following development and manufacture through the flight hardware stage: The Lunar Scientific Survey Module for use in both a manned and unmanned mode (unmanned range at least 500 km); the delivery system for the Remote Geophysical Monitor (RGM-Del), with a Saturn IV impact; the Augmented Surveyor (AS), and the lunar flying unit (LFU). The Surveyor Lunar Roving Vehicle (SLRV) and the very long range traversing vehicles for manned operation, like Mobile Excursion (MQBEX) and Mobile Laboratory (MQLAB), are unimportant in the AAP. Payload and length of traverse of the SLRV, as they exist now, are too small to be of much value in traverse geophysics. Based on the proposed geophysical program, the Geophysics Working Group suggests the following priorities:

Priority	Hardware
1	LSSM (unmanned with a range of 500 km and a payload 700 to 1000 lb)
2	RGM delivery system
3	Augmented Surveyor

Although not especially required for geophysics, the Geophysics Working Group is impressed with the overall contribution to lunar science that lunar flying vehicles can make.

Some geophysical measurements are made best as a function of time at selected sites and with arrays. Others need be made only once at a few sites on the Moon. Still other measurements need to be made continuously, or almost continuously, along traverses crossing the lunar surface.

Considerably more scientific value is likely to accrue from extended traverses than from short ones; traverse equipment capable of traveling 1000 kilometers is highly desirable and must operate with remote control from Earth. Clearly, two-way communication is necessary to permit TV guidance from Earth and to return to Earth. Traverse type geophysical measurements are needed to interpret observations of local, as well as regional, lunar features. The operation of the LSSM in an unmanned mode after the astronauts have left the lunar surface is viewed as providing the best opportunity for conducting long-range traverses with large scientific payloads. The development of an LSSM for both manned and unmanned operation is extremely important to lunar geophysics and should be given the highest priority by NASA. It must be noted that an LSSM without the added capability of unmanned operation is much less attractive, and the priority of such a vehicle must be considerably downrated. A payload of 1000 pounds and a range of 1000 miles are desirable.

Widespread distribution of individual instrument packages (remote geophysical monitors) on the Moon from an orbiter using a Saturn V launch vehicle is needed to obtain a very large array for synoptic measurements. Elsewhere in this report, the development of remote geophysical monitors suitable for unmanned deployment and operation is proposed. In this section, the development of delivery systems for the RGM is recommended and is denoted by RGM-Del. A scientific payload of 100 pounds subjected to not more than 25g (and preferably less) is needed. In view of the importance of the RGM concept to the proposed geophysical program the development of the delivery system receives a very high priority.

A desirable adjunct to the seismic instrumentation is the impact of a spent Saturn IV stage on the Moon to provide a seismic source of known locations and origin time. The details of the experiment are discussed elsewhere in this report. The development of the additional equipment needed to allow impact of the Saturn IVB with a circle error probability (CEP) of 50 kilometers is recommended.

A summary of characteristics is provided in table XI.

Supporting Research and Technology

Telemetry problem. - It is estimated that there may be as many as 30 geophysical stations in simultaneous operation on the Moon capable of transmitting data continuously to Earth. The total bit rate is not large, about 20 000 bps, but 30 separate receiving channels will be required unless some means of reducing the amount of simultaneous transmission is used. In addition to the fixed station, an unmanned LSSM, or a manned mission and a Lunar Orbiter may be active at the same time which will require telemetry at TV bit rates, at least occasionally. The missions must be carefully intermeshed to prevent two or more of them from requiring high bit-rate communications simultaneously.

A way of dealing with the deluge of information from the fixed stations must be developed. Turning stations off for an appreciable part of the lunar cycle would seriously degrade some lunar experiments (passive seismic, for example) and would wipe others out (lunar tidal studies). This solution is not acceptable, but several alternatives are obvious. Enough stations could be emplaced on Earth to handle the traffic. The lunar stations could be equipped to store data for later transmission at an increased rate on command. A satellite could be used to collect the data and relay it to Earth.

Evidently a serious communication problem could develop, and it is imperative that it be recognized now so that steps can be taken to prevent a bottleneck.

Lunar back-side communications. - Surface stations on the back side of the Moon and orbiting spacecraft pose a special communication problem. It is recommended that NASA begin the study of the means to relay telemetry data from the RF shadow of the Moon.

Lunar power supplies. - In other portions of this report, it has been assumed that the RTG will be used for power at all stations, regardless of the method of deployment. This statement even covers the case in which eight or more remote stations are

TABLE XI. - SUMMARY OF CHARACTERISTICS

Rank	Name	Desired range	Scientific payload, lb	Mode of operation	Application and comments
1	LSSM (unmanned Mode)	500 km	700 to 1000	Unmanned	Traversing (gravity, active seismic, magnetic, electric) and distribution of scientific packages.
2	RGM delivery system	--	100	Unmanned	Soft landing of RGM from orbiting spacecraft to different regions of surface of the Moon.
3	Augmented Surveyor	--	125	Unmanned	Land in regions not accessible to manned missions.
4	Saturn IV impact	--	--	Unmanned	Impact a spent Saturn IV on the Moon to provide a large seismic source with CEP about 50 km.

deployed from a single vehicle in lunar orbit. Evidently such a mission raises severe questions about safety during launch, contamination of the Moon in the event of a crash landing, and so on. Either the RTG must be further hardened or restraints must be relaxed if the RTG is to be used for power in the widespread manner that is assumed. Otherwise, an alternative source of power, consistent with a design goal of a 5-year lifetime on the Moon, must be developed.

The remote geophysical monitor and its delivery system. - The RGM is a simple rugged station emplaced from a manned orbiting spacecraft or from an unmanned LSSM. The RGM carries with it its own power (SNAP 19 RTG or equivalent) and telemetry to Earth, with a highly directional antenna. The system should be capable of being landed in any position and will automatically right itself with respect to the vertical. No special orientation in azimuth is required. The life of the RGM on the Moon should be at least 2 years with a design goal of 5 years. Its delivery system should let it down on the lunar surface with a maximum acceleration of 25g, preferably much less. The RGM and its delivery system should weigh no more than 800 to 1000 pounds when launched from the orbiting spacecraft, and the total weight delivered to the surface will be in the 100- to 200-pound range.

The development of the RGM and its delivery system is recommended. Further study of the means of locating the RGM on the lunar surface to an accuracy better than 0. 5 kilometer should be made.

Emplaced Scientific Stations other than the RGM. - A number of types of scientific stations are to be deployed by men on the lunar surface, soft landed, or deployed by unmanned traversing vehicles. Many of them differ from each other more in mode of deployment and in details of their scientific objectives than in basic design concepts. The following is a list of the stations:

1. The Emplaced Scientific Station is an upgraded ALSEP slightly modified to take advantage of design improvements that emerge in the Apollo period. No major redesign of the ALSEP to produce the ESS is recommended. The ESS is deployed by men.

2. The Expanded ESS (ExESS) is an enlarged ESS with greater weight (400 lb), power, and telemetry capability. It can accommodate more experiments and will serve as the central station for array experiments. Deployed by man, it is not expected to be available before dual missions are feasible.

3. The Augmented Surveyor (AS) is an upgraded version of the Surveyor Automated Soft Lander, which should be capable of supporting a group of experiments approximately comparable to those in the ALSEP.

4. The outlying array station is emplaced by men and provides array capability for a central station, which is most likely to be an ExESS. It is similar to an RGM, except that it need not be capable of surviving rough landings and of righting itself, and a Heat Flow Experiment may be connected to it. It could be a slightly modified RGM.

The Geophysics Working Group recommends that the emplaced stations listed above be developed. Recommendations concerning individual experiments are listed elsewhere in this report. The present recommendation covers the stations as

integrated packages, including mounting tabs and electrical terminals for the experiments, as well as power supply and communications.

The LSSM with both manned and unmanned modes. - A principal requirement for the geophysical exploration of the Moon is that experiment packages weighing several hundred pounds be provided mobility over the lunar surface. The most satisfactory vehicle to provide the required mobility for such weights is the LSSM. Since, in the manned mode, the range of the LSSM is severely curtailed by the limited capability of life support systems, provision must be made to operate the LSSM in the unmanned mode.

It is strongly recommended that an LSSM capable of traverses of at least 25 kilometers in the manned mode and of 500 to 1000 kilometers in the unmanned mode, together with the associated guidance and navigation systems, be developed. The payload should be close to the present 700-pound capacity.

The Deep Drill. - A number of measurements, some of which are not directly related to geophysics, would profit from the ability to drill into the Moon to a depth of 30 to 100 meters and to recover core and gases from the entire length of such a hole. The primary geophysical justification for deep drilling is that it upgrades the Heat Flow Experiment by an order of magnitude. If measurements in shallow holes are verified in deep holes, confidence in the measurements will be greatly increased, Additional scientific value from deep drilling comes from study of volatile matter that may be frozen in the core, of gases released during drilling, of organic material that is free of near surface contamination, of cosmic-ray-produced isotopes found at greater depths than are currently being generated, and of profiles of remnant magnetization. Conceivably, the hole could end in lunar bedrock and provide samples of this material. Alternative sources of bedrock, such as crater walls and ejecta, may have been altered profoundly by impact and radiation, making an undisturbed sample highly desirable. It is recommended that the development of the deep drill be continued.

Seismometers/Gravimeters/Strainmeters and Tiltmeters. - It is proposed to install seismometers at five distinguishable sorts of geophysical stations: the ESS, the ExESS, the RGM, the Augmented Surveyor, and the outlying array stations. The first two represent complex central stations emplaced by man; the latter can be distinguished by their modes of deployment and their principal functions. The RGM, deployed by probe from orbit or by an unmanned LSSM, is a simple, rugged instrument designed to be part of a widely dispersed seismic network on the Moon. It will function continuously as a passive instrument, and it is an essential part of the Saturn IVB impact experiments. The instrument on the Augmented Surveyor is a complex, soft-landed part of the passive network, The outlying array stations, which are emplaced from manned traverse, extend the capability of the ESS and ExESS instruments by enabling them to serve as parts of seismic arrays.

In the development of instrumentation for these diverse stations, every effort must be made to minimize the number of different seismometers. There is no advantage to developing several basically different instruments unless careful study shows

that this is the only way to achieve the objectives. But before the degree of standardization can be settled, the following related questions must be resolved

1. Now nearly identical can the instruments at the RGM and satellite stations be? Should one-component high-sensitivity instruments be substituted for three components in some cases? What is the optimal frequency response for each type of station?

2. The most sophisticated instruments will be at ESS and ExESS, and they certainly will include three-component long-period pendulums. How many short-period components should be provided in addition? Can similar stations be deployed by Augmented Surveyors?

The long-period pendulums can also serve as tidal gravimeters and tiltmeters, but they require further development to insure that they have adequate sensitivity and stability at periods of up to 28 days. These instruments may have to be buried to depths of 1 to 2 feet or more to isolate them from thermal disturbances. In addition, the development of special instruments for the measurement of strain and tilt should be pursued, especially if tidal data are to be a major source of information about the Moon. A sensitive seismometer measures tilt at a point and, therefore, may be affected by purely local structures. A tiltmeter with a long baseline would be useful and perhaps essential. A long-baseline strainmeter, which might consist of a laser interferometer 1 to 10 kilometers in length, could provide data on free oscillations, tidal strains, and secular strains that may be of a quality that cannot be obtained from other instrumentations.

Active Seismic Experiments. - Active Seismic Experiments in the manned mode can be accomplished with ALSEP hardware with only minor modification. Active Seismic Experiments and sonic sounding along unmanned traverses require development. All active experiments generate information at rates in the range of 20 000 to 50 000 bps. Means of storing this information for telemetry requires further development.

The Group recommends further study and development in the following areas:

1. Develop optimal instruments for ESS, ExESS, RGM, outlying array stations, and Augmented Surveyors.

2. Combine the functions of a long-period seismometer, tidal gravimeter, and tiltmeter into a single instrument for emplacement at central stations. Provide for burial of this instrument to a depth of 1 to 2 feet or more.

3. Study the feasibility of long-baseline tiltmeters and strainmeters and develop them, if feasible.

4. Develop Active Seismic/Sonic Sounder Experiments and suitable data storage systems for active experiments.

5. Develop improved low-noise amplifiers in the frequency range of 0.01 to 20 hertz.

6. Place a seismograph on the Moon as soon as possible to record seismicity and the spectrum of lunar noise. The Group recommends that every attempt be made to include the single axis seismometer on Surveyor **7,** even though this may require a slip in the launching schedule. On the Ranger, Surveyor, and Apollo sequence of lunar exploration programs, the seismic experiment **has** always received high scientific priority, yet for different reasons, it has not yet flown. The geophysical experiments planned for Apollo and AAP would benefit greatly in their design and implementation if a successful seismic experiment were conducted on Surveyor. To design future instruments without this information could result in much of the effort being wasted.

Lunar surface experiments (heat flow). - Heat flow studies for lunar surface experiments include the following items:

1. Upgrading the drill. Future development of the drill should follow two paths. One path is to increase the available depth and to automate the operation so that drilling from an unmanned vehicle becomes possible. It is desirable to design for depths in the range of 10 to 100 meters. There is also the possibility that 3-meter holes can be achieved easily and with far less weight by vibrodrilling. In this technique a solid or hollow rod is vibrated and simultaneously pushed into the lunar surface. ***On*** Earth, materials such as packed sand, which strongly resists penetration by pushing alone, are readily penetrated. The properties of the lunar soil determined from Surveyor data encourage the recommendation that the feasibility of this mode of drilling be studied.

2. Sensor development. The platinum resistance thermometers used with ALSEP have relatively low sensitivity and must be manufactured with great care to be stable against vibration, shock, and temperature extremes. The search for sensors with higher sensitivity and greater inherent stability should continue. Nuclear quadrupole resonance thermometers, which were not ready in time for ALSEP, are promising, and still better sensors may appear in the future. The Geophysics Working Group recommends that better sensors be incorporated during AAP when they are made available.

3. Heat flow measurements on unmanned vehicles. As drilling and emplacement techniques are improved, the feasibility of measuring heat flow from unmanned vehicles should continually be reviewed.

Lunar Orbiter experiments. - Only a small part of the lunar surface can be explored by landed hardware; therefore, it is necessary to seek methods to broaden the heat flow coverage. Several methods of measuring heat flow from orbit are suggested

1. Measurement of the flux radiated from permanently shadowed areas. This method provides a direct measure of the heat flow from the interior of the Moon in large craters.

2. Microwave and IR emission. The IR energy source is near the surface; the microwave energy comes from some mean depth that depends on wavelength. A suitable combination of data from these sources could yield the thermal gradient.

3. The depth to an ice-water interface. If an ice-water interface exists, it might be determined by a number of electromagnetic techniques. Since the temperature of the interface is known, the thermal gradient is again calculable.

4. Magnetic survey. This method could reveal the depth to the Curie-point isotherm, which provides another estimate of the thermal gradient.

The last three methods yield only the thermal gradient, and some estimate of the thermal conductivity is required to obtain the heat flow. A typical value of lunar thermal conductivity will probably have to be used, and these methods can give the heat flow only if it proves to be representative of specific sites all over the Moon. Furthermore, the last three methods cannot yield absolute values of heat flow. Absolute values of heat flow must be calibrated at places where the flux has been measured by emplaced probes. However, the lower accuracy of orbital heat-flow determinations is offset by the wide geographic coverage that they can provide. Therefore, the Geophysics Working Group strongly recommends that the feasibility of these various techniques for determining heat flow from orbital spacecraft be studied further.

5. Electromagnetic measurements. The purposes of the measurements include (a) studies of the solar wind and its interaction with the Moon; (b) optical properties of the lunar surface; (c) the electrical conductivity, dielectric constant, and magnetic permeability in the lunar interior; and (d) the use of these electromagnetic properties to infer temperature, moisture content, and compositional and structural information about the interior of the Moon.

Recommendations for lunar orbit and lunar surface experiments. - Experiments both in lunar orbit and on the surface have been considered and the following recommendations are made.

1. Lunar orbit experiments

The following lunar orbit experiments are recommended for development:

a. Photoelectric scanners with 100-meter resolution for use in the near UV, visible, and near IR.

b. Infrared radiometers with 100-meter resolution operating in the 5- to 30-micron and 30- to 300-micron wavelength intervals. Detectors capable of measuring temperatures down to 30° K, preferably without requiring cryogenic cooling, must be developed.

c. A microwave imaging system capable of operation at more than one wavelength.

d. Radar experiments. A number of radar experiments is possible, including radar imagery to map the subsurface, radar, and subradar reflectivity (10^7 to 10^{11} Hz and 10^5 to 10^7 Hz).

e. Radar or laser altimetry to determine the shape of the Moon.

The following lunar orbit experiments are recommended for feasibility studies:

a. Feasibility of extending subradar studies to frequencies below 10^5 hertz.

b. Development of multichannel or rapid-scanning IR spectrometers.

2. Lunar surface experiments

The following lunar surface experiments are recommended for development:

a. Magnetic deep sounding by study of the ratio between horizontal and vertical components of the magnetic variations.

b. Sounding by subradar scattering to give the thicknesses and properties of near-surface layers. Only an adaption of the Allouette topside sounder is required.

c. Apparatus for the simultaneous passive measurement of electric and magnetic fields in the 10^{-4}- to 10^5-hertz band.

The following lunar surface experiments are recommended for feasibility studies:

a. Measurements of mutual coupling between antennas to give conductivity, dielectric constant, and magnetic permeability at depths up to 10 kilometers. Such measurements could detect the presence of moisture.

b. The effect of the solar wind on the radiation patterns of antennas.

c. Sounding techniques using radar rather than subradar frequencies.

d. The feasibility of extending subradar studies below 10^5 hertz.

The following lunar surface experiments are recommended for theoretical studies:

a. The interaction of the solar wind with the Moon.

b. The use of the LM-CSM communications link for measuring electrical conductivity and dielectric constant in the Moon.

3. Recommended laboratory studies

The Geophysics Working Group recommends that studies be made (1) on infrared emission and reflection spectra of likely lunar materials with emphasis on the effects of surface films, simulated solar-wind bombardment, porosity, grain size, and shock metamorphism and (2) on the dependence of conductivity and dielectric constants of likely lunar materials on frequency, moisture content, temperature, pressure, and composition.

4. Recommended supporting experiment

It is important to measure ambient noise levels in the lunar vicinity in the range of 1 to 10^{11} hertz from Lunar Orbiter or lander as soon as possible.

5. Detectors

Instruments needed for supporting research and technology include the following items:

a. Gravity meters (g and traverse meters): Instruments with adequate accuracy (0.1 milligal) exist but require some modification for lunar use. Absolute gravity on the Moon (actually, g relative to the launch site, for example) can be determined to the same accuracy without major further development. On gravity traverses a certain minimal accuracy of elevation is required. In general, the elevation of any point relative to the central station should be known to about ± 1 meter on manned traverses. On long (500 to 1000 km) unmanned traverses a minimum elevation accuracy of ± 50 meters, tied to a moonwide reference, is required. The Geophysics Working Group recommends that systems to provide elevation control of this accuracy be developed for manned and unmanned roving vehicles.

b. Lunar surface magnetometers: Three-component magnetometers are to be deployed by men at central stations (ESS and ExESS), soft-landed as a part of Augmented Surveyor stations, and carried on traverses by manned and unmanned LSSM stations. The magnetometers should have sensitivities of 0.1γ. Very little development of the individual instruments is required; but when the instruments are used in conjunction with the Augmented Surveyor or LSSM, they must be isolated from magnetic disturbances associated with the vehicles. Development of suitable deployment/suspension systems is required. The Geophysics Working Group recommends that studies be made on the distances and shielding between the magnetometer and the vehicle (including other instruments in the payload) which will reduce magnetic disturbances to less than 0.1γ and that a means of deployment/support adequate to achieve this degree of magnetic isolation be developed.

c. Corner reflectors and Doppler transponders: The Geophysics Working Group recommends that the program of the Geodesy and Cartography Working Group be supported by the deployment of these devices at suitable locations on the lunar surface. Doppler transponders should be developed to measure velocities of Lunar Orbiters and thereby provide refined data on the gravitational field of the Moon, Corner reflectors should be emplaced at points near the edges of the lunar disk near the equator and poles to permit accurate determinations of the lunar librations by laser studies from Earth. It is highly desirable to develop corner reflectors that are considerably lighter than those currently proposed for lunar use. The recommended devices will yield important information about the distribution of mass in the lunar interior.

d. Other detectors: The Geophysics Working Group recommends the development of the following additional instruments as part of ESS and ExESS:

(1) A dust-transport monitor to measure the rate of movement of particulate material over the lunar surface

(2) A micrometeoroid detector for particles in the range of 10^{-11} to 10^{-6} grams

(3) In situ measurements in support of electromagnetic measurements made in lunar orbit, including thermal diffusivity, emissivity, reflectivity, density, electrical conductivity, and dielectric constant

Geophysics Sample Requirements

The measurement of physical properties of representative lunar samples and of related suites of rocks and minerals (both synthetic and naturally occurring on the Earth) is needed for the interpretation of field data to be obtained on the Moon. The requirements are much the same as those described in the report of the Falmouth meeting. Some measurements need to be made in situ on the lunar surface, and some measurements need to be made on returned lunar material. Other measurements may be made best on rocks or minerals obtained from the Earth since the intrinsic properties of coesite (or any other mineral) are expected to be the same for material of the same composition and state obtained anywhere. A list of the important properties is given in table XII.

Some properties, such as thermal diffusivity and electrical conductivity, depend strongly on the kind and quantity of gas or liquid present in the sample. It is highly desirable to measure these properties in situ and on the returned lunar material as soon as possible after return to Earth. It is recommended that facilities for the measurement of thermal diffusivity and electrical conductivity on the returned sample be established at the Lunar Receiving Laboratory.

The pressures (to about 50 000 atm) and temperatures (maximum of 1000° to 2000° C) throughout the Moon can be attained in the laboratory today with readily available high-pressure equipment. The present set of data on physical properties measured at high pressure or high temperature is rather small and, in general, the data are adequate; there are almost no data that have been obtained at pressures above a few thousand atmospheres on materials of value to the geophysical interpretation of the Moon and extraterrestrial materials. The systematic determination of the properties of such material as a function of pressure and temperature and, possibly, of water content is desirable. Support of this kind of research is encouraged,

The returned lunar samples to be used for the measurement of physical properties of value to geophysicists should meet the following criteria: (1) representative samples of the surface rubble layer and solid rock are needed, (2) a few oriented (to a few degrees) samples should be obtained, (3) surface features of a few samples should be preserved (if possible), and (4) some material should be returned in a hard vacuum

TABLE XII. - MEASUREMENTS OF PHYSICAL PROPERTIES

Property	Measurement				
	In situ	In lab on Earth material	In lab on returned lunar sample	As function of pressure	As function of temperature
			Thermal		
Conductivity[a, b]	X	X	X	X	X
Diffusivity[a, b]	X	X	X	X	X
Expansion	--	--	X	X	X
Radioactivity	X	X	X	--	--
Specific heat	--	X	X	X	X
Emissivity[c]	X	X	X	--	X
			Elastic[b, c]		
Velocity P	X	X	X	X	X
Velocity S	X	X	X	X	X
Compressibility	X	X	X	X	X
			Anelastic		
Q[b]	X	X	X	X	X
Creep[d]	--	X	X	--	X
Mechanical strength[d]	--	X	X	X	X
Prestress	X	X	X	X	X
			Electrical[c]		
Dielectric constant	X	X	X	X	X
Resistivity	X	X	X	X	X
Emissivity	X	X	X	--	X
			Magnetic		
Remanent magnetization	X	X	X	--	X
Susceptibility	X	X	X	--	X
Curie point	--	X	X	--	--
B-H curve	--	X	X	--	X
			Optical[c]		
Albedo	X	X	X	--	X
Emissivity	X	X	X	--	X
X-ray	--	--	X	X	X
			Miscellaneous		
Density	X	X	X	X	--
Porosity	X	X	X	X	--
Permeability	X	X	X	X	--

[a]Including thermal radiation.

(10^{-4}

and certain measurements made on these samples before they become contaminated by the atmosphere of the Earth. The following tabulation lists the size requirements:

Property	Ideal solid size, in.	Minimum size, in.
Elastic	4 × 4 × 4	1-1/2 × 1-1/2 × 1 (solid)
Thermal	1-1/2 × 1-1/2 × 1	1 × 1 × 1/2 (solid)
Magnetic	4 × 4 × 4	2 in^3 (powder)
Electrical	1-1/2 × 1-1/2 × 1	3 in^3 (powder)
Optical	4 × 4 × 4	2 in^3 (powder)

The solid material need not have zero porosity (the term is used in this context to include samples that are coherent, as opposed to loose powder).

A class of properties not shown in table XI is also needed for the interpretation of geophysical data. Such properties as composition, radioactive content, extent of radiation damage, alteration, and structural state are not in the usual complement of properties determined primarily by geophysicists; but the properties are nonetheless extremely valuable for the interpretation of lunar geophysical measurements. The Geophysics Working Group encourages the determination of these properties by mineralogists and geochemists.

RECOMMENDATIONS

Recommendations for ALSEP on late Apollo missions are listed in appendix 11.

Astronaut Training

Astronaut training is highly desirable so that those astronauts engaged in the exploration of the Moon have a good understanding of the basic scientific elements of the experiments which they are helping to implement. Toward this end, the Geophysics Working Group recommends (1) that instruction in geophysics, including fieldwork, be included in the astronaut training program and (2) that continued and close contact be established between astronauts and Principal Investigators.

Program Opportunities

The Geophysics Working Group strongly recommends that any extension of the Apollo science program (such as the follow-on ALSEP now being considered) be

implemented by open solicitation of experiments from the scientific community. Only in this way can the manned space-flight program build the broad base of scientific support and participation necessary for an active and productive research program.

Basic Sciences, Experimental and Theoretical

The NASA support of basic science programs has been a benefit to the space program, and also to universities and other research institutions. This support should not be confined to flight programs but should be continued in all areas of basic science which contribute to the overall NASA objectives of space exploration.

Many scientific experiments appear very promising for lunar exploration but are not feasible now (1) because detector systems have not been developed to the point of having the desired sensitivity, or (2) because theoretical problems have not been fully investigated to insure proper design of the experiment or full interpretation of the results. It is strongly recommended that NASA continue to fund detector development and techniques and that theoretical investigations and concepts related to the lunar environment be conducted.

Mobility on Unmanned Traverses

The Geophysics Working Group believes that the extended spatial coverage of the lunar surface made possible by the LSSM or similar vehicles operating in the unmanned mode will contribute greatly to the study of regional variations of the Moon. It is strongly recommended that TV monitor coverage should be available from the vehicle throughout the lunar day or days until the mission is complete.

Liaison with Radio Astronomy

The possibility of a wide range of remote sensors in lunar orbit and on the lunar surface will require careful coordination of the requirements of electromagnetic compatibility not only among the various mission experiments, but also within the framework of existing international agreements governing Earth-based and space-based use of the electromagnetic spectrum. This requirement may be particularly severe for high-power radar equipment in Earth orbit or on a lunar mission, especially if the minimum acceptable noise levels in the radio astronomy quiet bands are not to be exceeded. It is recommended that advanced consideration be given to the selection of all frequencies to be transmitted to avoid contamination of the radio astronomy bands or otherwise to impinge on the assigned use of the electromagnetic spectrum.

Lunar Back-Side Communications

For both surface stations and lunar orbiting spacecraft, transmission of data from the lunar back side is essential. Thus, NASA should begin to study the future requirements of relaying data from the RF shadow of the Moon (relative to the Earth)

back to Earth. The use of the L_2 lunar libration point or a satellite hovering near it (such as described in the "Hummingbird" Study by von Bun, 1967) appears feasible. Development should be started about 1971.

Modular Concept for Science Packages

Any well-conceived and carefully designed research and exploration program evolves continuously, and with the accumulation of data, is quite likely to change. Because of the long leadtimes now necessary to change space-flight hardware, it is very difficult to take advantage of new data. The Geophysics Working Group strongly recommends that supporting structures, like those used with ALSEP, for space and planetary experiments be built on a modular design. The advantage of easy exchange of experiments is believed by the Geophysics Working Group to outweigh the disadvantages.

Project Scientist

The Geophysics Working Group believes that a position of Project Scientist could be useful within the structure of the manned space-flight program. The responsibilities of the Project Scientist would be to represent the scientific requirements and objectives of an experiment to the project manager and his staff. There should be at least one Project Scientist associated with every mission which includes scientific experiments; more than one may be desirable for a project in which the number of scientific disciplines is large. The position of the Project Scientist within the organizational structure must be at a level which insures adequate scientific inputs to the program.

Mission Scientific Team

The Geophysics Working Group strongly recommends that Principal Investigators (and their associates) for a given mission hold regular periodic meetings to discuss common problems and to generate common recommendations. This scientific coordination is essential to assure that any required program modifications be made in such a manner as to achieve maximum scientific output.

Development of Experiments for Future Missions

Three stages in the development of an experiment and the necessary hardware that can be visualized are (1) detailed consideration of the importance and feasibility of an experiment, (2) development of the necessary scientific tools to implement the experiment, and (3) production of flight hardware. To obtain the maximum scientific flexibility and most efficient production of high quality flight hardware, it is strongly recommended that sufficient time and funds be made available to prospective experiments to implement the first two steps in an orderly fashion. Generally, it is desirable for more than one group to be involved in these stages, which would lead to alternate prototype experiments.

Development of flight hardware for a specific flight of a program should be under the guidance of a single Principal Investigator or an investigator team, and parallel funding for the development of flight hardware for a specific flight should normally be avoided. In a large program involving many flights, development of flight hardware conceived by other investigators for the same experiment might be desirable.

APPENDM I

GRAVITY GRADIENT MEASURING INSTRUMENT

The gravity field of any near-spherical body at an external point can be expressed in the form

$$g = \frac{\gamma M}{r^2}\left[1 + \sum_{2}^{\infty} A_n \left(\frac{r_0}{r}\right)^n S_n(\theta, \varphi)\right] \tag{11}$$

where $S_n(\theta, \varphi)$ is the spherical harmonic of order n.

If we write

$$\delta g_n = \frac{\gamma M A_n}{r^2}\left(\frac{r_0}{r}\right)^n S_n(\theta, \varphi) \tag{12}$$

then the vertical gradient of gravity $\partial g/\partial r$ is given by

$$\frac{\partial}{\partial r}\left(\delta g_n\right) = \frac{-\gamma M A_n}{r^2} \cdot \frac{n+2}{r} \cdot S_n(\theta, \varphi) = -\delta g_n \frac{n+2}{r} \tag{13}$$

In terms of the anomaly $\left(\delta g_0\right)_n$ at the surface

$$\frac{\partial}{\partial r}\left(\delta g_n\right) = -\left(\delta g_0\right)_n \frac{n+2}{r} \cdot \left(\frac{r_0}{r}\right)^n \tag{14}$$

For $\left(\delta g_0\right)_n$ = **40** milligals (surface), the gradients corresponding to anomalies of order number **15, 25, 35, 50,** and **100** are all in the range of **1** to **3** $\times$ **10**$^{-9}$ cgs units $\left(\text{gal/cm or sec}^{-2}\right)$ for an orbital height **of 50** kilometers.

Here, the vertical gradient of gravity is considered. Thus, the estimate for the nth harmonic is to be compared with the normal free air gradient, $-\frac{2\gamma M}{r^3}$ which is equal to -2×10^{-6} cgs units for the Moon (0.2 milligal/m). The measurement of vertical gradient is preferred because errors in measurement due to the free air gradient then enter the measurement as 1 - cosine of a small angle rather than as the sine of a small angle which is relevant to measurement of the horizontal gradient. If stabilization of the attitude of the spacecraft to 1° is possible, the stabilization error corresponds to $(2 \times 10^{-6})/6500 = 3 \times 10^{-10}$ cgs units.

Thus, a gradient of approximately 40 milligals in 100 kilometers could be measured at a height of 50 kilometers with an accuracy of roughly one-third to one-tenth. This measurement would be extremely significant for geophysical purposes. Attention should also be given to errors ensuing from the rotation of the vehicle.

The question of the useful accuracy can be looked at in another way. Suppose that there is a sudden change of elevation of the surface topography. Then, assuming no compensation, the maximum value of $|\partial g/\partial z|$ is $\gamma \rho/H$ cgs units, where H is the height of the orbiting vehicle above the surface.

For D = 1 kilometer (and astronomical estimates are several times greater)

$$\left|\frac{\partial g}{\partial z}\right| \begin{array}{l} = 2 \times 10^{-9} \text{ for an orbiter at 100 km} \\ = 4 \times 10^{-9} \text{ for an orbiter at 50 km} \end{array}$$

These values are sufficiently greater than the limit of 3×10^{-10} corresponding to 1° stabilization of the attitude of the orbiting vehicle to make it possible to determine fairly precisely whether the change of elevation is compensated, and if it is, to provide rough estimates of the depth of compensation. Such information is of profound significance for the interpretation of the structure of the Moon and for hypotheses with regard to the evolution of the Moon.

Accordingly, the Geophysics Working Group wishes to endorse strongly the recommendation of the Geodesy and Cartography Working Group for a study of the potential of gravity gradient measurements in a lunar orbiter. It is suggested that an instrument with a precision of 0.3×10^{-9} cgs units, or better, is required.

The readout time should be of the order of 5 seconds or less which defines perturbations with wavelengths of the order of 30 to 40 kilometers.

Such instruments would be difficult to check on Earth, but control on the calibration would be provided by comparison with the low harmonics determined from orbital information.

A single accelerometer caged 3 to 10 meters below the center of gravity of the vehicle would require a sensitivity of 0.1 to 0.3 microgal to achieve the required precision. There would be an advantage in having a second accelerometer mounted at an equivalent distance above the center of gravity.

The Geophysics Working Group wishes to emphasize that, although the low-order harmonics 2 to 10 determined from Earth measurements of the orbit are of great geophysical significance, the high-order harmonics have equally important bearing on the regional variations of the structure of the Moon and on hypotheses with regard to the evolution of the Moon.

The Geophysics Working Group wishes to endorse the Geodesy Working Group recommendation that, if feasible at all, the measurements should be made at the lowest height consistent with the maintenance of the orbit.

APPENDIX II

RECOMMENDATIONS FOR ALSEP ON LATER APOLLO MISSIONS

The ALSEP program has the following arrays of experiment packages under procurement for flight hardware.

	Weight, lb
ALSEP I:	
Passive Seismic Experiment	23
Solar Wind Spectrometer	12
Suprathermal Ion Detector/Cold Cathode Gage	17
Laser Ranging Corner Reflector	17
ALSEP II:	
Passive Seismic Experiment	23
Magnetometer	16.6
Solar Wind Spectrometer	12
Suprathermal Ion Detector/Cold Cathode Gage	17
ALSEP III:	
Passive Seismic Experiment	23
Cold Cathode Gage	12
Heat Flow/Drill	35
Charged Particles, Lunar Environment	4.9
ALSEP IV:	
Passive Seismic Experiment	23
Suprathermal Ion Detector/Cold Cathode Gage	17
Active Seismic Experiment	23
Charged Particles, Lunar Environment	4.9

NASA has procured 15 Saturn IVB vehicles. Three vehicles are utilized for Earth orbital testing; a fourth will also probably be utilized for some form of testing. The other four vehicles are earmarked for the ALSEP program.

Assuming that we have some early successes, the Geophysics Working Group strongly recommends ALSEP-type scientific payloads for the additional seven Saturn launches.

The following constraints are reasonable:

1. Only minimal modifications of the ALSEP central station electronics will be possible.

2. The power available will increase from 56 to 70 watts.

3. The maximum payload is about 300 pounds, of which no more than one-third can be scientific instruments.

4. The time scale for delivery of flight hardware articles would be in mid-1969.

Near carbon copies of the existing flight-approved scientific instruments can be procured and ready on the shelf for inclusion on future ALSEP flights. There are distinct advantages to this, in that many instruments are developed. The additional time could be used to possibly improve the performance of the present instruments.

However, there are some geophysical instruments which are not now under procurement for flight hardware but could meet the schedule constraints and do not involve major new instrument development costs, The subcommittee recommends that, if an investigator proposes an experiment compatible with the stated constraints, NASA consider including those experiments. It is obvious that this can only apply to a flight hardware procurement program and cannot be *a* major new instrumental development program.

CHAPTER 5

REPORT OF

GEOCHEMISTRY WORKING GROUP

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INTRODUCTION

Since the 1965 Summer Conference on Lunar Exploration and Science at Falmouth, Massachusetts,[1] very significant advances in the exploration of the lunar surface have resulted from Surveyor and Orbiter programs. It is now possible to plan the exploration of the Moon much more realistically. In the area of isotopic, chemical, and petrological studies; the increased understanding of the lunar surface has had relatively little effect on the fundamental scientific problems outlined by the Falmouth Geochemistry Working Group. The summary of these questions outlined by this group is therefore restated here,

"Exploration of the Moon is one of the grandest adventures ever undertaken by man. In part it is an adventure in science. Major contributions to many scientific disciplines are certain to emerge from the lunar exploration program. The difficulties and complexities of lunar missions are enormous and place severe constraints on the scope of purely scientific exploration which can be achieved within the program. It is the responsibility of the scientific community to attain the maximum scientific benefit compatible with these constraints.

"One of the major unsolved problems with respect to the Earth-Moon system is the origin of the Moon. It has been variously proposed (1) that the Moon originated completely separate from the Earth and was later captured by the Earth, (2) that the Moon and the Earth essentially originated at the same time as twin planets, and (3) that the Moon originated from the Earth and was torn from it at an early stage in Earth history. In attempting to resolve the problem it is of great importance to compare the composition of the Earth and the Moon in terms of bulk chemistry and specific diagnostic elements and isotope ratios."

Available evidence strongly suggests that the Earth-Moon system has existed for a very long time. This immediately raises the problem of probable dynamic interactions between the two objects. Although dynamic interactions today are minor (lunar tides do little to permanently affect the surface of the Earth), evidence collected at Kilauea volcano in Hawaii suggests that even today lunar tides can trigger some volcanic eruptions and increase the flow rates of others. If the Earth and Moon were once much closer, as now seems probable, the possibility of much stronger dynamic interactions must be maintained.

Terrestrial evidence of strong interactions is either lacking or unconvincing, largely because of the antiquity of the presumed events and because of the removal of evidence by later erosion or metamorphism. Evidence of this type in the early Earth-Moon history, if preserved at all, will probably be found on the Moon.

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[1] Results of the conference were published as NASA 1965 Summer Conference on Lunar Exploration and Science. NASA SP-88, 1965.

Unlike the surface of the Earth, the surface of the Moon affords an opportunity to find structures and materials that date back to the time in the solar system when the Moon and the planets were formed from the dispersed matter of the early solar system. The discovery and the chemical and isotopic study of such materials would be of great importance in unraveling many ambiguities that now form part of our understanding of the origin of the solar system.

The most significant and meaningful scientific results expected from manned exploration of the Moon will be derived from the samples of lunar materials that are returned to Earth. The structure of the surface inferred from Surveyor and Orbiter photography strongly suggests that the samples collected in early Apollo missions will represent materials that are derived from a larger region than the immediate sampling locality, because material is mixed and transported by crater-forming processes. The continual mixing by impact processes also suggests that samples from a cratered terrain may contain materials that have formed at a variety of times during the history of the Moon. In addition, the Surveyor photographs indicate that rock samples on the surface of the Moon contain significant textural and mineralogical information regarding the geological processes that occur on the surface. It is expected that the wide range of sophisticated analytical measurements which are proposed for materials returned from early Apollo missions will produce very meaningful results on the composition of the lunar surface and will establish significant limits on the extent to which wide-scale chemical differentiation has taken place. It is highly unlikely, for example, that a lunar history that involves extensive volcanism as opposed to a history in which volcanism has played a minor role should not be distinguished in samples from early Apollo sites. However, the complexity of the lunar surface shown by the Orbiter photographs suggests that a satisfactory resolution of many of the fundamental problems regarding the Moon will require much more extensive and selective sampling and, on most of these materials, careful measurements made with very precise and sophisticated instruments. The ability to make isotopic and chemical analyses that contribute significantly to the resolution of basic scientific questions diminishes very rapidly when the constraints that exist on the lunar surface are placed on existing analytical methods; therefore, primary priority has to be placed on sample return.

It seems quite clear that chemical and mineralogical measurements made on the lunar surface will serve mainly as a guide in establishing the variability of materials in a given site. Chemical mineralogical devices on the lunar surface in both manned and unmanned modes are useful primarily to differentiate major mappable units and to select samples for terrestrial study.

The more selective sampling that results from having increased mobility and sampling capability greatly increases the variety and scope of chemical and mineralogical problems that can be attacked. A summary of requirements and constraints resulting from the major interest areas associated with returned lunar materials follows.

RETURNED SAMPLE REQUIREMENTS FOR GEOCHEMICAL AND PETROLOGIC INVESTIGATIONS

Isotopic and Chemical Studies as Related to the Early Solar System and Nucleosynthesis

Our best hope for learning about the origin of the solar system and nucleosynthesis by the study of the Moon is that it will prove to be generally a primitive, undifferentiated body. Alternatively, if differentiation of the lunar surface has been extensive but not complete, the location of the oldest areas will be a major objective of site selection. Even in this case, because of the spreading of material over the surface by large collisions, samples of primitive rocks may be available in many places. Deep, fresh craters like Copernicus are another potential source. In regions of volcanic activity, gases escaping from the lunar interior may have brought such material from deep in the Moon. The selection of primitive samples, if available, is extremely important.

It is possible that this material is a good sample of unfractionated, nonvolatile solar matter. The Moon has a density close to that expected for such matter. Chemical analysis for all possible elements would be useful. Samples required for such a program are of the order of hundreds of grams. The cleanliness requirements already laid down for sample collection in the Apollo Program appear sufficient for this purpose.

The isotopic variations produced by the decay of extinct radioactive species are the other major source of information on the events before and during the formation of the planets. The best studied example is I^{129} (t = 17 million years), whose decay product Xe^{129} has been studied extensively in meteorites. Other interesting cases are Pu^{244} and Cm^{247}. The evidence for early heating in meteorites has suggested that Al^{26} ($t_{1/2}$ = 0.8 million year) may have been present as a source of radioactive heat.

The samples of greatest value here are those which (1) are formed as minerals soon after the last synthesis of these isotopes, and (2) are best suited chemically to display changes in isotope ratio produced by radioactive decay (largest original ratio of the parent to the daughter element). For sampling purposes, it is important to obtain samples of the widest possible variety in composition and mineralogy. Large crystals of easily separated mineral phases are useful. Acidic rocks, if differentiation occurred very early, may supply mineral assemblage of great interest. Sample sizes for these studies are likely to be on a gram scale. Larger samples will be needed for concentrating uncommon minerals.

Interaction of Solar and Galactic Particles with the Lunar Surface

The study of the effects of nuclear particles of various energies has two objectives. First, these effects are a rich source of information on the history of the Moon. For example, solar-wind gases bury themselves in the external layers of the lunar surface, In 1 year, an easily measurable amount of gas will accumulate in the surface

layer. The gas tags these exposed layers so that past surface layers can be clearly identified; hence, the history of turnover or "gardening" can be followed in detail.

Second, because the Moon is an atmosphere-free and magnetic-field-free planetary body, it must hold a rich fossil record of the history of the solar wind and the solar-flare particles, and hence of the Sun. In addition to the solar-wind particles, a continuous stream of particles originating outside the solar system strikes the surface of the Moon. The interactions of the particles produces permanent chemical changes and raises the possibility that a long history of cosmic radiation and hence, of possibly dramatic events in the history of the galaxy, may be preserved. Similar information from meteorites, which have suffered a poorly known and variable ablation in the atmosphere of the Earth and which have an uncertain place of origin, gives only hints of what is possible with samples taken in controlled context.

A discussion of particle interactions with the lunar surface and a summary of the information that a study of these interactions can provide about the Moon and its environment can be divided into the categories of solar-wind flux, solar-flare particles, and galactic cosmic-ray flux.

Solar-wind flux. - The solar-wind flux in the kiloelectron-volt region is about $2.10^8/cm^2/sec$. The composition of the solar wind includes H, He, and probably other elements in roughly solar proportions. The penetration is 100 to 1000 Å. The effects include the accumulation of gases, sputtering, radiation-damage tracks, and other solid-state effects such as thermoluminescence, stored energy, and magnetic resonance.

Information about the Moon resulting from these measurements includes the following items:

1. A marker which designates past surface layers and, thus, turnover times.

2. The heating history (by gas retention) should be provided under certain conditions.

3. The shock history may be provided by investigation of these properties.

4. In conjunction with other evidence, especially absolute dating methods, it may be possible to detect ambient lunar atmospheres down to 10^{-4} g/cm^2 or extinct lunar magnetic fields with surface strengths above 100 gammas, if these existed in the past for sufficiently long periods of time. Also, the net mass gain or loss of regions of the surface or of the whole Moon should be measurable.

Information about the solar wind resulting from these measurements include the following items:

1. Partial composition of the present solar wind (surface samples) by the study of gases and tracks.

2. Compositional history by the same methods.

3. Shape and history of the highest portion of the energy spectrum.

4. Search for solar radioactivity (radioactive nuclei in the normal corona).

5. The solar wind can be sampled and the present composition (and variations thereof) can be analyzed by exposing suitable foils to the undisturbed solar wind. Such exposure could take place from the command and service module (CSM) outside the magnetosphere of the Earth, or at the lunar surface. Aside from the significance for solar and solar-wind research, the measurements would greatly aid in the interpretation of the solar-wind particle concentrations and distributions contained in solar surface material.

Solar-flare particles. - Solar-flare particles are flux variable in time, approximately 100 protons/cm^2 sec with E $\gtrsim$ 10 MeV, averaged over the last solar cycle. The predominant solar-flare particles are protons. The penetration of these particles into the surface ranges from millimeters to centimeters. The effects of the solar radiation include specific nuclear reactions, radiation effects, and tracks.

Information about the Moon resulting from this area of study includes the following items:

1. Marker for past surfaces on deeper scale than solar wind

2. Time markers provided by very great solar-flare events

Information about solar-flare activity, available from a study of lunar materials, includes the following items:

1. Average flux over longer periods (radioactive, stable isotopes)

2. Chemical composition and history (tracks, gas studies)

3. Energy spectrum and history

4. Possible detection and dating by comparing samples in the context of individual major flare events

5. Detection and measurement of nuclear reactions in the solar flares (radioactivity of the beam)

Galactic cosmic-ray flux. - The galactic cosmic-ray flux (10^8 to 10^{10} eV) is about 5 nucleons/cm^2 sec when modulated by the solar wind. The cosmic-ray flux is composed mainly of H, He, and heavy elements with higher than solar abundances. The mean penetration or interaction length for protons is about 100 g/cm^2. The penetration is considerably less for heavy elements. The effects of galactic cosmic rays include a wide range of nuclear interactions, production of active secondary particles (neutrons especially), and tracks of high-Z nuclei. The intensity of galactic cosmic rays has been about constant on a 10^6-year time scale, and it has certainly been present on a 10^9-year scale.

Information about the Moon, available from cosmic-ray studies, includes the following items:

1. Potentially accurate exposure ages on this depth scale (radioactive and stable isotopes and particle tracks)

2. Crater chronology, that is, dating the time of formation of individual craters

3. Determination of the vertical mass movement as a function of time (He^3/Ne^{21}, Ne^{22}/Ne^{21}, and Kr isotopes produced by epithermal neutrons and heavy particle tracks) by measuring the profile of isotopes produced by radiations with very different depth dependencies

4. Net addition or erosion rates, for example, in the highlands

Information about cosmic rays resulting from a cosmic-ray study of lunar materials includes the past history of flux, heavy element composition, and gross changes of energy spectra. This information can be obtained by measuring vertical profiles in surfaces exposed for different times and in surfaces previously exposed and then reburied by some episodic events. These methods are expected to yield information qualitatively superior and extending further back in time than that obtained in meteorites.

Higher energy cosmic rays: Higher energy cosmic rays ($E > 10^{10}/eV$) are of great potential interest; however, there are no methods of detection as yet.

Sampling Requirements

The depth, nature, and locations of samples required to obtain information relative to the interactions of solar and galactic particles with the lunar surface are discussed.

Depth. - Nuclear particle effects are most successfully studied in the context of their depth dependencies. Depth sampling can be achieved by drill coring, vertical sampling, and the examination of surface rocks. The following items are specific techniques and problems associated with depth sampling:

1. Equipment for drill coring, which will preserve the integrity of the vertical column including solid rock embedded in softer materials, should be developed. Cores from 1 to 30 feet in depth are required at the present. In later missions, it may prove necessary to drill core to even greater depths.

2. Depth sampling can be accomplished on the walls of craters of different sizes especially craters that are young with respect to the layer in which they are formed. In this vertical crater wall sampling, a few horizontal cores of 3 feet in length should be taken from inside the crater.

3. Surface rocks should be collected, especially those which can be related to a crater. From larger rocks, samples from the top should be taken; and for movable

rocks, additional samples from the bottom and from directly underlying material should be taken.

4. For solar-wind studies, sampling the uppermost layer of the lunar .surface by means of adhesive foil is desirable.

For sampling modes 2 and 3, a precise geometrical record (photography) is needed for meaningful interpretation of data.

Nature of samples. - The following sample sizes are required:

1. Solar-wind studies; tens of milligrams or even less

2. Stable isotopes produced by cosmic radiation or solar protons; fractions of 1 gram to a few grams

3. Radioactive isotopes; 300 grams for complete analysis, 2 to 30 grams for certain isotopes

4. Particle tracks; small samples of coarse ($>100\mu$) to very fine grained material ($<1\mu$), the coarse material being preferred

For item's 1, 2, and 4, mineral separation and grain size studies may be required in some samples; more material is needed in this case.

The physical nature of the samples includes both fine material and solid rock chunks in all sample collecting. For particle-track studies, material with mineral diversity containing coarse mineral grains is preferable, but not essential.

Sample location. - To establish the absolute chronology of lunar surface features and processes, samples for the investigation of solar- and galactic-particle effects should be obtained on all missions. A combination of samples (obtained as stated in the discussion on depth) from the following types of locations is necessary:

1. Young and old maria surfaces

2. Accumulating regions such as crater bottoms where a relatively uniform accumulation may take place

3. Places in the highlands where continuous erosion is expected to surpass accumulation

4. Surfaces exposed rather recently: ejecta blankets

5. Surfaces which had been exposed in the past and then subsequently reburied (at least 3 ft): crossing ejecta blankets

Instruments. - The necessary instruments include collecting devices and collecting tools.

Collecting devices include the following tools:

1. A coring tool which can reach a 1- to 3-foot depth in soft material for vertical and horizontal coring (Apollo-type core tubes appear suitable. However, a spacer should be added for the eventuality that the corer cannot be used for the full length to prevent scrambling of incomplete cores.)

2. A portable motor drill corer for coring consolidated material down to 1 meter

3. Drill corers with a capability of penetrating up to 30 feet of relatively soft material with some hard rock boulders interspersed (The core should retain the undisturbed section of soft and hard materials.)

4. Deep drilling perhaps desirable in later missions depending on earlier results

All cores should be capped in such a way (core catcher) as to preserve the vertical integrity of the cores.

Diagnostic tools include the following devices:

1. The development of petrographic equipment for recognizing mineral grain sizes and diversity should be encouraged.

2. The development of a radiation damage indicator should be encouraged. This indicator might depend on solid-state effects, such as thermoluminescence or paramagnetic resonance, or alternatively on the measurement of rare gases.

Additional considerations: No discussion of sampling can be complete without consideration of the serious possibility that radiation damage and shock effects may dominate the structural properties of the surface sample and even affect the composition of the sample. If the first Apollo samples show this damage, it will be necessary to know much more than is now known about general solid-state effects to interpret what is seen. Supporting fundamental research is badly needed in this area.

Chemical Composition and Widescale Differentiation of the Moon

A fundamental goal of the chemical investigation of the Moon is to establish or to place limiting values on its mean chemical composition. If the Moon is undifferentiated or if it has undergone simple differentiation, the abundances of the chemical elements and their isotopes in primitive rocks bear directly on nuclear processes in the early solar system and the origin of planetary bodies.

Present knowledge of the Moon allows a variety of compositional models based on analogies with chondritic and achondritic meteorites and the crust of the Earth. It is necessary to obtain evidence in order to choose among and modify these models. It may also be possible to establish whether the primordial Moon was homogeneous, or to what extent an inhomogeneous Moon has been homogenized by later history.

If the Moon has undergone complex differentiation, it is probable that only limiting statements can be made about its deep internal composition, even if it is possible

to analyze a very large number of samples. Sampling of many near-surface lunar rocks in mare and upland terrains and the results of remote sensing from orbiters may establish regional variations in the upper crust of the Moon. Deeper portions can be sampled in the walls, central peaks, and ejecta of large craters, or possibly in rocks brought to the surface by tectonic processes. Deep crustal depths may be sampled directly (if volcanic phenomena have brought up inclusions), indirectly by investigations of the volcanic rocks, or possibly in the ejecta from very-large-impact craters.

If volcanic rocks occur on the Moon, several problems of regional significance can be approached through chemical and isotopic studies.

1. The homogeneity of the lunar mantle can be investigated through measurements of elemental ratios (such as K/Rb, Ba/Sr or rare-earth element distributions), oxygen isotope ratios, and the isotopic composition of strontium and lead.

2. Regional studies of K, Th, and U distributions in volcanic rocks and any inclusions they bring up can be related to areas of anomalous heat flow or seismicity or to regional tectonic features, such as fracture systems.

3. Broad differences in the integrated volcanic histories of maria and uplands terrain may be indicated by the compositional variability of volcanic rocks of young and old ages. The volatile content and oxidation state of lunar volcanic rocks of various ages may help to establish regional differences in the outgassing rates of the Moon.

The surficial debris layer may give an integrated local or regional petrological record because of the continuous lateral and vertical overturn by impact. Sampling of individual centimeter-sized rock fragments in the surface debris layer may yield the range and mean composition of rocks in the area sampled. Samples in smaller size ranges may give information of broader regional importance; but with smaller sizes, the problem of recognizing a meteoritic component may increase. The usefulness of remote sensing studies from lunar orbit, such as γ spectrometry, largely depends on the regional or local significance of the surficial debris layer.

As in the case of the Earth, regional studies of the Moon imply sampling on a regional basis and obtaining a large number of documented samples representing petrological variations in place and time. Special attention must be paid to samples from the interior, for which sites cannot be completely specified without more knowledge of lunar petrological and geological processes, which will be attained in part from early Apollo missions. Nevertheless, the following general recommendations concerning sample selection can be made:

1. An attempt should be made to examine the central peak and the walls of a large crater such as Copernicus, to give a crustal section in at least one region. If it is not possible to explore the crater, recognizable ejecta in rays or at secondary impact craters should be sampled.

2. Volcanic features of as great a variety of types, locations, and ages as possible should be examined. If it can be demonstrated that certain recognizable volcanic features represent a more deep-seated magma generation, these would be favored for more intensive investigation.

3. Samples of lunar surface debris should be collected at as many distinct locations as possible to study the distribution of centimeter-sized pebbles which reflect the rariety of rocks from the vicinity of the sample. The spatial frequency of such samples should be determined on the basis of the age of the surface, with fewer samples on older surfaces.

4. A sample of Imbrian or Orientale ejecta is of prime interest because it has come from substantial depths and, presumably, at an early stage of lunar evolution.

5. It is presumed that Apollo missions will answer some of the first-order questions of the composition of the maria. It is necessary to obtain similar information from uplands terrain as early as possible in AAP missions.

Absolute Chronology of Lunar Events

The first geochronological question which must be asked is whether or not the surface of the Moon primarily consists of rocks which crystallized approximately 4500 million years ago and has been subsequently modified only by the impact of extralunar bodies. If this is true, the geological history of the Moon will be similar to that of the parent body of the chondrites, and lunar rocks which have not been excessively shocked will uniformly give 4500-million-year ages. At the other extreme, the present lunar geological features might be the result of a complex igneous, metamorphic, sedimentary, and tectonic history more analogous to that of the Earth, in which case the interpretation of geochronological data would be similarly complex. Possibly, a good start toward determining where the Moon should be placed in the spectrum between these two extremes will be made by the Apollo missions. Whether or not this possibility is realized will depend upon the degree to which suitable material can be collected from.these missions. If only thoroughly shocked ejecta is obtained, this fundamental problem.will still be the primary concern of at least the earlier Apollo Applications Program missions.

The further direction of lunar geochronology will be strongly influenced by the answer obtained to this fundamental question. If it is found that the igneous and metamorphic history of the Moon is primarily confined to the first several hundred million years following the formation of the solar system, the resolution of conventional geochronological techniques will be severely taxed. In this case extinct radioactivities, such as I^{129}, Pu^{244}, and Cm^{247}, could be very important in establishing a lunar chronology. In addition, it will be important to date some of the subsequent impact events to give an absolute basis *to* lunar chronology based on crater counting. Insofar as possible, the age of the rarer, younger igneous events may also be determined.

However, should the Moon be a geologically active body more analogous to the Earth, it will be of major interest to learn whether or not these magmatic and possibly metamorphic events are more or less continuously distributed in time, or occur episodically, possibly correlated with the origin of other lunar features, such as the maria. In addition, geochronological methods may be expected to be a useful tool in the resolution of more detailed problems of lunar geology.

At present, the area density of craters of various sizes is the principal basis for a lunar chronology. This will continue to be important because studies of this kind can be made over the entire surface of the Moon, without the necessity of a surface landing. As mentioned previously, radioactive age methods may be used to calibrate this method. In addition, measurements of the ages of craters and cratered terrains may be used to study the impact history of the Moon and Earth and to obtain data relevant to the evolution of the solar system.

Geochronological methods. - It is anticipated that, at least in the earlier investigations, heavy reliance will be placed upon the established techniques of whole-rock Rb/Sr and K/Ar dating and upon fission track dating of materials obtained from sufficient depth to be free of interference by neutron fission, The development and evaluation of whole-rock U/Pb and Th/Pb methods and the α-recoil method should be encouraged since these may also be of considerable value in lunar dating.

Because of the absence of a lunar atmosphere, there is also the possibility of using the cosmic-ray bombardment of the first few meters of the lunar surface as the basis for dating methods, analogous to the measurement of the exposure ages of meteorites.

Information concerning the age of the Moon may also be obtained by measurement of the isotopic composition of lead from rocks with low U/Pb ratios, in analogy to the use of common lead in determining the age of the Earth. Measurement of common Sr and the evolution of Sr throughout lunar history is a related problem which, although not likely to provide age information, may be of great importance in understanding the geochemical differentiation of the Moon.

These whole-rock ages may be supplemented by age measurements on separated minerals. This will be especially important if the whole rocks are not suitable for dating (for example, Rb/Sr ratios are too low), or if the rock has been metamorphosed. In the latter case, the age of metamorphism may, in many cases, be learned from measurements on the separated minerals, whereas the whole rock may preserve its original age.

Sample requirements and selection criteria. - The whole-rock measurements will require at most a few grams of the sample, and therefore can be made on all those samples used for other geochemical and petrological studies, provided that they contain appropriate concentrations of the relevant elements.

Measurements on separated minerals and larger samples (of the order of 2 kg) will probably be required. If possible, these should contain visible grains of mica and potassium feldspar or other minerals that fractionate Rb and Sr with respect to the bulk rock.

It is quite important that instruments be developed which will permit the astronaut to select samples having a sufficiently high Rb/Sr ratio or K concentrations to maximize the probability that at least some samples will be suitable for dating. The Rb/Sr ratio required will depend upon the age of the sample, and consequently it will be possible to give more exact selection criteria as knowledge of lunar chronology improves. Meteorites 4500 million years old are dated to an accuracy of about ±5 percent and have an Rb/Sr ratio of about 0.3. To obtain comparable accuracy in a rock

100 million years old would require an Rb/Sr ratio of about 15. Samples selected for K/Ar dating should have a K concentration of 0. 1 percent, although it is possible to work with samples of lower K content if it should prove absolutely necessary. It might be that the Rb concentration will be as low as one part per million, and it might not be feasible to make the highly sensitive measurements on the Moon necessary to select such samples. As a substitute for measured Rb/Sr ratios as a diagnostic sample selection criterion, it might be more practicable to measure K/Ca ratios to indicate materials suitable for Rb/Sr dating.

The choice of sample is governed by the event to be dated. Several types of events may be dated.

The time of formation of igneous or metamorphic rocks: If igneous or metamorphic rocks can be identified in place, it would be highly desirable if a number of Samples with differing Rb/Sr ratios can be collected from the same rock unit. If possible, these should include at least one sample with an Rb/Sr ratio much lower than the others. In addition to directly dating an igneous rock, it may be possible to determine the age by dating the contact metamorphism of adjacent rocks.

The age of formation of impact craters: It is likely that the age of formation of impact craters can be accomplished by K/Ar or particle-track dating of fused ejecta, and possibly by U/Pb dating as well, provided that Pb is lost relative to U at the time of impact. It may also be possible to date the impact by measurement of the cosmic-ray exposure age of previously shielded fragments ejected onto the lunar surface.

The age of stratified rocks: As on the Earth, it is likely that the age of stratified rocks will usually be dated reliably only by bracketing the strata between the age of the basement or included clastics and the age of a younger event superimposed upon the rock, such as an igneous intrusion or impact crater. In the case of pyroclastic ejecta, the igneous fragments could be directly dated.

The time at which material was buried: The time at which material was buried could, in principle, be measured by use of the cessation of the cosmic-ray exposure at that time. This is analogous to measuring the time of fall of meteorites (terrestrial age). A number of cosmic-ray-induced activities of differing half lives could be used in this way.

Other considerations. - If the Moon should turn out to have had a long history of igneous activity, it is of importance to learn whether this record was continuous or episodic. In the latter case, it will be valuable to know the age of the major episodes. It is unlikely that the limited number of AAP missions planned will permit an extensive answer to this question. The dating of fragments of ejecta which have been transported over long distances to the site of the mission may be valuable in extending the fraction of the lunar surface covered by geochronological measurements. The dating might involve the measurement of ejected pebbles which may be related to a particular ray crater or by the measurements of small fragments of ejecta of unknown source. Fragments 3 millimeters in diameter might suffice for K/Ar and Rb/Sr dating and could permit the identification of major igneous episodes even though the rocks had not yet been identified in situ. Even smaller fragments could be useful for particle-track measurements.

The Moon, like the Earth, has been continuously bombarded with extralunar matter; for example, interplanetary dust, meteorites, comets, and asteroidal bodies. The rate of influx of this matter corresponds to the addition of a layer of the order of 2×10^{-8} centimeters in thickness per year and to a total thickness of the order of 1 meter over the age of the solar system. On the Earth, rates of erosion and uplift on land areas are sufficiently high so that this extraterrestrial matter is continually diluted with much larger quantities of terrestrial matter, and the effect of this extraterrestrial accretion is extremely small. On the Moon the principal agents of erosion are probably the impacting bodies themselves, which have excavated and mixed the lunar surface to a depth of 100 meters or more, diluting the extraterrestrial matter with crater ejecta. At plausible impact velocities of about 20 km/sec, it is likely that more mass is ejected from the Moon than is accreted. In a steady state, this process will require the continual fragmentation of fresh lunar material. Furthermore, a large fraction of the impacting projectile will be included in the ejected portion. As a consequence of these processes, it is not anticipated that extralunar contamination will cause significant confusion in the interpretation of lunar chronology nor in the isotopic evolution of lunar lead and strontium unless the lunar concentration of the parent and daughter isotopes are far smaller than that of the impacting matter. This is not thought to be likely.

Indigenous Geochemical and Petrologic Processes on the Moon

Igneous, - The importance of discovering evidence of igneous activity, if it exists, cannot be over emphasized and bears directly on three geochemical problems of paramount importance: The possibility of a differentiated Moon, the source of heat for igneous activity, and provision of suitable materials to work out a chronology of lunar events, The existence of magmas does not directly prove a differentiated Moon, but it strongly increases the probability. Every effort should be made to determine the extremes of chemical variation and to estimate the volumes of different igneous rock types, leading directly to an understanding of the mechanism of differentiation and indirectly to an estimate of the average composition of the lunar surface.

The heat source, or at least the relative importance of the possible heat sources, in the Earth remains uncertain. Assuming that lunar and terrestrial igneous processes are similar, the duration of any lunar igneous activity on an absolute scale will place serious restraints on the lunar heat sources. For example, volcanism over a 4-billion-year period, as indicated on Earth, implies a very different heat source than does volcanism over a 1-billion-year period which ceased 3 billion years ago. Every effort should, therefore, be made to determine the time duration and absolute age of igneous activity.

The evidence for igneous activity is to be sought in intrusive and eruptive rocks.

Intrusive igneous rocks: Intrusions do not, in general, produce obvious topographical expressions; therefore, few probable sites can be suggested. The most obvious site is the apparent small dike seen in the Orbiter photographs of the central peak of Copernicus. This dike and other local igneous activity may possibly be due to local melting associated with impact; therefore. the information is ambiguous for the question of wide-scale igneous activity.

Large igneous intrusions on Earth appear to be limited to continents or continental margins. No such obvious units have been identified on the Moon, unless it be the highlands. Since likely target areas cannot be designated, no specific mission should be designed solely for the search for large intrusions; but the chances for discovery are believed to be increased by a mission to a large, deeply excavated crater in the highlands or to the central peak therein.

Extrusive igneous rocks: The probability that some extrusive igneous activity has occurred on the Moon is high. Most of the important geochemical questions, such as lunar origin, absolute ages of lunar events, bulk composition, and extent of chemical differentiation, can be as well answered with extrusive as with intrusive igneous rocks. Volcanic activity may be of several types. Thus, extensive volcanism associated with wide-scale lunar heating may be found, indicating a probable differentiated Moon; and local volcanism may be found as a result of melting caused by the impact of large hypervelocity meteorites. Both types are important geochemically; but the first, wide-scale volcanism, is the more important of the two types. For this reason, a high priority is strongly urged for a mission to the apparent volcanic flows in the Marius Hills with a lesser, but still desirable, priority to the Hyginus rills, or to Davy Rille.

The important questions, whether large impacts generate volcanism by local melting or whether they trigger volcanism by tapping deep-seated magmas, are both problems of basic importance to understanding the present lunar surface and the early history of the Earth. Examination of a large crater, such as Copernicus or Alphonsus, should contribute to the question. Local melting leads to volcanic rocks of the same composition as the lost environment, while deep-seated volcanism will probably yield lavas of a somewhat different composition.

Differentiation, if it occurs, will be expressed by a range in the composition of any extrusive rocks; therefore, a prior estimate of possible lava composition ranges should be attempted from measurements of the slopes on flow surfaces. The more siliceous a flow is the more viscous and the steeper the stable flow surface will be. If extremes of slope surfaces can be identified, they should be visited.

Specific missions to cones and vents of possible volcanic origin cannot be given high priority by the Geochemistry Working Group unless the vents have associated fumarolic activity. While the extreme importance of these features to the interests of other groups is recognized, from a purely geochemical viewpoint, most of the objectives can be met as well from the flows as from the vents.

Igneous rocks on the Earth have a tendency to fragment during eruption, leading (in the case of the more siliceous varieties) to widespread ash falls and ash flows. The possibility that similar volcanic activity has occurred on the lunar surface is high, and both crater-fill and mare material have been suggested to have this origin. The petrology of such fragmental extrusive volcanic rocks is of extreme interest, and the occurrence would imply a strongly differentiated Moon. The mare material in Mare Imbrium is most suitable to test the hypothesis of widespread ash flows, and the suggested small ash falls near the inner eastern rim of Alphonsus are suitable to test the crater material.

Samples: The sample selection for any igneous suites discovered should be made with the goal of maximum diversity in mind. A large amount of geochemical and petrological information can be drawn from 30-gram samples, and it is recommended that this be a minimum-sized sample. For certain rocks, particularly those suitable for dating by isotopic means, larger samples of at least 250 grams are desirable.

Volatiles and sublimates. - It is important to decipher the possible roles that volatile substances have played in lunar-volcanism or lunar-impact phenomena, There may also be intermittent outgassing taking place at present along rills or in vents. If possible, both the sources of such volatiles and the deposits of the solid sublimates should be identified and sampled.

Remote sensing orbital missions may identify present-day sources of volatile emissions which can be followed up by ground investigation. Aristarchus and Alphonsus have been suggested as possible sites of gaseous emission and are thus good candidates for possible AAP sites. All volcanic vents, rills, and craters identified in the course of lunar exploration should be carefully examined for volatile emissions. Gaseous samples should be collected for return to Earth, and mass spectrometers should be set up at likely lunar locations to continuously monitor gaseous evolution.

Sublimates, or deposits of volatile substances (including H_2O, NH_4Cl, alkali halide, et cetera) may be present on the lunar surface, Depending on the respective vapor pressures, these deposits may be located either near the source-area encrustations on surface rocks or along fractures; or the deposits may occur only in permanently shaded regions of the lunar surface. It is therefore important to sample possible sublimate deposits in all areas visited on the Moon, and these deposits should be specifically sought in areas where volcanic activity may have occurred. In addition, a portion of an AAP mission should be devoted to finding and sampling a permanently shaded area on the lunar surface. If this requires a polar site, then such a mission should be planned.

Refrigeration or thermal insulation of the sample containers will be necessary if the samples are largely ice, so that the specimens may be examined in the natural state.

Sedimentation and diagenesis. - It is geochemically important to ascertain whether water-laid sediments of any type exist on the Moon because of the obvious implications with respect to the previous occurrence of a hydrosphere. In addition, if sedimentary rocks are found, the nature of the cementation or induration can provide clues about the geochemical environment in the lunar crust. However, no special AAP missions need be planned to obtain such samples. Sedimentary rocks should be looked for at each site, and if found, the field relations and structures should be carefully described and adequate samples obtained,

Metamorphism and hydrothermal alteration. - Deep burial of lunar rocks may produce mineralogical transformations and chemical changes that will be important in determining the tectonic processes that occur on the Moon. It may be possible to estimate the pressures and temperatures of formation of such rocks by examining and analyzing the mineral assemblages. It is particularly important, therefore, to obtain samples of deep-seated lunar rocks. These may be found, for example, in the central

peaks of impact craters, such as Copernicus; and AAP missions should be planned to obtain such samples. Deep-seated rocks may also be present in any volcanic ejecta on the Moon, analogous to eclogites and garnet peridotites in terrestrial explosion vents. A search for such material is of great importance.

Contact metamorphic effects are expected in the vicinity of any intrusive igneous rocks that may be found on the Moon. A study of such materials can give information about the volatile emanations from such magmas and also about the depth and temperature of the intrusion. Hydrothermal alteration zones may be present along volcanic vents or rills, and samples of this material would also give information about the temperature and chemical nature of such solutions.

External Geochemical and Petrologic Processes on the Moon

Impact processes. - One of the basic goals in the geochemical, mineralogical, an petrological study of the Moon is to establish the relative roles played by indigenous processes (such as volcanism, degassing) and external processes (such as hypervelocit impact) in shaping the present lunar surface topography. Furthermore, it is important to establish whether large impacts trigger volcanism, a mechanism which may be well preserved on the Moon and can be of great value to the understanding of the analogs of the Earth. These data can be obtained by dating the impact glass in the ejecta and the volcanic material that fills the craters. The finding of high-pressure polymorphs of pyroxenes and olivine would also be of great interest to lunar processes and the study of the mantle of the Earth.

The evidence of hypervelocity impact structures on the Moon was derived from photographic interpretation of the morphology and inferred structure of the crater. Such evidence as the raised rim, the surrounding hummocky terrain, the radial bright rays of ejecta, and the occurrence of secondary craters around large primary craters (as well as the random distribution of the craters) is convincing. The impact origins can be confirmed by the occurrence of high-pressure polymorphs and selective phase-change features, et cetera, that are useful for the impact origin.

If lunar rocks with shock effects are widespread, then phase changes, partial melting, and outgassing would complicate the general mineralogical and petrological investigations of lunar samples. Furthermore, prior to dating the samples that involve rare gases. the samples should be checked mineralogically for evidence of remelting or strong shock.

Siliceous ejecta from terrestrial craters 300 feet in diameter show evidence of strong shock. If the lunar surface has been constantly turned over by impacts and has, therefore, undergone shock many times, the samples collected from such fragmental layers would further complicate mineralogical and petrological studies.

Samples collected for shock-effect studies in AAP missions should be selected according to degrees of impact metamorphism by rock types (including the unshocked specimens). Samples should be collected from fragmental layers of the fallout breccia within or outside of the crater where impact glasses are expected to be present and from blocks in glass-free ejecta and bedrock in the central hill or within the crater rim.

Sample size can vary from 1 by 1/2 by 2 inches or from about 50 grams to more than 1 kilogram, depending on suspected shock features. A normal sample size would be 200 to 300 grams. Increased mobility and range, such as the use of a flying vehicle, is required for collecting samples from various parts of a large crater (>5 km). Intelligent collection of such samples depends on the special training of the scientist-astronaut.

Infall debris. - If the craters on the Moon are meteorite- or comet-impact craters, external lunar material should be admixed in the fragmental or ejecta layer on the lunar surface. It would seem uneconomical to return meteoritic debris of known variety to Earth. However, the sampling of meteorites that fell on Earth is limited in types; therefore, additional varieties will increase the knowledge of the solar system and will provide corrections for the bulk composition of lunar material in which they are embedded. Such meteoritic fragments can be collected if bulk-fragmental or lunar-soil samples are to be returned and should be clarified in the study of the Apollo mission samples. The best areas of sampling of infall material cannot be determined at present because of lack of information. The study of infall material should include the smallest particle sizes into the cosmic dust range.

THE NEED FOR MOBILITY ON THE SURFACE

The very nature of the lunar exploration program is determined by the available hardware mobility. The different mobility systems that have been proposed are reviewed, and the utility of the systems for geochemical investigations is discussed. An attempt is made to describe the amount and character of the scientific information that can be obtained from the different systems. To make this as explicit as possible, reference is made in the discussion to specific mission profiles executed with different mobility constraints. These considerations of scientific output lead naturally into certain conclusions concerning the various possible systems.

From a chemical point of view, the overriding importance of returned samples in answering basic questions cannot be overemphasized. The fundamental questions about the Moon cannot be answered by making analytical measurements on the Moon — appropriate samples need to be returned to Earth-based laboratories where precise and sophisticated measurements can be made.

An adequate understanding of both processes and the origin of many lunar features requires that these features be sampled at more than one site. The large scale of most lunar surface features thus implies mobility capabilities on the lunar surface that exceed those of a man on foot.

Mobility Systems Treated

The following mobility systems have been considered:

1. Mobility on foot (1-km radius)

2. A system of two small flying vehicles (10-km radius with a two-stop capability)

3. A system of long-range flying vehicles (60-km radius)

4. A local scientific survey module (LSSM) with two small flyers (10-km radius for LSSM, 10-km additional radius with a flyer); LSSM assumed not capable of automated long range operation

5. An LSSM with two small flyers (10-km radius for LSSM, 10-km additional radius with a flyer); LSSM capable of long-range unmanned operation with a sample-collection system capability to rendezvous with a subsequent manned mission

6. A smaller roving vehicle capable of automated sample collection and with rendezvous capability

7. An automated, unmanned sample-collectiun vehicle capable of retur-ning Samples directly to Earth

8. A series of emplaced unmanned scientific stations, for example, a number of hard landers dropped from the CSM

It was assumed that the two small flyers could be carried in a single launch while the addition of an LSSM or long-range flyer required a dual launch, each of the Saturn V class. The smaller roving vehicle mentioned was assumed to be landed with a somewhat smaller launch system; therefore, the inclusion of the smaller roving vehicle implies a dual launch which has been downgraded from the LSSM dual-launch missions.

Discussion of Different Options

Options of minor interest. - Certain of the options are of minor interest in the development of an AAP exploration program and can be dealt with simply. These options include mobility on foot, emplaced science stations, and unmanned vehicles with the capacity to collect and return samples to the Earth.

Mobility on foot: As valuable as the initial Apollo landings will be, they can be considered only as the starting point for answering the major scientific questions about the Moon. Any meaningful program of exploration must extend the mobility of the astronaut beyond the 1-kilometer-foot-mobility radius. Practically none of the major objectives of the missions described in detail subsequently could be achieved by a man on foot. In Copernicus, for example, only the crater floor could be sampled from the landing site. The central peaks, which represent the major motivation for going to Copernicus, would be inaccessible.

Emplaced science stations: The Geochemical Working Group sees little reason for development of in situ chemical or mineralogical analyses in unmanned emplaced science stations. Unmanned roving vehicles capable of sampling a wide area and of delivering samples that can be picked up for return to Earth laboratories for analysis have considerably higher priority.

Unmanned vehicles with the capacity to collect and return samples to Earth: The use of a roving vehicle as an adjunct to a trained observer is a particular modification of another concept of the unmanned rover concept which includes the possibility of an unmanned return to Earth. While many interesting possibilities exist for the use of this capability, it has a relatively low priority in a program of manned exploration. However, the capability is probably a necessary extension of technology for planetary exploration and should certainly be considered in the long-range planning for solar system exploration,

Options directly increasing the mobility of the astronauts (single-launch systems). - A system of two small flying vehicles with a 10-kilometer radius, a two-stop capability, and a 50-pound payload is considered. The small flying vehicles immediately extend the range of the astronaut to the point that many interesting regions become accessible for sampling. It is now possible to sample the central peaks of Copernicus (mission profile tables), and the major objective of this mission can be realized. The flyers also add vertical mobility, a feature that is considered essential for the sampling function. There are numerous advantages of the small flyer for single-launch missions, and no reasonable alternative has been shown. The development of this system appears to be essential to future lunar exploration.

Options directly increasing the mobility of the astronauts (dual-launch missions). - Only the systems directly affecting astronaut mobility are discussed. Unmanned systems are considered in a later section.

System of long-range flyers: The development of long-range flyers would greatly enhance the capabilities for exploration of the Moon. Consider, for example, the dual-launch mission with long-range flyers that has been outlined for Aristarchus. In the detailed mission profile it would be possible to visit and sample the following features: Cobra-Head (primary target), Schroter's Valley (valley and walls for a considerable length), the ejecta blanket from Aristarchus, a volcanic dome area, and a contact zone between two maria.

With a single launch using the small flyers, it may not be possible to sample any of these features. This would depend on whether it would be possible to land in the quite rough region near Cobra-Head. If this were possible, the single-launch mission would examine Cobra-Head, but little else.

The essential point is clear; long-range flying vehicles greatly enhance the geochemical return from a given mission. In most cases, a single dual mission with this capability is also much more efficient in sampling a given region than two single launches to the same area.

Since long-range flying vehicles are clearly of great utility in geochemical work, their development is recommended. If the development cannot be undertaken simultaneously with that of the small flyers, it is most strongly urged that the design of the small flyer be done with the idea clearly in mind, from the beginning, that a scaled-up version will likely be necessary in the future.

LSSM with two small flyers: The addition of the LSSM essentially doubles the range of the small flyers and enhances the desired mobility. In the Aristarchus mission, for example, Cobra-Head and parts of Schroter's Valley are accessible from a

region that looks like a possibly better landing site (though this is not certain) than that required for the single-launch exploration of Cobra-Head. However, the other features that have been previously listed for the mission using long-range flyers, appear to be inaccessible; therefore, the combination of an LSSM and small flyers is not as attractive as the long-range flyer.

Unmanned roving vehicles. - In this section, roving vehicles that act as collectors of samples for Earth return are considered. For the purposes of discussion, the distinction is not made between an LSSM modified for remote operation and an automatic field assistant (AFA) developed exclusively for unmanned use.

Even in the most optimistic estimates, only a small area of the Moon will be explored by manned missions in the AAP. The extent of geochemical coverage of the Moon would be qualitatively enhanced by the development of an appropriate roving sampling vehicle capable of long traverses. A specific example is discussed of the enhanced scientific results possible in the mission profiles in which an Alphonsus mission and a Davy Rille mission are linked by an unmanned rover.

Such a vehicle sent on ahead of a manned mission could operate in two modes: (1) the vehicle could select samples over an extended region before astronaut arrival and deliver the samples to a rendezvous site for pickup; and (2) the vehicle could be started out on a sample-collection traverse after the astronauts left; then the vehicle could rendezvous with a second manned mission. Both modes of operation are useful.

The vehicle should be equipped with remote geochemical analytical instruments. The instrumentation would serve three functions: (1) to provide some geochemical characterization of regions that are traversed but not sampled, (2) to aid in sampling decisions, and possibly (3) to locate unusual areas of high interest and, hence, modify the mission plans for rendezvous.

The vehicle would also be useful in intensive exploration of a relatively small area (for example, the interior of Copernicus). Sent on ahead, the vehicle could select samples from a wide variety of sites and deliver the samples to a central location near the landing site of a subsequent manned mission. The trained astronaut could make a sample selection and decide whether or not certain areas had been adequately sampled. This mode of operation takes maximum advantage of the man-machine system and provides the most efficient use of the astronauts' time on the lunar surface.

Optimum Requirements for the Roving Sampling Vehicle

The optimum requirements for the roving sampling vehicle are as follows:

1. The ability to locate sample stations with respect to identifiable lunar surface features to within 10 meters on high-resolution, orbiter-like photographs

2. The capability to make traverses of 500 kilometers with at least 100 stations for observation and sample collection

3. A carrying capacity of 25 kilograms of samples collected in 100- to 250-gram pieces for a total of 100 samples

4. Individually packaged or identified samples

5. An instrument weight capacity of at least 25 kilograms to allow inclusion of geochemical analytical instruments by which onsite sample selection could be accomplished

No specific requirements are foreseen for the samples to be packaged in any specialized way to avoid special contamination problems, nor are any special requirements foreseen for vacuum packaging. Stereoscopic television is not required. It is essential that the roving vehicle rendezvous with an astronaut who will further package the Samples for return to Earth.

The essential conclusion of these considerations is simple; a roving vehicle with the appropriate characteristics is highly desirable. The value of the LSSM would be greatly enhanced for geochemical studies if the vehicle could be designed for unmanned operation with the specifications similar to those given above. In fact, it is urged most strongly that if the development of the LSSM vehicle is undertaken, it should be designed from the beginning for manned and unmanned operation.

Conclusions and Recommendations

1. Enhanced astronaut mobility is essential for future meaningful lunar exploration.

2. The development of small flying vehicles (10-km radius), capable of being carried on a single launch, has first priority.

3. Long-range flying vehicles flown in dual launches add greatly to the number of scientific objectives that can be accomplished with a given number of large boosters.

4. If the development of long-range flying vehicles and short-range flying vehicles cannot be undertaken simultaneously, the design of the small vehicles should be made from the beginning with the knowledge that scaled-up versions will likely be needed in the future.

5. Surface vehicles of the LSSM type are most useful for geochemical investigations if they can also be used as unmanned roving vehicles capable of collecting samples and delivering them to a rendezvous point for return to Earth.

6. If the development of the LSSM vehicle is undertaken, it should be designed for both manned and unmanned operation.

ORBITAL PROGRAM AND MEASUREMENTS

At this writing almost nothing is known about the chemical composition of the Moon. The density sets certain bounds. The γ-ray experiment on Luna X suggests that the surface rocks are, on the average, basic or ultrabasic. Because of several

limitations of experimental design, quantitative data are not available. The Surveyor α-scattering experiment possibly will give compositional data at a few points.

This lack of data results in a complete disagreement as to the nature of the processes producing the surface features which have been seen. Experts holding the most diverse views find confirmation in the excellent photographs obtained by Lunar Orbiter and Surveyor cameras. The same layers on the maria, for example, are suggested to be lava and carbonaceous chondrite material,

The uncertainty has not seriously affected the planning of Apollo missions. Any samples of the Moon and any field and instrumental observations are certain to produce a great increase of knowledge at this stage. The proposed landing sites, the locations of which are dictated in large part by practical constraints, are as good as any to begin.

The selection of sites for the AAP is another matter. In this program, the landing capability is to be much wider, and sites and missions must be chosen for the greatest scientific return. In other sections of the report, the most important geochemical objectives have been stated and include the recovery of samples of the oldest and the most primitive rocks, of volatiles and organics, of volcanic material, of surfaces of various ages, and of complexities of exposure. Some suggested AAP missions, for example, Copernicus and Aristarchus, sample such a variety of terrain that the missions are of value almost independently of compositional information. The choice of other missions depends, in part at least, on interpretations which may not be valid. Important possibilities may well have been overlooked entirely. The missions the Geochemistry Working Group and others have suggested might well be altered if processes of differentiation are known to have been slight, extensive, or dominant on the lunar surface.

Compositional mapping of the lunar surface is a practical possibility with the use of orbiters and can provide information concerning the processes of differentiation. The time problem in making the observations is increased by the fact that the necessary orbiters require a new program, which can cause a considerable delay.

Before discussing the individual sensing experiments, the items which possibly can be accomplished with orbiting remote sensors are summarized. The following are the main objectives:

1. The AAP site selection, which can be affected by delineation of provinces, measurements of scale of variations; location of unusual or unique features; and correlation with photographic evidence which can aid in the interpretation of photographs

2. Determination of meaningful averages for the whole Moon; this cannot be done by any reasonable number of landing missions

3. As an aid in understanding of Apollo and AAP returned samples (How typical are they? The samples are equally useful in interpreting the orbital data.)

4. Data on inaccessible regions of the Moon

5. The development of the capability for studying other planetary bodies (For these the prime source of geochemical knowledge — sample return — may be Unavailable for a very long time.)

Advanced Remote Sensors

There are four remote sensors now well enough advanced to be recommended for early flight.

The y-ray experiment. - The y-ray experiment (0.3 to 10 MeV) can measure K at most levels expected in lunar materials and Th and U at the levels present in differentiated rocks. The elements Fe, O, and perhaps other major elements can be usefully measured using cosmic-ray effects on the surface rocks. Spatial resolution is comparable to satellite altitude; therefore, low orbits are preferable. Second-generation sensors can have a telescopic capability with an aperture perhaps of 10° to 15". The depth of penetration is of the order of tens of centimeters.

Engineering development of the simple system is now well along. Design studies and a few balloon experiments have been done for the telescopic system. Other NASA-supported developments are contributing to their development.

The X-ray experiment. - The X-ray experiment derives chemical information from X-ray fluorescence under X-ray and particle bombardment from the Sun. The major elements from Mg through Ni are measured with present sensors; lower Z elements, particularly C, can be measured with more advanced systems. The depth of penetration is of the order of a millimeter or less. The excitation by X-rays from the quiet Sun will apparently be adequate at times of solar maximum, but not at solar minimum. Solar-flare periods provide much more intensity.

The electronic portion of this equipment is planned for sharing with the y-ray experiment and hence is in an advanced state. The sensors have also undergone testing.

The a-particle experiment. - The a-particle experiment, proposed by Davidson, has not received much support; it deserves more. Sources of gas on the Moon, as on the Earth, must emit radon and thoron. Decay of these gases, adsorbed on the surface or in ballistic flight, will give rise to a coat of a-emitting paint on the Moon. The radon daughters may be distributed over the lunar surface, but because of the short half life, thoron products should be localized near the sources. In addition, various other processes may produce concentrations of U, Th, and other a-emitters at the surface in certain places.

The instrumentation has not yet been developed for flight, but it is straightforward and shares much with the y-ray and X-ray systems. A development study is about to be funded.

Mass spectrometer. - The mass spectrometer detects gas emitting sources on the lunar surface and is quite practical from close lunar orbit. A mass spectrometer of the type presently being flown by Nier with the time response adjusted to about 0.5 second will detect a gas outflow of as little as 100 to 200 g/sec of gases, for example, CH_4 or CO_2, at an orbital altitude of 20 to 70 kilometers at a slant range of 100 kilometers.

The gas-outflow detection capability could locate sources of volcanic gases or water outgassing in small amounts. The equipment required is essentially on the shelf.

A set of vanes for localizing the direction of the emitting source or for use of the device on a rotating subsatellite are alternative site-locating methods.

Development of Other Remote Sensors

Other remote sensors are not as well developed in either the scientific or the engineering sense. Studies are needed to permit judgment of the utility for remote sensing, These studies include the following topics:

Infrared spectroscopy. - Lyon has developed instrumentation for studies of the Earth from an Earth-orbiting vehicle. This instrumentation limits sensors to the atmospheric windows, which may not yield the best compositional information. Other wavelength regions also need study. It is possible that minerals can be identified and organic molecules detected at the surface.

Neutron albedo. - There is some chance that concentrations of hydrogen (water) in the outer layers of the Moon can be detected in this way.

Ultraviolet region. - Fluorescence, above 2000 Å and in the little-studied vacuum ultraviolet may yield compositional information.

Methods to Achieve Orbital Missions

At this conference, several possible means have been considered for achieving orbital missions. The use of Earth-launched anchored interplanetary monitoring platform (AIMP) or Pioneer spacecraft has the advantages of low cost and proven system reliability. If a start is made next year, this system will provide an early launch. The disadvantages are a rather high orbit and limited payload weight. The absence of attitude control and limited telemetry bandwidth does not seriously degrade the information obtained. The use of a subsatellite carried in an early AAP mission or even in the Apollo service module is an attractive possibility. The advantages are the economy and reliability gains obtained from not having to develop a major rocket system and the flexibility which includes the possibility of more than one subsatellite per mission. Orbits are at 150 kilometers or lower on various missions. Latitude coverage will be small on Apollo but may be better later, especially if subsatellite propulsion is used. Payload limitations will be as stated previously if the subsatellite is AIMP, but may be much less severe if a larger system is used. The risk exists that these systems might have to be removed if new requirements were imposed for the manned program. Finally, there is the proposed compositional-metric mapper. This system, designed specifically in part for remote sensing missions and with a large scientific payload, would undoubtedly reach the objectives. The disadvantages are the requirements for a major new start, a late date for first launch, and later launches on 2-year centers.

The following are the chief missions proposed for new orbiters:

1. Compositional mapping with remote sensors

2. Photogeological mapping of potential AAP sites

3. Geodetic mapping at a precision of 6 meters with film return

The AIMP system is unsuitable to objectives other than the first. It can, however, combine this with important experiments in the area of fields and particles. Larger subsatellites can meet the first two objectives; perhaps the third can be accomplished by cameras on the CSM. In any case, if trade-offs are necessary, it is believed that the first two objectives deserve priority.

The compositional-metric mapper might achieve all major goals. However, in this case the requirement for film return exacts a weight penalty against the scientific payload.

There has been serious and continued consideration in NASA of Apollo and AAP missions devoted entirely to manned orbital science, with the lunar module (LM) weight and volume available for this purpose. The capability of such missions is large enough to reach all possible scientific objectives, including astronomical systems at various frequencies (especially those which can exploit the sharp edge of the Moon as a shutter); radar study of lunar structure; particle and field experiments; and advanced versions of geological, geochemical, and geodetic systems. The problem at present is to provide a large payload made up of experiments which are ready for flight at an early date. One or more missions of this type may be competitive with later AAP landing missions and should be seriously considered.

Recommendations

The following are the recommendations of the Geochemistry Working Group:

1. A compositional remote sensing experiment package (including at least γ-ray, X-ray, and α-sensors) should be given a high priority. The use of SM subsatellites of early manned orbiting missions and of AIMP and Pioneer direct launches should be' studied and the best possibility chosen for early flight.

2. Development of these remote sensing experiments must be continued and accelerated in Fiscal Year 1968. Study of other potential experiments — gas emission, infrared, ultraviolet, and neutron albedo experiments — should be made to determine which are useful for early flight. These studies, however, should not be permitted to interfere with the general support of science programs by NASA.

3. The AAP missions devoted to orbital science have important scientific potential. Serious study is needed to establish scientific priority relative to later landing missions.

ANALYTICAL TOOLS FOR GEOCHEMICAL INVESTIGATION ON THE MOON

The Geochemistry Working Group is unanimous in the view that a completely meaningful study of the Moon can be made only in Earth-based laboratories using returned lunar samples. Nonetheless, the Geochemistry Working Group believes that there is a compelling need for the development of better analytical instruments to be flown on AAP lunar missions. In this section, the current status of instrument development is reviewed and recommendations for future action are made. The essential conclusion is that instrument development has not proceeded rapidly enough and that instrument development needs to be emphasized more vigorously in the future.

Four overlapping classes of instruments need to be considered:

1. Those instruments which will help the astronaut make an on-the-spot decision as to a sample which should be taken from a particular location (Instruments that would help an astronaut make a directed search for particularly interesting samples are included.)

2. Those instruments which will allow the astronaut, probably with the help of Earth-based observers, to make a selection for Earth return among a set of previously gathered samples

3. Those instruments which can be mounted in a remotely operated sampling unit, such as an automated field assistant, to assist in sample selection

4. Those instruments which will convey the maximum amount of geochemical information about areas that are covered but not sampled (The information would be particularly important for extended traverse missions.)

An enormous amount of money and effort is being expended to obtain lunar Samples for Earth study. The ultimate value of these samples depends on the amount of samples, the variety of samples, and the suitability of the samples for certain types of study. It is clear that the effort to obtain samples in the first place should be matched by a corresponding effort to insure that the samples are the best possible that can be obtained from the mission. The quality as well as the quantity of the sample to be considered is especially important in view of the limited sample-return capability of the lunar missions.

On the Earth, an expert observer of a given discipline can generally select appropriate samples by simple visual observation. There is no guarantee that the same will be true on the Moon. The continued bombardment and "gardening" of the surface may make a sample unrecognizable to the Earth expert.

Even if the features of a sample are recognizable, the wealth of different kinds of measurements that are to be made on the returned samples will make it difficult for an observer to make a choice of samples without additional analytic information and without the advice and support of Earth-based scientists in communication with the astronaut during the mission.

Because of the nature of lunar exploration, samples will be returned only from certain selected areas. Even in those areas selected, the returned samples will represent only a fraction of the potentially interesting samples. To obtain a broad geochemical coverage and to assist in the selection of future landing sites, it is essential to develop instruments that give the most meaningful geochemical data.

For the astronaut, it is important that the instruments act as an aid and not a burden. The visual observation of a scientifically trained astronaut is still the first line of attack on the collection of scientifically important samples. If the analytic instruments take too much of the potential observing time of the astronaut (or even thinking time) then the instruments will have failed. Mission plans might be set up so that the astronaut generally has the option, not the necessity, of instrumental aid. In remotely operated devices, weight considerations and the difficulties of remote sample preparation will also probably limit the number of instruments that can be carried.

These considerations might be taken as an argument limiting, rather than expanding, the development of geochemical instrumentation. The opposite view is taken; because the number of instruments is limited, the instruments that are chosen should be the most informative and reliable that can possibly be made. This means more, rather than less, emphasis on instrument development.

Review of Current Status of Instrument Development

In the Falmouth report, the following list of equipment was recommended for development and evaluation in simulated lunar missions:

1. Portable equipment considered useful on the open surface for sample differentiation includes the following items:

   a. Combined X-ray-fluorescence spectrometer and scattering density indicator

   b. Rock splitter

   c. Thermometer

2. Equipment for use in the LM includes the following items:

   a. Binocular microscope with arrangements for opaque samples and separated grains

   b. Multichannel analyzer and pattern analysis computer

3. Bulkier, heavier, or less convenient equipment for use in the LM and/or on the surface includes the following items:

   a. Combined y-spectrometer-neutron analysis equipment

   b. Gas-sample compressor for collecting atmospheric samples

c. Moderate-to-low-resolution mass spectrometer

d. Water and organic material detector

e. X-ray diffractometer

f. An alpha- or proton back-scattering spectrometer

As far as can be ascertained, little or no progress has been made in items 1(b), 1(c), 2(a), 3(b), and 3(d). However, substantial progress has been made on some of the other devices. These instruments are discussed separately.

X-ray emission spectrometer. - A device currently under development by the Goddard Space Flight Center uses an energetic alpha-emitter (Cm^{242}, Po^{210}) to excite characteristic X-rays. Since the X-ray excitation function rises sharply with decreasing atomic number for alpha-particle excitation, the device is particularly good for the common low atomic number elements of common rocks. The final version of the instrument will weigh from 1 to 2 pounds, excluding the multidual analyzer used to measure the proportional counter output. Sample preparation is minimal or unnecessary, and a reading can be obtained within several minutes.

A prototype instrument is currently being tested for the ability to distinguish between different rock types and to measure geochemically significant quantities, such as Mg/Si, Ca and K/Si, and Mg/Fe element ratios. Although the energy resolution of the prototype is limited, some promising preliminary results have been obtained. Additional testing is needed to evaluate the final utility of this instrument in the field.

Solid-source mass spectrometer. - A low-weight solid-state mass spectrometer will shortly be available as a breadboard design suitable for testing the utility of the basic design concept for analytic work. As developed by the Goddard Space Flight Center, this device has a sputtering source of ions and uses a double-focusing system for mass analysis. One particular modification to be tested involves the use of a Penning-type discharge tube with a small mass analyzer.

The final device is envisioned as weighing approximately 25 pounds and would consume approximately 25 watts. It is thus potentially suitable for the LM or AFA, but not as a handheld instrument.

In principle, the device should give good element resolution and much higher sensitivity than the X-ray emission device and should extend to trace element analysis. It is likely that the yield of a given ion will vary according to the matrix in which an element occurs, and this is apt to be the practical restriction on the useful accuracy of the device in examining unknown surfaces. In addition, there is really no experience at present in terrestrial laboratories using this principle for chemical analysis. Much work must be done before the utility of this device can be assessed.

Neutron-gamma analyzers. - Bombardment of a material with neutrons produces a yield of y-rays resulting from neutron capture, neutron inelastic scattering, and neutron activation. These y-rays are emitted with characteristic energies and can be used to identify the elements in the target. If a pulsed neutron source is used, then diffusion of neutrons in *the* target material can be studied — a measure which is extremely

sensitive to the presence of hydrogen atoms in the target. A unique feature of this method is that it explores the surface to a depth of some 50 centimeters. The sensitivity of the method varies markedly for different elements, being very good for Fe, O, Mg, and Si, but very poor for Ca and K.

Active development programs designed to explore the utility of such devices are in progress in at least three laboratories. Radioactive sources do not appear to be useful neutron sources, and all the devices currently envisioned use neutron generator tubes. It should be possible to construct a neutron-gamma analyzer weighing approximately 30 pounds with a power consumption of approximately 20 watts. Probably the strongest drawback to the device is the limited lifetime of the neutron generator tubes. It is estimated that only several tens of measurements (each taking several hours) could be made. Thus, the device would not be suitable for on-the-spot sampling by an astronaut or for extended traverse missions. One expert in this field has estimated that it could take more than 2 years of intensive work to develop a flight-qualified instrument.

Alpha-back scatter analyzer. - A fully flight-qualified instrument has been developed for the Surveyor program. Major light elements can be determined with a varying precision of several percent at best, but 10 hours is required to make a single reading. This device is suitable for either an AFA or extended traverse mission and should be of some help in these modes in sample selection and regional characterization. The amount of directly useful geochemical information is, however, greatly limited; and the device is of little use in onsite sample selection in a manned mission.

X-ray diffractometer. - An X-ray diffractometer weighing approximately 10 pounds and consuming 25 watts exists as a prototype unit. The performance is comparable to a good commercial diffractometer unit. Only 5 minutes is required for a single reading.

This device is potentially of great use in selecting certain mineral types between various previously gathered samples in a manned mission. In this use, the major problem that must be solved is the analysis of the diffractometer measurements to give information that is useful to the astronaut. Direct analysis by the astronaut is out of the question; the problem must be handled either by high-speed computers on Earth or by a combination of computers and expert diffractometer analysts on Earth in communication with the astronaut. One suggestion that should be examined is that the diffractometer be mounted in the LM with an automatic sample feed with data readout to Earth. The data could be analyzed by Earth-based experts and the results fed back to the astronaut within a half-day interval. The result could then be used as the basis for choosing particular samples for return, or for providing motivation to revisit certain sites where unusual minerals occur.

Overview of the Instrument Problem and Recommendations for the Future

For the moment, only the alpha-back scattering device exists as an available flight instrument. Instruments in various stages of development include an X-ray emission analyzer, an X-ray diffractometer, a solid-source mass spectrometer, and a neutron-gamma analyzer. The first three of these appear promising and should certainly be pursued to determine what they can do. It appears likely that the X-ray emission device, at least, will be very valuable on manned and unmanned missions.

In view of the previously stated position of the Geochemistry Working Group emphasizing the importance of instrumentation, the current situation cannot be viewed with satisfaction. The development of instruments that were previously recommended, such as the X-ray emission device, has not proceeded as rapidly or been carried as far as the group would prefer. By this time, there should be a fairly complete definition of the capabilities of these devices and even several competing versions among which to choose. This desire implies no criticism of the groups involved, only of the level of effort that apparently has been possible.

A second, more general criticism of the instrument development program is, namely, that there seems to be a lack of imaginative thinking on the development of instruments with no simple Earth analog that would be uniquely useful for lunar studies.

One major reason for the present unsatisfactory state of affairs has been the failure to define more precisely the detailed requirements for such devices. For example, it is clear that for geochemistry it is important to measure both elemental abundances and mineral compositions. However, the problem has not been faced as to which elements and which minerals need to be determined and with what precision or accuracy to be useful. It is obvious that the lack of knowledge about the chemistry of the lunar surface makes it very difficult to make such specifications without ambiguity. Nevertheless, it is also clear that a study of the problem should produce more useful limits than those used at present. For example, Orbiter photographs, as well as older telescopic studies, indicate that volcanism and plutonism, (that is, liquid-crystal fractionation processes) are the most likely sources of chemical variations on the lunar surface. Therefore, it is reasonable to use the vast amount of information that exists on terrestrial volcanic rocks as a guide in estimating the relevant elemental and mineralogical variability of lunar surface rocks.

In addition, it has been proposed that meteoritic material may be more abundant on the Moon than on the Earth. Thus, the very extensive body of chemical and mineralogical data that exists on meteoritic matter should be very useful in determining which chemical and mineralogical parameters are most useful in identifying various meteoritic materials and in distinguishing them from lunar volcanic rocks. The sensitivity and accuracy, as well as the very nature of an instrument, depend upon the specific job the instrument is trying to accomplish. We propose that a detailed study be made to help stimulate the appropriate instrument development of Instrument Requirements for Geochemical and Geological Exploration of the Moon.

The study would include an examination of all possible chemical and mineralogical parameters to determine how much more useful some parameters are than others in the differentiation of materials of different origin, for example, chondritic meteorites and achondritic meteorites, individual lava flows, highly differentiated rocks from ordinary flows, glass or fine-grained material from crystallized material, et cetera. One particular question that requires definition is which elements are important. It may be that certain trace elements or the radioactive elements are sufficiently diagnostic in terms of the overall chemistry of a rock so that the trace elements can reliably be used to define mappable or geologically definable units. It is quite possible that such a study will reveal some elements whose abundance variation is so great and so systematic that requirements for accuracy can be greatly reduced. Furthermore, such a study should make it possible to select diagnostic elements or minerals that can be detected with the greatest sensitivity. Such a study should be carried on by scientists,

who are intimately familiar with the geochemistry of volcanic and meteoritic materials. Several examples of the type of parameters that might result from this study are as follows: the K/Ca ratio which is a much better index by which to classify chemical variation than an analysis for Al, Mg, Si, and Fe. The K/Ca ratio varies by a factor of 500 in common rock types, where Mg/Si or Mg/Fe ratios vary by less than a factor of 10. Similarly, the Al/Si or Ca/Si ratios are a much better index for distinguishing chondritic material and ultramatic rocks from other rocks than the Mg/Fe, or (Mg or Fe)/Si ratios. Probably the most distinctive chemical characteristic of chondrites is the Ni content or Ni/(Mg or Fe) ratio. Similarly, the question may be asked: is the S content or N content, perhaps, as useful in detecting organic materials as the C content.

The radioactive elements are interesting in that the presence of the elements determines the thermal balance of the Moon. The precision with which the radioactive elements need to be measured to shed light on this problem should be also clearly spelled out in the study.

The proposed study of instrument requirements for geochemical exploration should also include measurements other than elements and minerals. For example, the presence of volatiles, such as organic compounds, water, and ammonia, are of considerable interest. The importance of each of these measurements and the level at which the measurement would be interesting should also be treated.

The chronology of the lunar surface can be determined by cosmic-ray effects. Remote measurement of the extent of these effects in different locations would provide a detailed map of the age of various features on the Moon. Radiation effects might be measured by a variety of solid-state effects or by rare gas analysis. The delineation of the need for instrumentation to measure radiation effects remotely would be a valuable product of the proposed study,

Several other properties that might be measured remotely include the particle size distribution (texture) and the ferromagnetic properties of the material (or more precisely, the amount of free and combined iron). It is again emphasized that the proposed study should be performed by working scientists active in the relevant fields, which would clearly delineate the requirements for instruments and, as such, do much to stimulate instrument development by both university scientists and industry.

However, the study will be of little value unless there is an accompanying commitment of funds. A selected NASA laboratory or center should be given the responsibility to integrate and implement the results of the proposed studies.

CONTAINERS AND ADEQUATE SAMPLE RETURN

The Geochemistry Working Group reviewed the sample container that has been constructed for return of materials for the early Apollo missions. The group is impressed by the difficulties placed on the astronaut in the packaging of samples for the return trip because of the vacuum and mechanical requirements. The difficulty in closing the sample box could conceivably lead to leaving behind important samples that

are collected, especially if emergency ascent procedures are required. The Geochemistry Working Group makes the following recommendations:

1. A grab-sample pouch consisting of a single bag about *8* by 12 inches in dimensions to hold up to **4** to **5** pounds of sample is required and must be designed. The first scientific task of the astronaut is to fill the grab-sample pouch and to load the pouch into the ascent stage of the LM.

2. The first priority for a sample return box is that it be designed so that it can be easily closed, whether or not it is vacuum sealed, so that samples can be returned. The second priority is to have a vacuum seal that will maintain a pressure of 10^{-6} torr. An alternative simplified sample return box should be designed, that can be returned in a closed condition even if a positive vacuum seal cannot be attained. An alternative design for a sample return container, such as the nested cylinder design, should be developed as a more effective, simple to seal, vacuum container.

3. The present sample return bags do not meet the requirement to return up-to-1-kilogram bags; therefore, bags with 1-kilogram capacity are necessary.

4. Attention is called to the requirement for increased sample return in the AAP missions. Every effort should be made to increase the sample return volume by the designation of space, such as the LiOH canister space, as sample return areas.

POSTMISSION ANALYSES

The program of analyses and study planned for the first returned lunar samples is unprecedented, both in scope and detail. The variety of analyses called for by a proper study of these samples requires extensive participation by scientists from universities, industry, and Government laboratories. The management and coordination of such a complex and comprehensive program of study will require continual planning and review by a group responsible for this program, particularly once lunar materials are being analyzed in terrestrial laboratories. The Geochemistry Working Group has considered both the Apollo and AAP aspects of the sample analysis program,

The Geochemistry Working Group concurs with present plans that the staff of the Lunar Receiving Laboratory (LRL) should be augmented by a team of specialists in making preliminary examination during the quarantine period. The preliminary examination team should be considered a temporary part of the LRL staff, that is, be subject to the training regulations established for LRL personnel.

It is recommended that, if sample quarantine regulations can be relaxed in AAP missions, the facilities available at the Manned Spacecraft Center be augmented to allow a much wider variety of preliminary examinations, for example, microprobe studies, X-ray identification, X-ray fluorescence analyses, et cetera. It is recommended that a separate and independent board, the Lunar Sample Advisory Board, be established to advise the Director of Science and Applications of the Manned Spacecraft Center on the use of returned lunar materials in scientific research. This group should consist of approximately 12 people who represent the various areas

of interest involved with lunar materials. This board should be responsible for the planning and scheduling of the overall program of analytical work to be done on returned lunar materials, including the preparation, preliminary examination, and allocation of materials for particular measurements.

In addition, it should be the concern of this board to identify areas in which additional work on the lunar materials is necessary and to expedite those measurements that are especially important in planning further missions.

Specific Suggestions on Program for Analysis of First Apollo Samples

Control sample. - The Geochemistry Working Group considered the question of control samples to be analyzed at the same time that returned lunar samples are analyzed. The group makes the following recommendations:

1. Control samples as close in properties to the returned lunar samples should be run at the same time that returned samples are analyzed. The control samples shall be picked in consideration of the analytical work to be done, such as meteorites for cosmic-ray-induced activity, or appropriate terrestrial rock samples for other chemical analytical work.

2. The Geochemistry Working Group restates Its recommendation that control samples be run through as much of the preparation and analytical procedure as possible, prior to the return of the first lunar samples. The LRL will prepare samples and make them available to the principal investigators in order to check possible flaws in LRL technique, to identify possible difficulties in the analytical procedure, and to clarify the flow patterns of samples with regard to multiple use of samples.

Typical sample flow patterns. - The Geochemistry Working Group has outlined the basis of sample flow patterns for two samples, a relatively homogeneous consolidated rock and an unconsolidated debris sample. The analysis of each sample is divided into preliminary analyses, to be done at LRL, and into subsequent analysis to be done in large part outside of the LRL. Figure 1 is a typical flow chart for sample analysis.

Analysis of a large single sample of approximately 1 kilogram. - The analysis of a large single sample of approximately 1 kilogram includes the following procedures:

1. The counting of the bulk sample is to be completed during a quarantine period. It is required that there be no holdup of sample material as a result of incomplete counting. It is recommended that an additional counting capability be established at the LRL to augment the single counting system now in operation.

2, The sample is to be split into several large portions, in approximately the following manner:

a. Twenty percent, or 200 grams, is to be retained as a museum specimen. Orientation is to be preserved.

a

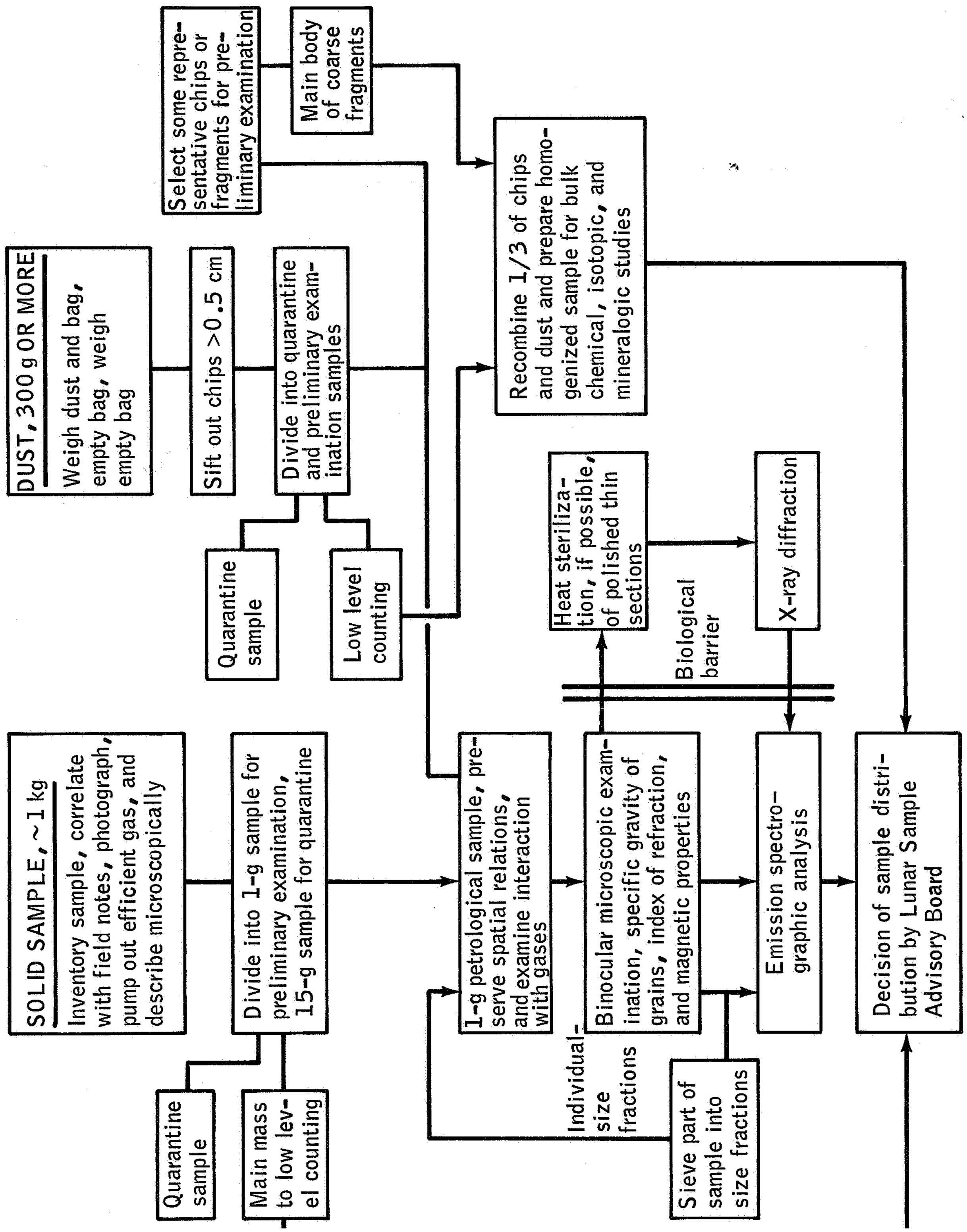


Figure 1. - A typical flow chart for sample analysis.

b. One hundred and fifty to two hundred grams of slab or core, preserving geometrical relations from top to bottom, is to be reserved for cosmic-ray induced activity studies.

c. One hundred and fifty grams is to be homogenized for bulk chemical analytical work and isotope studies (Pb, Sr, et cetera).

d. An additional amount, up to 200 grams, may be required for mineral separation so that individual mineral analyses can be made.

e. One hundred grams is to be reserved for biological and organic geochemical studies.

f. Two hundred grams is available for other purposes.

Recommendations. - Specific recommendations are made on the following points:

Sample splitting: The LRL should be prepared to use a variety of approaches in cutting, chipping, and crushing samples to limit contamination, to limit the amount of sample lost, and to retain the orientation of some portions. The LRL should demonstrate this capability to the satisfaction of the principal investigators before samples are returned from the Moon by the provision of control samples to scientists making sensitive determinations of chemical and isotopic parameters.

Homogeneity and homogenization of samples: Adequate polished thin sections shall be prepared from all pieces of material supplied for cosmic-ray studies, from the samples to be homogenized for chemical analysis and mineral separation, and from other portions to test homogeneity of the specimen. The LRL shall have the responsibility of preparing a homogenized sample with minimum contamination, to be established by control sample procedures, as stated above.

Mineral separations: Cooperation of the Principal Investigators on mineral separation of designated samples is encouraged. Most mineral separations should be done at or immediately under the direction of the LRL, which should be equipped to perform carefully monitored mineral separations of samples up to several hundred grams. The individual Principal Investigators should be able to make the mineral separations in special cases; but the larger the sample required, the greater must be the justification to proceed independently and the greater the emphasis on cooperation. The samples selected for mineral separations shall be analyzed by bulk analysis techniques and should come either from the homogenized sample or from a sample that is geometrically closely related to the homogenized sample.

Special Requirements for Unconsolidated Materials

The committee discussed the problems associated with sampling and distributing unconsolidated materials, that is, dust and coarser grained material. Major differences in the flow chart for coherent material (fig. 1) are the following items:

1. Large (greater than 0.5 cm) coherent chips or fragments should be removed by coarse seiving immediately after opening the sample bag.

2. The dust sample should be further subdivided into size fractions after microscopic and reactivity tests.

3. Special techniques, such as scanning electron microscopy, may be required for analysis of dust.

PROPOSED AAP LUNAR SURFACE EXPLORATION PLAN

The aims of geologists and geochemists are sufficiently alike to expect the exploration plans for one group to be similar to those of the other group. A possible difference, if one exists at all, is in the natural desire of the geologists to see as much area covered as quickly as possible, with the realization that reconnaissance mapping at least highlights the local process, while the geochemist may desire a more detailed understanding of an area so that samples collected can be placed in better context and used to answer questions beyond the processes shaping local structure and topography.

In considering the possible inner exploration sites, the following exploration objectives, not necessarily in order of importance, were selected as the major areas of importance for geochemists:

1. The location of primitive rocks, bearing on the problems of the cosmic abundances of elements, the origin of the Moon and the Earth-Moon system, and the possibility of wide-scale differentiation in the Moon

2. The location of the oldest rocks, bearing on the geochronology of the Earth-Moon system and the extent of metamorphic alteration, if any

3. A stratigraphic chronology for lunar events, other than extralunar processes, such as impact

4. The investigation of the history of intensity, overall energy spectrum, and the composition of cosmic rays and solar particles; establishment of impact crater chronology by cosmic-ray and geochronological methods; study of surface transport phenomena and determination of rates of erosion, accumulation, and vertical turnover from cosmic-ray-produced isotopes, trapped solar-wind particles, and heavy particle tracks

5. The verification of lunar volcanism. The extent of any volcanism (whether local or regional), the amount of differentiation and the process of differentiation, and the nature of volcanic outgassing and possible sublimate deposition

6. The presence of organic matter and condensed volatiles, bearing on the possibility of a past hydrosphere and atmosphere. Cryogenic trapping of the products of lunar outgassing. Possible sites for life forms, past or present

7. The effects of impact metamorphism in changing the nature of the lunar surface and the mineralogical constitution of the surface materials

The sites recommended, the major reasons for visiting the site, and the proposed spacecraft are listed in table I. The numbered reasons refer to the numbered objectives previously listed.

Sites considered in addition to those listed in table I were the Apennine Front which could be a prime objective in category 3; the Imbrian flows which could be a prime objective in category 3; Hyginus Rille; a prime objective in category 5; and, briefly, the craters Sabine, Ritter, Kepler, and Alpetragius for which no prime justification was made.

TABLE I. - RECOMMENDED AAP SITES

Mission	Spacecraft	Site	Reason (a)
AAP-1	ELM[b]	Davy Rille	1, 2, 3, 5
AAP-2	ELM	Copernicus	1, 2, 3, 4, 7
AAP-3	ELM or ALM,[c] Dual and rover[d]	Marius Hills	1, 4, 5, 6
AAP-4	ELM or ALM	Copernicus[e]	1, 2, 3, 4, 7
AAP-5	Dual and rover	Aristarchus	2, 3, 5, 6, 7
AAP-6	Dual	Alphonsus	2, 3, 4, 5, 6
AAP-7	Dual and highland traverse	Tycho	1, 2, 3, 4, 7
AAP-8	ELM	North Pole	2, 4, 6

[a]An underlined number indicates that the site is a prime objective for that category.

[b]Extended lunar module.

[c]Augmented lunar module.

[d]Marius Hills requires a reasonably long range mobility, and for this reason, a dual launch with longer staytime is proposed. If an ELM launch with a flyer mobility of 60 kilometers and 7-day staytime could be arranged, the prime objective could be met.

[e]Copernicus is such a large and important feature that it is believed that necessary goals cannot be met in a single mission. Two single ELM missions are proposed, one to concentrate on the central peak and crater volcanism, the other to concentrate on the exposed wall sections and impact phenomena.

MISSION PROFILES

The following mission profiles are written from the point of view of geochemists. Actual missions will have many more goals than the geochemical goals and the missions should not, therefore, be considered complete within themselves.

Profiles are presented for three of the recommended missions, and for one of these, the area around Aristarchus, alternative profiles are presented for different mobilities to illustrate the importance of mobility hardware in planning reasonable scientific objectives.

AAP-2, Single Manned Mission to Central Copernicus

Purpose of mission. - The purpose of the mission includes the following items:

1. To investigate and sample large, recent-impact crater sites

2. To search for samples of very old lunar rocks

3. To obtain samples that give a record of cosmic-ray history

4. To date the age of the Copernican event and its widespread effect on the lunar surface

5. To obtain samples showing the effects of recent erosion and mixing processes

6. To obtain samples displaying shock metamorphic effects

7. To verify the mineralogy and petrology of the central hills, including a possible dike

Objectives of mission. - The objectives of the mission include the following items:

1. To collect samples at all sites visited in their geological context

2. To emplace a mass spectrometer for gas analysis as part of Apollo lunar surface experiments package (ALSEP) deployment

Equipment of manned landing. - The equipment for the manned landing includes the following items:

1. A contingency sample container

2. Hand sampling tools such as a hammer, tongs, and a small scoop

3. A sample container that can be immediately sealed

4. Tool for sampling incoherent material and returning an undisturbed section of 1 to 3 feet in length

5. Acamera

6. A diagnostic portable sample selector

7. A temperature measuring device

8. A hand-carried mass spectrometer, with a mass range of 2 to 100 at 10^{-4} to 10^{-12} torr

9. An emplaced mass spectrometer, solar-cell powered, with a mass range of 2 to 50, 10^{-6} to 10^{-12} torr, slow scan, and a design life of at least 1 year

Flight and mobility hardware. - The flight and mobility hardware includes the following items:

1. Two small lunar flying units (LFU)

2. Sample return capability of at least 50 kilograms

Ground support equipment and facilities. - The ground support equipment and facilities include the following items:

1. The Lunar Science Data Room, an area in the Mission Control Center at the Manned Spacecraft Center for real-time compilation of surface scientific information with consultation capability with the flight crew, if necessary

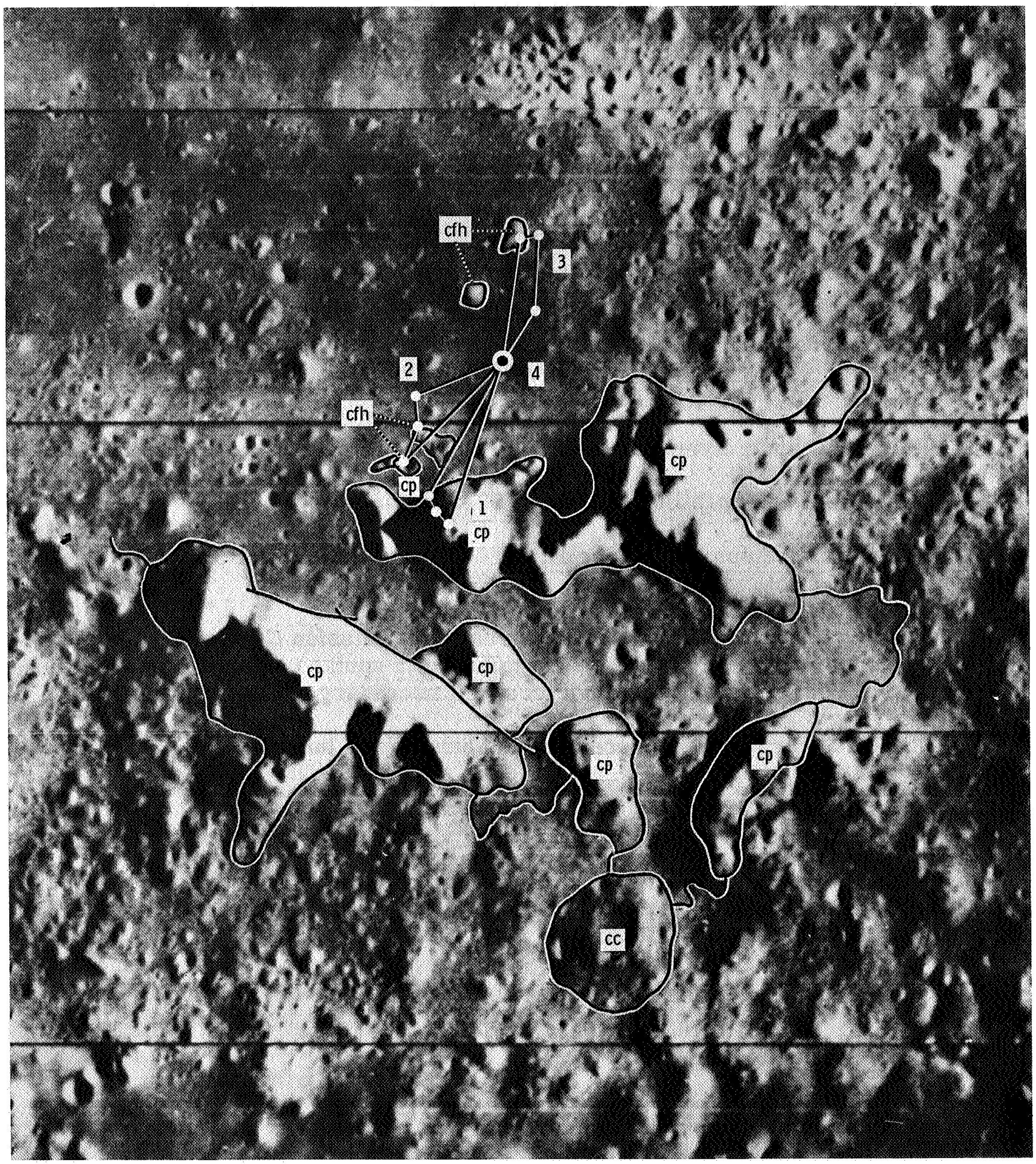
2. The LRL, for postflight receiving and handling of lunar samples

Manned Excursions in Central Copernicus

The excursion sites in central Copernicus (table II) include the central peak, the crater floor, a small hummock north of the site, and the immediate vicinity of the LM. The proposed mission sites are illustrated in figure 2.

The total length of the explored area is 16 to 18 kilometers, depending upon the landing site. The total weight of the payload is 100 pounds and is composed of the following items:

Component	Weight, lb
Stereo camera	10
Tools	25
Gravimeter	10
Seleis transmitter	5
Samples and container	50
Total	100



cc Central crater
cp Central peak
cfh Central floor hummock
LM
2 Excursion number
O Excursion stop

Figure 2. - Single launch mission to Copernicus.

TABLE II. - EXCURSION SITES IN CENTRAL COPERMCUS

Excursion	Location	stop	Activity
1	Central peak	1	Erect relay transmitter on a sample peak. Investigate nature of central crater; sample. Excurse on foot, taking pictures and sampling, and read portable gravimeter. Search out suitable landing spot on N or NW slope for next stop and attempt visual location of proposed boundary in crater floor of highlands and maria.
		2	Sample suspected petrographic boundary (dike). Read gravimeter, photograph. Excurse to foot of N to NW slope of central peak.
		3	Sample deepest available point of central rock mass, read gravimeter, photograph. Return to LM.
2	Copernicus crater floor	1	Attempt sampling impact crater site 6 km W of LM
		2	Locate and sample contact of maria and uplands if located in excursion **1.**
		3	Sample sites of opportunity. Return to LM.
3	Small hummock north of site	1	Sample hummock 6 km N of LM and apparent contact between light and dark material east of hummock.
		2	Stop on contact.
		3	Sample site of opportunity (differentiated rock or impact feature). Return to LM.
4	Immediate vicinity of LM	1	Deploy mass spectrometer, if not included in ALSEP.
		2	Obtain **1-** to 3-ft profile sample of upper 6 in. to 2 ft of surface, for study of cosmic-ray effects and small-scale impact history.

AAP-5 Mission to the Region Near Aristarchus

The region near the crater Aristarchus is very diverse, but because of exceedingly rough terrain offers few landing sites. Missions can be planned, assuming both short- and long-range mobility, and three different mobility assumptions were used in planning the missions. Option I, a dual landing with two long range LFU vehicles, is the mission recommended by the Geochemistry Working Group.

Option I: Dual-manned mission to the region of the crater Aristarchus and a rendezvous with an unmanned mission starting in Mare Imbrium. - The recommended landing point for **AAP-5** is located near the west rim of Schröter's Valley, approximately 20 kilometers west of Cobra Head.

Manned phase of mission: The geochemical purpose of the manned phase of the recommended **AAP-**5 mission includes the following study and sample items:

1. A possible site of recent or present volcanism and outgassing (Cobra Head)

2. A site of unusual lunar erosion (Schröter's Valley)

3. Areas containing possible organic matter and ancient life forms (sediments in Schröter's Valley)

4. Large impact crater and ejecta blanket (Aristarchus)

5. A possible site of possible post-Imbrian volcanism

6. A contact between Imbrian-flow material and the underlying plateau (Fra Mauro material)

7. The ejecta surface of a small, young impact crater

8. The floor of a large, old, flat-floored crater (Herodotus)

Unmanned phase of mission: The geochemical purpose of the unmanned phase of the **AAP-5** mission, which will rendezvous with the manned mission, includes the reconnaissance and sampling of the following items:

1. Imbrian flows

2. North rim, floor, break in the west wall, and rill issuing from the crater Krieger

3. Sequence of possible post-Imbrian volcanic sites

4. Sections across Schröeter's Valley

Objectives: The objectives of the manned phase of the **AAP-5** mission include the following activities:

1. Collect samples in their geologic context at all sites visited

2. Place a mass spectrometer near a site of possible recent gaseous activity

3. Sort, select, and package samples collected by the unmanned lander

Equipment of manned landing: The experiments for the manned landing include the following items:

1. A contingency sample container

2. Hand sampling tools, such as a hand coring device, a hammer, tongs, and a small scoop

3. Sample containers that can be immediately sealed

4. A 1- to 3-foot coring tool for sampling incoherent material and returning an undisturbed section

5. A camera

6. A diagnostic portable sample selector (X-ray diffractometer)

7. A shock-mounted sample container for fragile samples

8. A portable temperature measuring device

9. A drill corer with the capability to penetrate 10 meters

10. A hand-carried mass spectrometer, mass range 2 to 100, 10^{-4} to 10^{-12} torr

11. An emplaced mass spectrometer, solar cell powered, mass range 2 to 50, 10^{-6} to 10^{-12} torr, slow scan, with a design life of at least 1 year

Equipment of unmanned landing: The equipment of the unmanned landing includes the following items:

1. Slow-scan monocular television

2. Stroboscopic headlight

3. Diagnostic sample selector (X-ray, fluorescence, and diffraction)

4. Mass spectrometer, same specifications as handheld instrument

5. Sampling claw capable of taking a 250-gram sample of both coherent and incoherent rock

6. Sample packaging for at least 100 sequential samples, each weighing 250 grams or more

7. Several 6- to 12-inch-long S-10 drive tubes for sampling of powders

Flight mobility hardware: The flight mobility hardware includes the following items:

1. Two large or one large and one intermediate LFU with a range of 60 to 100 kilometers

2. An unmanned rover (previous launch) with a 500-kilometer capability, design life of 6 months, sample payload of 25 kilograms, and a scientific equipment payload of 25 kilograms

3. A sample return capability of at least a 100-kilogram mass

Ground support equipment and facilities: The ground support equipment and facilities include the following components:

1. Real-time monitoring by a geochemist of surface experiments for a period of at least 6 months

2. The Lunar Science Data Room, an area in the Mission Control Center of the Manned Spacecraft Center, for real-time compilation of surface scientific information with compensation capability with the flight crew, if necessary

3. The LRL for postflight receiving and handling of lunar samples

Manned excursions: The recommended AAP-5 manned excursion (table III), in order of priority, includes traverses to Cobra-Head region, 25 kilometers to the northeast of Cobra-Head (a multistop reconnaissance), the Aristarchus ejecta blanket (nonstop), ejecta surface of a young impact crater 15 kilometers west of the LM, a post-Imbrian volcanic dome 35 kilometers southwest of the LM, the floor of the northwest segment of Herodotus 65 kilometers south of the LM, and the LM landing site.

Unmanned traverse: The unmanned landing for AAP-5 mission is located 70 kilometers northeast of the crater Krieger in Mare Imbrium. Significant features to be sampled along the proposed traverse, in the order that they will be reached by a vehicle moving in a generally southwestern direction, include the following items:

1. Mare floor and mare ridges with north-to-south orientation

2. Contact zone and elevated material overlying the north wall of Krieger

3. Floor and breach in west wall of Krieger, and rill running west from breach in west wall of Krieger

4. Dome on mare surface west of Krieger

5. Rill (north-to-south oriented, southwest of Krieger)

6. Steep-fronted elongated tectonic feature 90 kilometers southwest of Krieger

7. Possible side trip to dark-haloed crater

TABLE III. - PAP-5, MANNED EXCURSIONS IN ORDER OF PRIORITY

Excursion	Location	Stop	Activity
1	Cobra-Head	1	Rim of Cobra-Head
		2	Foot of wall of central depression
			Sample of condensed material
			Deploy emplaced mass spectrometer
		3	Bank of secondary rills in center of Cobra-Head
			Sample for condensed carbonaceous or highly altered material
		4	On return, make flight reconnaissance of a section of the valley, if fuel permits
2	25 km to NE, multistop reconnaissance	1	Numerous stops in Schroter's Valley[a]
		2	Terminal stop at contact between Imbrian flow and plateau
1	Aristarchus ejecta blanket, nonstop	1	45 km to ESE of LM for nearest occurrence of blanket. Sample coherent rocks with differing degree of shock and 1- to 3-ft cores of incoherent and coherent materials, oriented samples, and 6-in. cores from top of large ejected blocks
4	Ejecta surface and young impact crater 15 km W of LM and post-Imbrian volcanic dome 35 km SW of LM	1	Similar to excursion 3
		2	Sample apparent volcanic flows (6-in. cores), sublimates, or altered material near vent
5	Floor of NW segment of Herodotus 65 km S of LM	1	Cores of hard (6 in.) and/or soft (1 to 3 ft) material
6	LM landing site	1	Up to 10-m core
		2	Detailed examination and sampling in walking distance of LM

[a]Special attention should be given to the collection of samples from any stratigraphic units along the walls and bottom of Schroter's Valley. Samples should also be taken across any major unconformities or disconformities, as far as practical.

8. Domes in the northern boundary of Imbrian-flow material north of Cobra-Head

9. Light-colored material at the foot of an apparent volcanic flow-front contact north of Schroter's Valley

10. Schroter's Valley north wall, floor, central rill, and south **wall** just north of the LM

11. Reconnaissance of LM landing site prior to manned landing

12. Rendezvous with the LM

Option 11: Dual-manned mission to Aristarchus area. - The landing point is located on the west rim of Schröter's Valley, 20 kilometers west of Cobra-Head and 2 kilometers or less from the edge of the valley. It is assumed an **LSSM** will be available which can be used for an unmanned reconnaissance after the close of the manned mission. The LSSM would have to rendezvous with a later manned mission to the crater Krieger, a mission not specifically recommended by the Geochemistry Working Group.

Manned phase of mission: The purpose of the manned phase of the mission is to study and sample the following sites:

1. A possible site of recent or present volcanism and outgassing (Cobra-Head)

2. A site of unusual lunar erosion (Schroter's Valley)

3. Areas containing possible organic matter and ancient life forms (sediments in Schroter's Valley)

4. A possible site of post-Imbrian volcanism

5. Contact between Imbrian-flow material and the underlying plateau (Fra Mauro material)

Unmanned phase of mission: The purpose of the unmanned phase of the mission, if rendezvous with a single-launch mission to the region near Krieger can be expected, includes reconnaissance and sampling of the following sites:

1. A possible excursion into Cobra-Head

2. A section across Schroter's Valley

3. A sequence of possible post-Imbrian volcanic sites

4. A rill with north-south orientation north of an Imbrian fluid front

5. A side trip to a dark-haloed crater

6. An isolated dome on the lunar surface

7. A rill issuing from the west of the crater Krieger

8. A break in the west wall of the crater Krieger

9. A sample of the floor and uplifted material engulfing the north wall of the crater Krieger

10. Imbrian flows

11. Rendezvous in Krieger and delivery of samples

Objectives: The objectives of the mission include the following items:

1. Collect samples at all sites visited in their geologic context

2. Place a mass spectrometer near a possible site of recent gaseous activity

3. Send an LSSM on an unmanned sampling trip to the crater Krieger

Equipment of manned landing: The equipment for a manned landing is identical with Option I.

Equipment of LSSM: The equipment for the LSSM is identical with the unmanned phase of Option I.

Flight mobility hardware: The flight mobility hardware is an LSSM with two short-range lunar flying units.

Ground support equipment and facilities: The ground support equipment and facilities are identical with Option I.

Manned excursions: The manned excursions recommended for Option II (table IV) include a visit to Schröter's Valley, an LSSM trip to the northeast for Schröter's Valley floor, and a trip to the west rim of Schröter's Valley near Cobra-Head (a short range LFU trip).

Unmanned excursion: The unmanned excursion under Option II includes the investigation and sampling of the following sites:

1. Sampling and mass spectrometry of Cobra-Head

2. Investigating light-colored material at foot of probable volcanic flow front contact north of Schröter's Valley

3. Collecting samples from domes in the northern boundary of Imbrian flow material north of Cobra-Head

4. Investigating a dark-haloed crater (possible side trip)

5. Investigating a steep-fronted, elongated tectonic feature 90 kilometers southwest of Krieger

6. Investigating a rill, north-to-south oriented, southwest of Krieger

7. Investigating a dome in a mare west of Krieger

8. Investigating the floor of Krieger and breaks in the west wall, and a rill to the west

9. Investigating the elevated material and contact zone north of Krieger and an overlying wall

TABLE IV. - OPTION 11, MANNED EXCURSIONS TO SCHRÖTER'S VALLEY

Excursion	Location	Stop	Activity
1	Schröter's Valley	1	Near west rim of valley, top of slope. Sample down slope to the foot of the slope SW of LM
		2	Make LFU flight from bottom of slope to edge of Cobra-Head central depression; sample for evaporate or altered material; deploy the emplaceable mass spectrometer
		3	Fly north to central rill, sample material at bottom of rill, and return to LSSM
		4	Traverse up slope to west and return to LM, sampling at appropriate intervals
2	LSSM trip to NE for Schroter's Valley floor	1	Valley floor, sampling
		2	Make LFU flight to NE to contact of Imbrian flow material and plateau. Return to LM
3	West rim of Schroter's Valley near Cobra-Head, LFU trip	1	Near rim, top of slope, sample Cobra-Head deposits. Locate route for unmanned LSSM trip to Cobra-Head. Full range of flyer expended. Return to LSSM/LM

AAP-6 Dual-Manned Mission to Alphonsus Area

The mission to the crater Alphonsus is prepared with the assumption that two short range lunar flying units will be the only manned mobility hardware available. An unmanned LSSM will carry out a traverse after departure of the manned landing. The LSSM traverse terminates in the vicinity of the Davy Rille, and objective recommended as an early AAP mission. The essential rendezvous plans for the LSSM are realized but the necessary logistics have not been solved. A typical series of excursions to the crater Alphonsus is outlined in table V.

TABLE V. - AAP-6, TYPICAL EXCURSIONS TO ALPHONSUS[a]

Excursion	Stop	Activity
1	1	60-km traverse to dark-haloed crater
	2	Several 10-km traverses at bottom of crater Rendezvous with manned LM
2	1	8-km sortie toward central peak. LFU flight to central peak with several collection stops. Return to LSSM/LM, doing traverse geology
3	1	Same as 2 to different part of central peak
4	1	Explore bottom of peak[b]
5	1	LSSM drive to depression and fly down depression for reconnaissance

[a]If flyers with a capability of a 20-kilometer radius (with two stops) would be available, the scientific value of the mission would be qualitatively improved, in that manned observation of the two major features of the crater Alphonsus would be possible. These are the central peaks and a dark-haloed crater.

[b]This excursion includes three essential parallel traverses.

Manned phase of mission. - The manned phase of the Alphonsus mission includes the following purposes:

1. To make observations and collect samples of a large, old highland crater of uncertain but probable impact origin

2. To search for samples of primitive, or at least very old lunar rocks

3. To examine and sample, with an unmanned vehicle, sites of probable volcanic sublimate deposition and possible present volatile activity

4. To seek out a possible wide range of volcanic rocks, testing the extremes of the differentiation processes

5. To obtain samples giving a long record of cosmic-ray history

6. To identify and sample a suitable site to determine the erosion and mixing rate of surface materials

7. To study the products of impact metamorphism of materials other than maria materials

Unmanned phase of mission. - The purpose of unmanned exploration following AAP-6 is to explore and sample the following features:

1. The crater wall of an old crater (Alphonsus)

2. A flat depressed feature in the crater rim (Lake Titicaca)

3. The highland regions in order to establish their geochemical nature and to interpret lunar chronology

4. The Mare Nubium to establish and compare age relationship with floor of Alphonsus

5. Several mare-highland contacts

6. The ejecta of a bright young crater

7. The eastern part of Davy Rille complementary to the proposed single-manned landing mission in the region

Objectives of the manned mission. - The objectives of the manned mission are:

1. To collect samples in their geologic context

2. To place a mass spectrometer near a possible site of recent gaseous activity

3. To drill and core a 10-meter hole at the landing site

Objectives of the unmanned LSSM mission. - The objectives of the unmanned LSSM mission are:

1. Reconnaissance and sampling of sites as commanded from earth

2. Rendezvous with a manned mission in Davy Rille

Equipment of manned landing. - The equipment for a manned landing includes the following items:

1. A contingency sample container

2. Hand sampling tools such as a hammer, tongs, and a small scoop

3. Sample containers that can be sealed immediately

4. Coring tool, 1 to 3 feet in length, for sampling incoherent material and returning an undisturbed section

5. A camera

6. A diagnostic portable sample selector (X-ray diffractometer)

7. A shock-mounted sample container for fragile samples

8. A possible temperature measuring device

9. A drill corer with the capability of penetrating 5 meters

10. An emplaced mass spectrometer, solar cell powered, with a mass range of 2 to 50, 10^{-6} to 10^{-12} torr, slow scan, and a design life of at least 1 year

Equipment of unmanned landing. - The equipment for an unmanned landing includes the following items:

1. A slow-scan monocular TV

2. A stroboscopic headlight

3. A diagnostic sample selector (X-ray fluorescence and diffraction)

4. A mass spectrometer, same specifications as handheld instrument

5. A sampling claw capable of taking a 250-gram sample of soft, coherent and incoherent rock

6. Sample packaging for at least 100 sequential samples each weighing 250 grams or more

7. Several 6- to 12-inch-long S-10 drive tubes for sampling of powders

Mobility systems. - The mobility systems include two lunar flying units, with a 10-kilometer radius, two planned stops and a 50-pound payload and an LSSM, unmanned.

Sample return capability. - The mission has the capability to return a 50-kilogram sample, including filled coring tubes.

Ground support equipment and facilities. - The ground support equipment includes the following facilities:

1. Real-time monitoring by a geochemist of LSSM exploration

2. The Lunar Science Data Room in the Mission Control Center for real-time compilation of surface scientific information with the consultation capability with the flight crew

3. The LRL for postflight receiving and handling of lunar samples

GENERAL RECOMMENDATIONS

1. The most important single scientific objective of many manned lunar landings, even in the AAP program, will be the return for laboratory investigation of Samples from selected areas on the Moon. Mission profiles should be set up in such a way that the probability of achieving this objective is maximized. Mission profiles should provide for optimum sample return at any given time during a mission in case of a sudden and premature termination of a mission.

2. The Geochemistry Working Group is convinced that the overall goal of understanding the origin and evolution of the Moon requires that manned sampling on all AAP missions be directed toward understanding of specific features; for example, fresh craters with central peaks, sinuous rills, or dark-haloed craters. The absolute age and chemical structure is of particular importance.

3. Sampling on the scale of these lunar features clearly requires a manned mobility of 10 kilometers and more.

4. If a surface vehicle is developed, it should be designed for manned and unmanned operation and should be able to collect and store samples for eventual rendezvous with a manned mission. (See the section on mobility for more detailed requirements.)

5. Changes in the design and operation of the LM should allow it to take advantage of the full sample return capability (250 lb) of the command module.

6. Late AAP missions may require changes in the command module to increase the return payload to 400 pounds so that a minimum of 250 pounds of sample can be returned.

7. Late Apollo and AAP missions will require the development of additional types of sample containers.

8. The astronaut should be aided in field identification of rocks by sophisticated diagnostic devices that are simple to operate. Efforts towards the development of these devices should be increased by establishing a group (preferably at a NASA ten- ter) with the responsibility of defining specifications and developing such devices.

9. A remote sensing radiation experiment (including y-ray, X-ray, and α-ray sensors) for mapping the composition of the lunar surface should be flown at the ear- liest flight opportunity so that the information can be used in planning later missions.

10. It cannot be emphasized too strongly that the continuing support of scientific study of materials and data returned from lunar missions is necessary.

CHAPTER *6*

REPORT OF BIOSCIENCE WORKING GROUP

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ABSTRACT

The single action which emerged from every group deliberation was the absolute requirement for telefactored mobility on the lunar surface prior to the astronaut landings. This mobility would be required for the purpose of probing rock samples and selectively collecting and packaging them in a clean condition to rendezvous at some later time (weeks or months) with the astronaut who could then be more effective during the relatively short stay there. The type of vehicle and the probes that it should carry are discussed in some detail in the report and vary, of course, with the needs of other working groups. However, the development of such a vehicle and the probes that it should carry seem to be the next general thrust of the post-Apollo program.

INTRODUCTION

The Bioscience Working Group reaffirms its deep commitment to a continued program of scientific exploration of the Moon. The overriding interests of the group call for extensive participation in fundamental scientific studies of returned lunar samples in Earth-based laboratories.

The multidisciplinary scope of bioscience researches brings to focus various specific talents and preparatory experience — organic geochemistry, micropaleobiology, microbiology, et cetera — for planning the collection, return, and detailed investigation of lunar samples to ascertain whether knowledge of the origin and evolution of living systems has been preserved in the lunar crust from an early stage in the evolution of the solar system. Detailed knowledge of the amount, distribution, and exact molecular structure of any organic molecules (prebiotic, biogenic, life-associated macromolecules), micro-organism fossils, and preserved viable microbial forms is of utmost importance in the search for answers to major questions relating to origin and history of the Moon and to the relationship of the Moon to the Earth and the solar system and to knowledge relating to the origin of life.

Collecting and returning noncontaminated, well-preserved samples in large amounts (250 lb) from the Moon is a critical problem. The problem of careful sample collection and packaging needs special emphasis because of possible interference: astronaut contaminants might interfere with the detection of microbiological forms of a very low order of frequency; lunar module (LM) descent products might interfere with the identification of indigenous organic compounds that may be present in the parts-per-million, or lower, range. For these reasons, it is highly desirable that a method be developed for unmanned, roving collecting and packaging of selected samples; during a subsequent manned mission, the samples would be retrieved and returned to Earth for detailed study. It is imperative that the single-mission astronaut collection and packaging methods needed to obtain lunar samples with minimized organic chemical or microbial contamination must receive increased attention for early missions in the Apollo Applications Program {AAP). Moreover, another point to be emphasized is

that the collection and preservation of minimally disturbed and noncontaminated lunar samples will become more difficult as the lunar exploration program continues because of the use of flying vehicles and the accumulation of LM descent products.

Members of the Bioscience Working Group will continue to participate actively in the AAP, examining samples gathered from manned and unmanned traverses and from deep coring. Research activity of the members will expand dramatically if positive results, in the form of biochemically important compounds or organized elements, are detected on early missions.

This report does not contain details of the plans or opinions regarding aspects of early Apollo missions, although it is obvious that some of the bioscience problems defined in this report for AAP have remained (with unsatisfactory solutions) in the early flight program. Likewise, this report does not treat in any detail the problems and concepts relating to back contamination and the quarantine of the lunar samples in the Lunar Receiving Laboratory (LRL) since these matters are the responsibility of the Interagency Committee on Back Contamination and are being implemented by the Manned Spacecraft Center (MSC), Houston.

The principal areas of interest for lunar exploration that have been identified by the current members of the Bioscience Working Group are as follows:

1. Viable life forms. AAP offers the possibility of exploring a variety of lunar sites that may harbor dormant or indigenous organisms. Some areas on the Moon may appear to be sterile (by comparison with the Earth), but this does not preclude the possibility of organisms or dormant spores being found if an appropriate sampling program is developed for the post-Apollo period. This will include subsurface and polar samples.

2. Organic analyses. The prime requirement for organic chemical analyses must continue into dual-launch AAP because this will be the first program in which unmanned local scientific survey module (LSSM) type selection, collection, and packaging will provide samples which have not been subjected to suit leakage, fuels, ablative materials, and other potential sources of terrestrial contamination. Furthermore, AAP traverses will provide samples from a wider variety of locations and depths; and the capability of storage at ambient, subsurface lunar temperatures will be developed.

3. Fossils. The continued examination of lunar material for evidence of microfossils is a requirement for the study of the "museum" history of the Moon. Again, the probability of detection is dependent upon the choice of landing sites, the location and depth of sampling, and the search for meteoritic impact fragments of the carbonaceous chondrite classes.

4. Lunar environment. A prime aspect of contamination control during lunar missions is the survival of terrestrial micro-organisms under lunar environmental conditions. In all missions where man is involved and/or unsterilized hardware is used, microbial contamination of the lunar surface cannot be avoided. However, it is not known how long terrestrial micro-organisms might remain viable in or on the Moon or how rapidly and to what distances chemical contaminants (LM combustion and fuel products) will spread. Another aspect of environmental studies is concerned with human beings in space and on the lunar surface. How long can a man survive and

remain functional on the lunar surface? What tasks can he perform and how efficiently? What medical constraints exist in the AAP? While some questions of this nature are obviously operational medical requirements, the space environment may cause microbiological, physiological, or psychological alterations in man, alterations that could act as constraints on planning AAP missions. Any such alterations must be defined before future planetary programs can be completely planned.

5. Back contamination. Another important aspect is to determine whether or not viable or dormant life forms exist on the Moon and are potentially hazardous to living terrestrial systems. Although this aspect is primarily the responsibility of the Interagency Committee on Back Contamination and of MSC, the Bioscience Working Group is extremely interested in the scope and implementation of this aspect of the program because much of the data resulting from the back-contamination examination will be of value to other microbiologists in the future.

The following sections of this report outline the overall plan for bioscience exploration of the Moon and identify a number of major problems that interface with research requirements, requiring solution for the AAP.

SAMPLE COLLECTION AND RETURN

Although Apollo missions will present the first tangible information for intelligent planning of further bioscience exploration, plans must be initiated immediately to insure sufficient versatility and flexibility for a rational research program. Information from early Apollo missions should permit progression from the random site selection and sampling into carefully planned experiments in which there is a realistic basis for proper selection of the material to be returned to Earth. Those people interested in organic chemistry and microbiology have more difficulty formulating mission plans than do those in other working groups because Surveyor, Orbiter, and other programs have not thus far contributed significant information which can be used to pinpoint landing sites and total mission plans.

For post-Apollo missions, as in the early Apollo missions, the sampling requirements for bioscience are more demanding and severe than those for most other groups, excluding geochemistry. Moreover, the Bioscience Working Group predicts that the success of the bioscience research will depend to a great extent on the quality of the sample received, in terms of the lack of biological and organic chemical contamination and of the preservation of possible viable organisms. It may be mentioned that contaminated samples will lead only to misleading interpretation that may result in a controversy which could thwart the whole program. However, the Bioscience Working Group does not wish to impose bioscience sampling requirements on samples collected for use by other disciplines, and the Bioscience Working Group does feel obligated to point out that astronaut microbial contamination on any lunar samples may delay or prevent release of that sample from the LRL. The collection and return of samples free from microbial and organic chemical contamination is the paramount requirement. Although this requirement is stressed several times in this section, potential sources and control methods that should be utilized are discussed in another section.

Criteria for Samples for Organic Analyses

The collection of samples for organic chemical analyses does not necessarily require the extreme caution that is necessary for microbial sampling, provided that samples can be maintained in a frozen state. Whereas it is theoretically possible for one single organism (approximately 10^{-12} g) to grow into a colony under suitable environmental conditions, at the present time organic molecules must be present in the range of 10^{-9} g in order to be specifically identified. For example, a single thumbprint could produce a set of recognizable amino acids.

It is recommended that several types of samples should be collected: (1) surface and subsurface unconsolidated dust, sand, or soil; (2) consolidated surface or subsurface rocks from pebble size (5 mm in diameter) to rocks several centimeters in size so that inside material can be removed; (3) deeper unweathered rocks that may represent original lunar material; and (4) meteorite fragments lying on the surface.

The sample size necessary is difficult to predict until some estimate of the carbon content of the Moon has been obtained. It is possible to detect microgram and even nanogram quantities by gas chromatography and mass spectrometry, but since the organic matter has to be extracted first for complete analyses or for stable isotope studies, a useful sample size should be 1 kg/sampling site. When limited amounts of material are available, samples smaller than the kilogram amounts discussed still provide useful information.

Criteria for Samples for Microbial Examination

All samples collected during Apollo and AAP missions will be subjected to microbiological analyses during quarantine to insure the absence of harmful organisms. For microbiological purposes, steps should be taken to assure that samples representative of the most interesting regions of the Moon are obtained. The sites of highest interest for the microbiological studies are the subsurface, the permanently shaded areas, and the poles. Again, it is imperative that any samples designated for microbiology be collected aseptically to insure that terrestrial contamination will not affect the validity of the laboratory analyses. As additional sites are sampled, the requirements for Sampling procedures and return methods will become increasingly more stringent because the Moon will have become more contaminated with Earth materials. Samples obtained at the potentially colder areas under discussion must be collected in such a manner as to prevent deleterious effects; that is, samples obtained by core drills must be taken without significantly altering the indigenous temperature because of the lethal effect of heat as well as the potential volatilization of organic substances.

Beginning with Apollo, every possible effort should be expended to develop and fly an aseptic sampler that can reliably collect noncontaminated near-surface and subsurface samples. However, for AAP, drills should be developed that can obtain uncontaminated cores to a depth of 2 meters without altering the indigenous chemical and physical characteristics of the samples and store them in a manner which will prevent alterations during transit to Earth.

Subsurface Sampling

Three types of subsurface material are desired. First, several short cores approximately 15 centimeters in length should be taken from a few millimeters to centimeters below the surface with an aseptic corer devised for the purpose of obtaining noncontaminated material which may be cultured upon return. Use of such an instrument should be made in the early Apollo missions.

Second, at least one core extending to at least 2 meters is desirable from each major site. The lowest depth in the core should insure insulation of the sample from solar activity occurring at the surface of the Moon. The core would, therefore, represent the bulk of the unconsolidated sediment in the lunar crust. A serious effort should be made to develop and manufacture such a corer for collection of aseptic samples. The core would serve as a stratigraphic record of changes taking place from the surface downward.

Third, a long core, perhaps 100 meters, penetrating into the base rock would help establish whether the Moon contains carbon in solar abundance or whether it has been differentiated. The nature of the organic material will be important, of course, for comparison with terrestrial igneous rocks. Sterility of the sample is not an absolute requirement, but cleanliness (freedom from grease, coolant, et cetera) is a requirement. Samples could later be taken from inside the core to assure minimum contamination.

In the long-core drilling operation, it is desirable not to heat the central area of the core. Lubricants must be avoided, as they would contaminate the core; the drill bit should not contain carbon compounds (with the possible exception of diamond) for the same reason. (The rotary, percussive drill currently under development would in principle fulfill these requirements.)

Summary of Sampling Requirements

The following is an overall set of guidelines for the acquisition and handling of samples designated for microbiological study.

1. The sample should not be subjected to excessive grinding or shearing.

2. No liquid solvent or active gas should make contact with the sample.

3. Samples should be transferred, stored, and transported at a temperature not to exceed the temperature of the sample at collection time (lunar subsurface ambient), and under no circumstances should samples become wet from thawing.

4. Inert gases (such as helium and argon) or nitrogen are acceptable gases for storage.

5. When taken at short depths (less than 25 cm), samples need not be stratigraphically intact.

6. For deeper probes (drill core samples), samples should be maintained stratigraphically intact.

7. Sample containers should not contain materials that have appreciable vapor pressures, can react with biological materials, and can promote or destroy biological activity.

8. Sample containers should be sterile before and during sample introduction. The containers should be sufficiently tight so that the outside container surfaces could be sterilized by a gas or liquid.

9. Lids on the sample containers should be held rigidly enough to preclude loosening as a result of vibrations or shocks normally encountered during ascent, flight, and descent.

Utilization of Unmanned Landers

It is felt that the proposed landing of Surveyor-type vehicles, sample collection immediately under the spacecraft, and subsequent self-return is not justified. The primary reasons for this are that sample collection would suffer from the same problems as those associated with Apollo, (contamination by retrorockets, limited amounts of sample return, blind sampling, and constraints due to the equipment and fuel required for the return mission).

However, it is felt that unmanned landing vehicles in other modes can be utilized to great advantage in the bioscience program. The vehicles could include the following items:

1. Vehicles similar to the LSSM can be used to land instruments for limited analysis to aid in planning subsequent manned landing vehicles. Such "diagnostic" research instruments need not be elaborate and could consist of simple detectors (gas chromatography, mass spectrometry) for C-H containing compounds, water, and subsurface gases. These instruments could be combined with those of other investigators (Lunar Atmospheres Working Group) that must have lunar-based data to give a meaningful experimental package.

2. A more comprehensive and possibly less expensive means of accomplishing the above limited analysis would be using multiple "bio-bombs" delivered to the lunar surface from an orbiting command and service module (CSM). It is understood that approximately eight of these probes weighing up to 200 pounds each could be delivered by this mode. The possibility of utilizing these probes as diagnostic tools and aseptic sample collectors should be investigated. The probes utilized for limited analyses could telemeter data back to MSC to be used in mission planning. Those probes used for sample collection could be retrieved by subsequent manned missions with mobility capabilities.

The most promising means of obtaining sterile and organic chemically clean Samples is the unmanned LSSM-type roving vehicle. This device would be directed to proceed out of the estimated zone of contamination by visual real-time guidance from MSC. To aid in selecting sample sites, the rover should be equipped with probes, including a

mass spectrometer for detecting carbon compounds and water. Samples should be collected at the surface and at depths up to 2 meters. By this means, it should be possible to collect samples which are free from biological and organic chemical contamination. This approach requires that the sampling equipment be sterile and free of organic chemical contamination when it reaches the sites and that it should not be constructed of materials which would introduce organic contamination during sampling. After collection, the samples must be stored in a manner that will not alter the ambient temperature and pressure and must be packaged so that they will not be contaminated during manned retrieval. After sample collection, the roving vehicle could then proceed to a rendezvous point for retrieval by a subsequent manned mission. This type of dual-launch mission permits samples to be taken in areas not necessarily accessible to a manned landing and greatly simplifies problems which accompany contamination.

Sample Packaging and Storage

It has frequently been stressed that samples must be stored in such a condition that organic contamination from the container is prevented. In the case of contamination, the addition of any nonlunar material must be prevented. For microbiological materials, small amounts of viable contamination introduced during packaging or collection may lead to proliferation unless the samples can be maintained in a frozen state until testing. A rise in temperature may also cause decomposition of any organic matter present in the lunar material.

The packaging and storage suggestions below relate to the construction materials that may be used in the storage containers, to the means of sealing and storing the samples, and to the method of keeping the samples cold.

Storage. - Suggestions for sample storage are as follows:

Material: The most suitable material for storage containers is Teflon, since it is unreactive and can withstand fairly large temperature fluctuations. However, it may prove more advisable to seal the collected samples in a metal foil. Aluminum would probably be the best material for this purpose because of its low density. If Teflon bags were wrapped in foil, added strength could be obtained, perhaps allowing the samples to be stacked and cabin space to be conserved.

Cleaning of containers: All containers for lunar samples should be treated with analytical reagent-grade organic solvents to remove soluble organic matter that may contaminate the sample. The containers should then be dried, outgassed in vacuum, and packaged for shipment. In the special case where samples must be collected aseptically to allow microbiological culturing, the containers should be sterilized by dry heat. All metals should be first baked out at 500° C in a vacuum to remove absorbed gases or organic molecules that may be captured within pores of the metal.

Sealing containers: Teflon bags should be sealed immediately after collection, possibly by some mechanical means such as a spring or a metal band with a twist lock arrangement. It is important to have a simple, although still effective, sealing method to prevent Contamination by the astronaut or other means after collection.

Return sample containers. - It is evident that the return sample containers to be used in the early Apollo missions have many shortcomings, particularly with regard to sealing, weight, complexity, and form. Most of the shortcomings have resulted from CSM constraints or from uncertainties concerning the nature and size of the Samples to be collected and returned.

One or more additional design concepts should be developed before AAP starts to enable a switch to more suitable containers as soon as the information obtained from the first successful Apollo mission has been assimilated.

Gas pressure in return sample containers: The return samples can be stored in high-vacuum, low-vacuum, or inert-gas atmosphere. There is no doubt that a high vacuum equal to that of the lunar atmosphere would be most preferable if a low temperature can be maintained. However, there is considerable doubt whether such high vacuums can be maintained in static situations because of the difficulty in sealing the containers on the lunar surface. If a high vacuum is not feasible, two alternatives are left: a degraded vacuum caused by leakage into the containers or an artificial inert atmosphere.

Given these alternatives, the Bioscience Working Group recommends the establishment of an inert atmosphere in the chamber by using a gas such as nitrogen before sealing. This would certainly prevent CSM air from leaking into the container and might prevent oxidation of organic compounds and inorganic minerals, if such an event were to occur. This could be true, especially if volatiles were to be liberated by heating the sample.

Low-temperature control: The maintenance of low temperatures in the sample-storage chambers is a necessary requirement for the preservation of the organic material and viable life forms that may be present. It is recommended that not only those samples that are specifically collected aseptically, but all bioscience samples should be stored cold on the surface of the Moon and on the return to Earth. This can be accomplished in four ways:

1. If samples that are collected cold are first packed in Teflon bags and then placed into a radiative shaded container, they would possibly maintain their temperature for several hours without artificial cooling.

2. Low temperature on the Moon may be achieved by a portable shade placed over the vehicle or platform on which the samples rest. A larger shaded area should also be installed near the launch vehicle. Samples could therefore be shaded continually from direct radiation while on the lunar surface and would maintain temperatures close to collection.

3. Low-temperature storage during the journey back to Earth could be achieved by using refrigeration units or by using the principle of gas expansion (Joule-Thomson effect) into a vacuum. The most useful method must be derived by the cabin design engineers, taking into account weight, reliability, and compatibility with life-support systems. Temperatures of liquid nitrogen or oxygen would be preferable, if that is feasible.

4. Collection could be accomplished by a lunar vehicle at lunar dusk. Rendezvous would take place with the manned operation at dawn, when the samples retrieved would be stored in refrigerated systems.

Future configuration: The present form and number of sample boxes to be carried on the early Apollo missions are dictated by the place in which they are to be carried during the Earth-Moon round trip. It is hoped that, for later missions, alternatives can be found to permit (1) the utilization of reliable high-vacuum seals, (2) storage in low temperatures, and (3) an increase in the amount of returned material to more than 250 pounds.

Purdue Aseptic Sampler

The Bioscience Working Group reviewed in detail the past history and present status of the development of sampling tools for collecting lunar material without biological and organic chemical contamination. It is recommended that the efforts by the Purdue University soil engineers should be continued. However, simultaneous development of several prototypes of samplers is strongly recommended rather than the development of a single prototype presently being considered.

The justification for the simultaneous development of several aseptic samplers relates to possible trade-offs between mechanical complexity and reliability of the Sampler and the microbiological design criteria. For example, certain modifications in the required temperatures for decontamination would allow substantial simplification of several of the mechanical systems planned by the Purdue engineers.

The Bioscience Working Group recommends, therefore, that an MSC scientist be appointed as the group representative in further sampler developments. In addition, it is recommended that all possible effort be expended to insure that an acceptable aseptic sampler be developed and that at least three samplers be included on the first and on each succeeding Apollo mission.

DIAGNOSTIC TOOLS AND *IN SITU* ANALYSES

Analyses for organic carbon during early post-Apollo missions will be much less desirable than the detailed analyses that can be done on returned samples. However, after the first few missions, meaningful diagnostic experiments to be done of the lunar surface can be designed.

Automated *in situ* analyses will be useful for the following purposes:

1. Exploration of areas inaccessible to man

2. Preselection of samples during manned or unmanned sample-collection excursions to insure collection of the most useful samples in optimum quantity

3. Selection of sampling sites

4. Analysis of gases emanating from cracks or vents in the surface of the Moon

Two general types of techniques can be utilized:

1. Diagnostic tools, capable of sensitive and quantitative measurement of a parameter related to the abundance of organic material

2. Specific instrumentation producing detailed data which can be interpreted in terms of particular compounds

Organic Composition Analysis by Mass Spectrometer

Mass spectrometry and gas chromatography appear to be the most suitable in situ techniques for obtaining specific and interpretable data on lunar organic matter. Small, lightweight mass spectrometers have been designed for use in rockets and on other planets. A mass spectrom'eter operating on the Moon would not need a vacuum system. A considerable amount of reference data will be available after the first few missions. Preliminary mass spectrometric experiments will be carried out at LRL, and later, much more sophisticated and detailed mass spectrometric analyses on the same Samples will be done. Thus, an experimental relationship between such preliminary data and the detailed final results will have been established, providing a basis for the interpretation of similar data obtained on the Moon. Preliminary mass spectrometric testing of material on the Moon will enable the Bioscience Working Group to recognize interesting and valuable samples.

A useful mass spectrometer would have a mass range of 2 to 400 with unit resolution. A sampler would require about 0.1 to 2.0 grams of granular or powdered sample, and a heater would raise its temperature slowly. The mass spectrum of the products evolved from the sample would be continuously scanned. The spectrum can be observed and evaluated by the astronaut or, preferably, telemetered to Earth-based observers in real time for interpretation and decisionmaking. Fully automated systems, programed to respond to particular spectral characteristics, could also be considered for triggering collection of a large sample for later return to Earth by man.

The interpretation of the spectra of complex systems could be facilitated by placing a gas chromatograph between the sample heater and mass spectrometer.

The hardware for this experiment is almost a reality, representing one of the experiments being prepared for the Voyager 1973 mission by the groups at Jet Propulsion Laboratory, Yale University, and Massachusetts Institute of Technology. Approximate physical parameters of this particular equipment (sample heater, gas chromatograph, and mass spectrometer) are a weight of 10 to 20 pounds, a size of 12 by 8 by 6 inches, and a power requirement of 10 to 30 watts.

The combination of such an instrument package with a diagnostic tool such as the organic carbon analyzer or water detector described subsequently could optimize the use of the mass spectrometer. Samples that are devoid of organic material or that

contain such large amounts of water or ice that they interfere with operation of the instrument could be avoided.

Use of these instruments requires a certain amount of onboard data processing capability and real-time telemetry to Earth-based monitoring scientists.

In the class of more sophisticated diagnostic tools, the development of a rather new technique, electron spectrometry, for operation on the Moon should be pursued. Such an instrument could be capable of quantitatively analyzing for C, N, O, P, and S in various oxidation states (that is, distinguishing between carbonate carbon and organic carbon) in solid samples. The absence of an atmosphere and of an appreciable magnetic field on the Moon would facilitate the operation. Improvement of the sensitivity (efficiency of electron ejection and collection) would have to be stressed and developed.

Organic Carbon Analyzer

A less specific, but smaller tool which can be used for sample location or site collection uses pyrolysis and subsequent flame ionization detection of volatile organic products. Reduced carbon can be detected with a sensitivity of 10 parts/million and a precision of ±25 percent.

About 20 milligrams of a coarse-sized sample is placed in a stainless-steel tube electrically heated to 850° C. An inert-gas stream sweeps out volatiles during the temperature rise and carries them into a hydrogen-flame detector. The detector has a linear dynamic range of 2×10^3 and a quantitative capacity of five orders of magnitude. The detector is selective for C-H bonds, since aerosols of electron-conducting materials are scrubbed out in a precolumn of glass wool. Less than 10 watts is required, with peakloads of about 40 watts during heat up of the sample time. The technique could be automated.

The advantages of the pyrolysis flame-ionization-detector mode are that (1) solid samples are directly measurable; (2) the sample need only be in a mesh size dimension less than 1 millimeter; (3) a small sample is required; (4) no wet chemicals are required; (5) no gases which will interfere with other measurements are produced (major gaseous components will be CO_2, CO, H_2O and N_2, and the carrier gas He; (6) carbonates and water will not interfere; and (7) only volatilizable carbon is detected.

The following are apparent applioations envisioned for the flame-ionization-detector mode:

1. A sample-materials check for organic content at the LM as a means of choosing those samples to be returned

2. Site selection for later sample collection by a survey-automated field assistant

3. A test vehicle to select only samples for retrieval based upon organic carbon content

4. Multiple-hard-landed diagnostic systems for remote analysis of inaccessible regions

Subsurface Gas Analysis

The lunar atmosphere is rare, and there will be a significant addition made to it by retrorocket blast products. Lunar outgassing may produce gases of biological and protobiological interest; such gases may be adsorbed on the surfaces of rocks. It would be very interesting to know the concentration of the following gases in subsurface rocks: H, O_2, N_2, CH_4, CO, CO_2, CH_3CH_3, $CH_2{:}CH_2$, CH_3-SH, H_2S, SO_2, and NH_3.

The subsurface gases can be classified as inert gases, permanent gases, electrophilic inorganic gases, and volatile organic molecules.

The mass spectrometer, which is already planned for an LSSM-type roving lunar module, could detect the inert gases and N_2, O_2, CO_2, CO, H_2O, H_2S, and NH_3. The electrophilic gases (NH_3, O_2, H_2S, and H_3P) are especially important in establishing the nature of organic materials that could be in equilibrium with the gaseous molecules. Electron-capture gas chromatographic technology could be applied if greater sensitivity is required.

The unknown nature and the potential complexity of any gaseous subsurface make it most judicious to develop gas chromatographic systems capable of inorganic and organic separations. The chromatographic systems could, in addition to supplementing the mass spectrometric analysis, provide a good analytical capability. Although the Moon has an obvious advantage for the mass spectrometer, gas sampling probes for subsurface gas chromatographic modes have been constructed which provide for the sampling valve at the probe end. Such mechanisms provide for sample-slug transport over relatively long distances by the carrier stream, making it entirely feasible to perform remote analysis.

It is, therefore, recommended that concurrent competitive modes be funded and that consideration be given to determining the operational feasibility so that the modes can be weighed in the proper frame.

Measurement of Temperature and Water Activity Profiles

Water activity, temperature range, gas composition, and available nutritional components are some constraining parameters of living systems. Water activity and temperature range represent, by far, the greatest restraint on life. Temperatures above 90° C and relative humidities below 30 percent are generally considered prohibitive, and systematic stratigraphical measurements of these two properties in the subsurface must be made. Since water vapor pressure is dependent on the surface

activity of minerals, a direct measurement of the actual vapor pressure of water is required.

An ideal water sensor would have a wide monotonic dynamic range and would be small enough to be incorporated into a multistage probe with a resistance thermometer. Such a device could be designed into a double-sleeved probe that could penetrate the surface. The sleeve could be moved to expose the paired sensors after insertion; and measurements could be obtained in a programed, arranged sequence during the lunar day and night. Equilibrium will be established in time, wherein the probe humidity must reach equilibrium with the surfaces of the soil.

Emplacement of multiple sets of these units is highly desirable in strategic areas which have reconnoitering value to establish future sampling sites and to provide information on the distribution of water and the existence of permafrost areas.

CONTAMINATION CONTROL

Throughout this report, the Bioscience Working Group has stressed the problems that will occur if samples returned from the Moon are contaminated with substances of a terrestrial origin. This section is devoted to an explanation of the two primary sources of contamination.

LM Contamination

When landing, the LM will skim over the lunar surface, showering it with combustion products and unburned fuel from the reaction control system and main engines. Having landed, the He pressure on the excess fuel and oxidizer will be vented, one vent aimed to the rear (direction of flight approach) and the other vent aimed to the side. Furthermore, the beryllium apron around the main engine exhaust will disintegrate over the immediate vicinity of the landing site. The exhaust gases also contain the combustion products of the fiber-glass-laminate lining of the engines (polyester resins, phenol-formaldehyde, and adhesives are used).

To summarize the recommendations of the Bioscience Working Group, a quotation of the 1965 Falmouth Conference[1] is in order:

"The working group recommends that a study be made of the problem of organic contamination of the lunar surface resulting from the burning of the LEM's (LM) rocket fuel. We understand that on its lunar landing, the LEM's controls will burn about 4000 lbs. of N_2O_4-dimethylhydrazine mixture. We strongly recommend that a study be made of the trace organic impurities in the fuel and of the combustion products formed

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[1]Results of the conference were published as NASA 1965 Summer Conference on Lunar Exploration and Science. NASA **SP-88,** 1965.

when the N_2O_4-dimethylhydrazine mixture is burned in a vacuum. The organic chemists need to know more than the obvious volatile combustion products. They need to know what higher molecular weight organic compounds are present or are formed, including those present in minute amount (down to at least 0.01 percent). Since gas chromatography and mass spectrometry will be one of the organic chemists' chief tools in searching for lunar organic compounds, these techniques should be used in the search for organic products resulting from the combustion of the retrorocket fuel."

Other measurements, such as optical rotary dispersion and stable isotope ratio determinations are also recommended on the fuels and ejected material.

It is understood that a study program is beginning to form, but it must be stressed that the program should be implemented immediately and in cooperation with the appropriate principal investigators.

It is imperative that not only should the principal investigators know what fuels are to be used and what their combustion products are in vacuum, but also in what types of containers they are stored, how the fuels are transferred to the LM, and what steps are to be taken to insure that contamination of the fuel does not occur between process time and the time of ignition above the lunar surface.

Microbial Contamination

The possible consequences of microbial contamination of returned lunar material is a problem of real concern to microbiologists who will work with the sample for life detection purposes. It can also be shown that uncontrolled microbial contamination could be sufficient to be of concern to those doing organic analyses.

Consequences. - The confusion and disadvantages that could result from returned samples contaminated with viable Earth micro-organisms can be illustrated by the following:

1. Earth organisms mistakenly identified as indigenous to the Moon could lead to erroneous scientific conclusions.

2. In the presence of Earth organisms, identification of lunar life forms might result in the same type of confusion that exists on Earth regarding the presence of. organisms in meteorites.

3. Microbial contamination may result in delay in release of the sample from the **LRL.**

Sources. - The possible sources of microbial contamination of lunar material are as follows:

Micro-organisms present in the spacecraft atmosphere that are vented following the lunar landing: Provided the tank pressure venting is done during the day, the potential levels of contamination from this source may be small. Studies with micro-organisms in simulated lunar environments, as proposed elsewhere in this document,

may confirm the extent of the combined germicidal action of heat, vacuum, and radiation. For missions conducted at night, the extent of the contamination resulting from venting is unknown and must be eliminated by appropriate filtration.

Outside surfaces of the spacecraft and offloaded equipment: Except for equipment involved in collecting or storing returned samples, microbial contamination on other surfaces will present little problem. The absence of a lunar atmosphere should make the transfer of surface contaminants rather difficult. The surfaces of collecting tools and storage devices must be sterile at the time they are used.

Effusion of micro-organisms from the suits of the astronauts: This constitutes the most serious possible mode of lunar sample contamination. Possible indications are that it will be impossible to prevent all such outgassing. However, little is known of the effects of the lunar environment on micro-organisms carried as aerosols from the suit. However, places of leakage may be shaded. This means that unless suitable barriers are present or remote sampling is done at a defined distance, micro-organisms from the suit may contaminate a sample being collected.

contamination during return to Earth: Based on the present models of return inner containers and return boxes, it is not likely that the samples will be contaminated with micro-organisms during the return flight.

Contamination in the LRL: This possibility is remote, and the checkout and dry runs at the LRL prior to the first return missions should identify any areas where improvements are needed.

Equipment and materials associated with the astronaut: Materials and equipment such as food bags, urine collection and storage devices, feces collection and storage devices, and the portable life support system (PLSS) represent sources of immense levels of microbial contamination. The Bioscience Working Group reaffirms its position that all such sources must be properly contained and that this containment must not be violated during or after lift-off. In those cases where total containment may be impossible (PLSS condensate, LM boilerplate, et cetera), in-line biological filters should be installed.

PREMISSION REQUIREMENTS

Microbiological Studies with Lunar Environment Simulators

Throughout the planning of Apollo and the AAP, the Bioscience Working Group was guided by the assumption that terrestrial microbial contamination of the lunar surface may remain viable and will present a serious threat to proper interpretation of data resulting from the analyses of returned samples. It is necessary to accept this assumption because the survival of terrestrial micro-organisms in the lunar environment has not been experimentally determined. The possibility exists, however, that the extreme daylight temperatures, the radiation flux, and the vacuum of the lunar surface could collectively have an immediate sterilization effect on terrestrial micro-organisms. If this could be determined experimentally, some equipment and mission

constraints could possibly be relaxed. Even if the effect was not immediate but proceeded at a rapid rate, in situ operational procedures might be developed (suit leakage deflectors, in situ sterilization utilizing concentrated solar radiation, elimination of shadow effects, et cetera) that would decrease sample contamination below detectable levels. The Bioscience Working Group recommends that lunar environmental simulators be utilized for carrying out an experimental program that includes the following procedures:

1. The death-rate kinetics of micro-organisms that effuse from astronauts and equipment should be determined.

2. If sterilization is not almost instantaneous, the effects that lunar environmental conditions have on the morphological and physiological properties of terrestrial micro-organisms should be determined. Do variations occur? Does mutation occur? If so, at what frequency? Can the organisms be recognized as terrestrial in origin?

3. Determine if in situ sterilization can be accomplished and how much time is required at the various temperatures that can be reached conveniently on the lunar surface.

4. Determine the contamination profile from a point source using standard orifices at different levels of inclination.

5. Determine whether the virulence of terrestrial micro-organisms is altered by the influence of space flight. Are virulence and infectivity enhanced or altered? Are the reactions to prophylactic and therapeutic procedures altered?

Biomedical Studies

Studies of the biomedical effects of space flight and of lunar exposure on astronauts may appear to be operational in nature; but they present, in addition, an important opportunity to study man's adjustment to stress and new environments and may represent a source of major constraints to AAP implementation. This biomedical research opportunity is especially important in the post-Apollo period when space flights of longer duration are planned and extended periods of exploration on the Moon are involved.

Apollo Suit Tests

The need for lunar samples free of organic chemical and biological contamination has resulted in a request for the development of aseptic samplers and the consideration of other means of preventing contamination. The Bioscience Working Group at the Falmouth meeting 2 years ago made the following recommendation:

"It is recommended that an immediate study be started to determine the amount of microbial and organic contamination escaping from the astronauts' suits due to outgassing on the Moon's surface. The study should also define the extent of the area around the astronauts that would be contaminated by outgassing. This study should

consist of more than theoretical calculations and should be a practical experiment performed using suited individuals in a man-rated vacuum chamber.

Progress in the implementation of this recommendation has not been satisfactory. The suit made available for study by the Public Health Service was not of the type to be used in Apollo and had an abnormally high leak rate. Therefore, little useful information has resulted from the studies performed. Moreover, the tests were not done in a vacuum or in the presence of simulated lunar radiation and heat.

The Bioscience Working Group strongly recommends that suit outgassing experiments be conducted using a flight-qualified Apollo-type suit. These tests must provide not only information on the total number of viable micro-organisms that may exit from the suit, but also the expected distribution of these micro-organisms on the lunar surface.

Teflon Acceptance Testing

At the NASA Falmouth Conference, the Bioscience Working Group recommended the following:

'Before Teflon is finally accepted as a suitable material for gaskets and for sample collection bags, the Working Group recommends that its behavior under near lunar pressures (10^{-12} torr) under various types of radiation exposure (ultraviolet, infrared, etc.) and under temperatures up to 400" K be investigated."

A recent status report indicates that the above recommendation has been implemented by MSC. However, the Bioscience Working Group has not found any reports of such tests and is not otherwise aware that the tests are actually being conducted. Therefore, the Bioscience Working Group wishes to repeat the recommendation made 2 years ago.

Astronaut Training

The Falmouth Conference recommended, ". . . that all astronauts be given training in aseptic and chemically clean sample collection techniques." Included in the recommendation was an indication of the training time needed and an outline of the specific subjects to be included in the training. The status report indicated that the training program has been tentatively accepted and is awaiting funding or mission scheduling. In February 1967, a working group which met at the Goddard Space Flight Center pointed out that:

"The astronaut training program has not at all been implemented in terms of bioscience. In fact, the possibility of its being done for the first landing, if it goes on schedule, is apparently out of the question."

The Bioscience Working Group has been informed by representatives of MSC that proposals to conduct bioscience training programs are under consideration and that a block of Apollo astronaut training time has been reserved for future use. In addition,

the Bioscience Working Group has been informed that the Interagency Committee on Back Contamination has made repeated unsuccessful recommendations that the training be implemented without delay.

The Bioscience Working Group has considered the history and present status of this situation and wishes to point out that in relation to many other Apollo and post-Apollo requirements that require instrumentation development, refined research programs, or both, the training that the Bioscience Working Group wishes to implement is simple and straightforward and requires no great amount of funds. What it does require, however, is an implementation mechanism — someone to be given the responsibility and authority for getting the job done. The Bioscience Working Group can conclude only that NASA has not properly considered the recommendation for this training, since training in other disciplines has been implemented.

Faced with the previously discussed facts, the Bioscience Working Group once more wishes to point out the need for astronaut bioscience training and recommends immediate implementation. Furthermore, since NASA has been aware of this training for over 2 years, the Bioscience Working Group is not impressed with statements regarding the unavailability of astronaut time. The Bioscience Working Group wishes to reaffirm the position that such training must be an integral part of the overall astronaut training program. In addition, although it is recognized that for Apollo this training may be limited to crewmembers and backup crews, the Bioscience Working Group wants to emphasize the need for a continuing program in bioscience training for all astronauts. This program should consist of two parts. The first part should be designed to familiarize astronauts with the biosciences, the techniques used in this field, and the role of biology in extraterrestrial exploration. This program should be initiated with the recently selected astronauts, be made available to all current astronauts, and be an integral part of the training of all future astronauts. The second part of the training would be similar to that envisioned for Apollo crews and backup crews (specific, detailed training required to insure proper implementation of bioscience requirements for each specific mission). This training program should include microbiological orientation and consideration of organic geochemistry. The concepts of sterility and chemical cleanliness must be stressed.

Sample Quarantine Considerations

Although the principles, procedures, and regulatory requirements associated with quarantine of material returned from extraterrestrial bodies are the responsibility of the Interagency Committee on Back Contamination and of MSC, the Bioscience Working Group wishes to emphasize the following points:

1. It is fully recognized that, although the possibility of an indigenous, organized life system existing on the Moon is low, the consequences of returning such a system could be catastrophic. Therefore, quarantine and quarantine testing should be an integral part of each Apollo and AAP mission.

2. The imperative requirement to eliminate or at least reduce potential sources of microbial contamination should be reemphasized. The uncertainty that could result if terrestrial micro-organisms are returned within the sample could result in the delay or even elimination of distribution of samples to principal investigators.

3. Because of mutual interests and requirements of this group and the quarantine group, the Bioscience Working Group should be informed on the quarantine testing program.

4. The Bioscience Working Group recommends that the quarantine release schemes and other information on LRL sample handling and release be made available to all principal investigators as soon as available.

Funding

The search for extraterrestrial life forms and evidence for the past existence of these forms has been given the highest priority for the lunar and other space programs and has been explicitly stated by the Space Science Board of the National Academy of Sciences in 1962, which said:

"On solid scientific grounds, on the basis of popular appeal and in the interest of our prestige as a peace-loving nation capable of great scientific enterprise, exobiology's goal of finding and exploring extraterrestrial life should be acclaimed as the top priority scientific goal of our space program."

It should be realized that adequate funds and funding schedules must be provided to support the technical means of proper sample collection and for adequate Earth-based facilities to investigate the returned samples. These facilities for terrestrial-based data acquisition should be funded in the same category and with an emphasis similar to that placed on flight hardware. As the Apollo Program will yield the first samples for analysis, the precedents established in this program may influence later space activities. All laboratories involved in analyses of returned lunar samples should have equipment funds, operating funds, and research funds made available with sufficient leadtimes to permit the design and implementation of first-class investigative efforts.

EQUIPMENT DEVELOPMENT AND SUPPORTING RESEARCH AND TECHNOLOGY (SRT) REQUIREMENTS

Throughout this report and in the past, the Bioscience Working Group has stressed that its strategy in obtaining the most significant and meaningful scientifical results depends on the detailed analyses performed in Earth-based laboratories. Although some areas of investigation — geophysics, particles and fields, et cetera — rely heavily on lunar-based data collection, it is not feasible to attempt duplication of such terrestrial research capability in the lunar environment. Therefore, the success of the bioscience program depends on the quality and quantity of samples that are returned for study. To support and enhance this effort, the following equipment and SRT requirements are presented.

Aseptic Sample Collector for Apollo

Although this conference was designed to plan for AAP, the Bioscience Working Group would like to stress again its requirement for a subsurface aseptic sample collector. It is encouraged by the concept presented by Purdue University, but recommends that the concept be simplified to provide ease of construction and to enhance reliability. The Bioscience Working Group recommends that all possible effort be expended to insure that a satisfactory aseptic sampler is flown on the first Apollo mission.

Development of Manned and Unmanned LSSM

Landing, development, and ground-based control of the unmanned LSSM represents the most promising method of obtaining sterile, organic, chemically clean samples. This mode of exploration permits sampling not only outside zones of contamination, but also in areas not accessible to manned landings. These automated LSSM units can also be used for survey of future landing sites. Use of this mode for lunar exploration should be studied to determine optimal collection and sealed packaging of samples from large areas of the Moon and rendezvous with a later manned mission, where samples can be retrieved and the LSSM used for manned mobility.

Development of Diagnostic Tools and Methods of _In Situ_ Analyses

To enhance the sample selectivity of the astronauts and LSSM, the following equipment should be developed for flight in the AAP:

1. An organic carbon analyzer
2. A subsurface gas probe and gas chromatograph
3. A pyrolysis unit with a mass spectrometer (organic composition analysis)
4. A humidity and temperature profile probe
5. An electron spectrometer

Study of Systems and/or Concepts for Returning Samples at Temperatures Equal to or Lower Than Ambient Temperature at the Time of Collection

A feasibility study whereby samples could be collected by an unmanned mission, sealed, and stored until retrieval by a manned mission should be made. It is possible that sufficiently low temperatures may be maintained by simple shading from direct sunlight.

A study should be initiated to ascertain feasible methods of preventing a rise in temperature of the samples after collection. The various modes of coolant (cryogenics, refrigeration, et cetera) should be utilized to prevent degradation of viable

micro-organisms and the volatilization of organic gases. This refrigeration is required from the time of collection until the samples are delivered to Earth-based laboratories for analyses.

Development of Subsurface Drills

A prime method that could be utilized on an automated LSSM for sample collection is a drill capable of obtaining samples at a depth of about 2 meters without altering the internal temperature of the core. These cores could be stored, sealed, and later retrieved by a manned mission.

The rationale for, and a complete description of, each of the equipment items in this section are presented in other sections of this document.

It is recommended that designers of equipment accepted for lunar onsite experiments be appointed as principal investigators responsible for testing and approval of the final model. They should be encouraged also to participate in planning of experiments, if this would strengthen the scientific objectives.

SITE SELECTION COMMENTS

The decision of sampling will be based on practical considerations and on the types of samples needed. In the early Apollo missions, mobility will be limited to a very short distance from the space vehicle; whereas in later flights, an LSSM may be utilized practically for collection of data and/or samples on a regional basis.

It is imperative that sampling sites be chosen which are free of known or suspected contaminants. Sterile samples for biological culturing should be collected in the early flights at least 0.5 kilometer from the landing capsule. This would minimize chances of fuel and exhaust contamination. It may be stressed here that unless the greatest precautions are taken, the results of the entire organic geochemical and microbiological research program will be questionable.

Four general locations appear at present to be of interest for sample collection. These are maria and crater floors, unconsolidated samples outside of maria and craters, "meander" valleys and rills, and permanently shaded areas and polar regions.

Maria and Craters

The composition of the floors of the maria and craters is still unknown and speculations vary from black lava flows to lacustrine sediments or even asphalt. Samples from maria and crater flows are therefore necessary to determine this point. Of particular interest are two specific types: those that have evidence of exhalations in them and those that appear to have a breach in the rim and an overflow channel leading away from them. The first would indicate that volatile material is being released, and it is essential to determine whether carbon compounds are significantly present; Alphonsus

and Aristarchus are representative areas. The second maria type — the Krieger area, for example — appears to be indicative of being a reservoir of some fluid.

Unconsolidated Samples on Plains and Highlands

Unconsolidated samples on the plains or highlands away from the maria rims would be important as possible areas where soil micro-organisms may have established themselves. Short aseptic cores of this material should therefore be collected in several areas.

Since much of this material may be a mixture of original lunar surface rocks and meteorites pulverized by impact, the organic matter may be derived in large part from meteoritic material. Scoops of this material from the surface and from immediately below the surface (~20 cm) should be obtained in quantities of about 1.5 kilogram each. Material enriched in organic matter which is exposed for any length of time to the action of high-energy ultraviolet light may polymerize, and it would be important to determine the nature of these products. The samples should be collected as cleanly as possible and rapidly stored in specially prepared sample containers, preferably by the unmanned LSSM. The objective here would be to look for biologically important organic molecules.

Meander Valleys

Several sinuous meander valleys or rills appear in Orbiter IV photographs, as, for example, in frames IV 270 H 151 LF 139 W 4-89, IV 280 H 158 LF 137 G4-85, and IV 27C H-150 LF 139 W4-90. Such valleys (apparent at 20" to 30" N and 40" to 60° W in the lunar map) are often wide, about 10 kilometers, and show structures within them that are erosional. One interpretation of their origin is that of erosion by a fluid. If by chance this was water, it may have carried with it organic matter and soluble salts that may be concentrated either in the beds or in the wall sediment. Samplings of the valleys should, therefore, be given high priority for organic matter, soluble salts, and viable organisms and fossils. The pattern of these valleys indicates repetitive processes which may point to sources of the fluid being at shallow depths below the surface.

Permanently Shaded Areas and Polar Regions

If at any time in lunar history organic compounds were formed, volatile compounds must have existed at some stage of this process. In that case, it is reasonable to assume that these may have condensed and accumulated at the permanently shaded parts of the Moon, where they would have been protected from the influence of heat and irradiation of the Sun. The earlier organic chemistry of the Moon can thus be studied by sampling these permanently shaded areas. These are more and more abundant at higher latitude, and it may not be necessary to reach one of the poles directly in an early mission but to operate in an area where large, permanently shaded places can be reached in reasonably short traverses from a sunlit landing point. It should be emphasized again that subsurface samples, preferably a core of a depth of a few meters (1 to 2 m), would be highly desirable.

The need to collect, transport, and store samples at or below the original temperature has been stressed elsewhere, but should be reiterated.

SUMMARY AND RECOMMENDATIONS

Objectives

The general objective of bioscience investigations during the Apollo and post-Apollo exploration programs is to answer the fundamental questions regarding the origin of the Moon and the solar system and the development of life or life precursors outside the Earth. To achieve this objective, investigations will be conducted primarily in organic chemistry and microbiology at Earth-based laboratories.

The objective of the organic chemical exploration of the Moon involves the search for molecules of possible biological or prebiological origin. Detailed knowledge of the amount, distribution, and exact structure of organic compounds, if any, present on the Moon is of extreme importance. Since the organic chemical investigations used in attempts to answer these questions would be on a molecular level, the conclusions would not necessarily be dependent on the assumption of life and life-related processes as they are now known.

The biological objective for the lunar exploration program involves the search for evidence of viable or nonviable organisms and the search for any types of "life" systems that may be present or may have been present on the Moon. The biological objective also includes the search for life-associated macromolecules, stereoconfigurations and their constituent moieties, such as amino acids, nucleosides, bases, sugars, lipids, and hydrocarbons, as well as the search for microfossils. Biology studies will also consider inorganic components that may have been influenced by metabolic processes.

Sample Collection and Return

Because bioscience exploration of the Moon places emphasis on research performed at Earth-based laboratories, adequate collection and return methods must be developed to insure desired amounts of returned samples in an unaltered state; specific criteria are established for lunar samples, for organic analyses, and for microbiological examination. The overriding criterion is the prevention of organic chemical, and biological contamination in the sample. Beyond this, the Bioscience Working Group has detailed requirements relating to the types of lunar materials to be returned and the types of locations from which samples are to be collected. Included are consolidated and unconsolidated materials, surface and subsurface samples, material from medium-depth and deep cores, and material obtained from cooler regions (permanently shaded) and regions of possible permafrost. Because of several factors — mainly, the possibility that samples will be contaminated by an astronaut — the Bioscience Working Group most strongly recommends, in addition to manned landings, the use of an unmanned LSSM for the collection and packaging of biologically uncontaminated, chemically clean, and refrigerated samples. Moreover, the Bioscience Working Group

envisions that diagnostic instruments on the manned expeditions and unmanned rovers could provide a means of selecting those types of samples best suited for the bioscience areas of research.

The requirements regarding the packing and storage of lunar samples are specified. For bagged collection, Teflon is presumed to be the most suitable material. Methods of cleaning, sterilizing, outgassing, and sealing all bags and return containers are of great importance.

Three methods of storing return samples were discussed: high-vacuum, low-vacuum, and inert-gas atmosphere. If vacuum arrangements are not reliable and will endanger the sterility of returned samples, the use of a nitrogen atmosphere in the return sample boxes would be preferable.

Temperature control for return samples represents a requirement not discussed previously. Temperature control in the early Apollo missions is not feasible at this stage, but the requirement becomes more critical as post-Apollo exploration continues. Furthermore, it relates to all of the bioscience samples; and, in fact, temperature control relates to the preservation of materials of biological and organic chemical interest and may be a problem of greater magnitude if organic condensables are discovered in certain regions. A feasibility study should be initiated for this new requirement,

An adequate aseptic sampler for astronaut use has not been developed yet. Several prototypes of the concept recommended by Purdue University should be built, and investigations should continue to develop a mechanically less complex design.

Diagnostic Tools and In Situ Analyses

The instruments needed for automated diagnostic and in situ analyses have been discussed, and some of the generic types are specified. Such instruments will be invaluable in exploring areas not suitable for manned missions, for pretesting and screening samples prior to return, for selecting sites suitable for future landings, and for analyzing possible gases from cracks or vents in the lunar surface.

Three types of instruments are needed: diagnostic tools for semiquantitative estimates of organic carbon; in situ probes to measure physical and chemical components such as water, temperature, and gases; and instrumentation for qualitative identification of organic matter. These latter qualitative analyses are best performed by mass spectrometry. Such hardware is being developed largely for the Voyager 1973 mission.

In addition to these instruments, basic support of the development of electron spectroscopy as a tool for quantitatively analyzing for C, N, O, P, and S in the various oxidation states is strongly recommended.

The tool package for survey should include an organic carbon analyzer, pyrolysis mass spectrometry, a subsurface gas analysis instrument, and an instrument for measuring humidity and temperature profiles.

Contamination Control

The possibilities of return sample contamination are so numerous and their impact on the bioscientific research to be performed so serious that the Bioscience Working Group has reviewed in detail the sources of contamination and the recommended contamination control methods. The two principal sources of interfering contamination are LM contamination and microbial contamination from the astronauts and their support systems.

Premission Requirements

This report includes a review of studies and developments that should be accomplished during a premission time frame in support of bioscientific research. A number of microbiological studies in lunar environment simulators are needed. The lunar environment simulator studies relate to the need to estimate the germicidal effects of the lunar temperature, vacuum, and radiation on Earth microbial contaminants taken to the Moon. These data are important in developing future sampling devices.

The Bioscience Working Group urges that Apollo suit leak tests, fuel and Teflon acceptance tests, and astronaut training programs be implemented as soon as possible and that the LRL quarantine schemes be made generally known to all principal investigators.

Finally, the Bioscience Working Group has presented views on SRT funding during premission periods.

Equipment Development and SRT Requirements

To enhance the success of the overall bioscience goals, the Bioscience Working Group has specifically identified a number of equipment-development and SRT requirements.

1. Aseptic sample collector (manned and unmanned)

2. Automated local scientific survey modules (unmanned)

3. Instruments for diagnostic and in situ analyses

4. A refrigerated return sample container and apparatus and study on optimum methods to prevent sample heat up

5. Subsurface drills (2 m)

Site Selection Comments

The Bioscience Working Group has discussed in detail the relative value of exploration at various lunar sites. Four general types of subsurface locations that appear

to be of interest for bioscience sample collection are maria and crater floors, unconsolidated samples outside of maria and craters, meander valleys, and permanently and partially shaded areas and polar regions.

CHAPTER 7

REPORT OF
GEODESY & CARTOGRAPHY
WORKING GROUP

TABLEOFCONTENTS

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INTRODUCTION

The Geodesy and Cartography Working Group concentrated on a set of vitally interrelated topics: the lunar ephemeris describing the position of the center of mass of the Moon, the angular motion about the center of mass of the Moon, the gravitational field of the Moon, the size and shape of the Moon, and positions of points on the actual lunar surface. This grouping is natural not only for the interrelations to be discussed subsequently, but also for the common metric character of the topics. In each topic, the significant questions are answered by accurate measurements of distance, direction, and time dependence of distance and direction.

This metric quality is already one indication of the importance of the set of topics, since positional knowledge is a prerequisite for many lunar activities. In some respects, the need for a metric framework may be too obvious; it is easy for an investigator in some other discipline to assume implicitly that the framework will be available within the accuracy he requires, overlooking the fact that much effort may be necessary to obtain it. The plan proposed for a geodesy and cartography program embraces the legitimate research objectives of geodetic and cartographic scientists and recognizes the stated and implicit requirements from other scientific and operational areas.

Pre-space-age knowledge of the lunar ephemeris, angular motions, gravity field, and figure of the Moon came from classical astronomical techniques. Up to the present, spacecraft to the Moon have provided observations yielding appreciable advances in each of these topics. Hence, the program is ongoing, and the natural action now is determination of the appropriate succession of steps in an orderly progression. Individual discussions in later sections begin with a synopsis of current status and then develop recommended future activities.

However, the detail of the later sections is not necessary to illustrate the basic concepts and the interrelations involved. This can be accomplished by a few examples. Consider first the lunar ephemeris. As treated by classical astronomy, the lunar ephemeris depends in part upon the mass distribution of the Moon. Analyses based on the ephemeris yielded the questionable result that the lunar mass density decreases with depth below the surface. However, the most recent results from the motion of Lunar Orbiters give a mass distribution which increases slightly with depth. This more satisfying result highlights an urgent need for reexamination of the analysis of the lunar ephemeris. Another aspect of the ephemeris concerns recent refinements to the theory. These were substantially confirmed in a study of measurements of the range from Earth to Lunar Orbiters; such ranges include, of course, the motion of the Orbiter about the lunar center of mass and the motion of the center of mass about Earth. However, ranging from Earth to optical or radio transponders on the lunar surface similarly involves the lunar ephemeris, the lunar librations, and the transponder locations in

selenocentric coordinates. Since the center of mass is obviously not directly accessible, improvement of the lunar ephemeris is inescapably linked to these other topics.

As a second example, the interrelationship between the gravitational field and the lunar surface is informative. A comparison of the actual surface profile and an equipotential surface is a prime source of information about the lunar interior. To be most sensible, the comparison should be performed with profile and potential data of comparable accuracy. Thus, as the lunar gravity field is refined by analyzing the motion of Lunar Orbiters, the surface figure and location of features should be correspondingly refined by photogrammetry and altimetry from the Lunar Orbiters.

The role of photography in lunar geodesy and cartography deserves careful statement. The geodesist tends to consider photography foremost, as a tool to measure relative directions. The geodesist might use a camera package to photograph stars and features on the lunar surface and thus measure directions for a three-dimensional triangulation to locate points on the surface. These points would constitute a geodetic control network on the lunar surface. The network, in turn, would assure a well-defined coordinate system for surface features and a lunar-wide reference for elevations, but the same metric photography has other potential uses. The directions between well-defined surface points and the Orbiter positions can be used in determining orbits. An economical cartographic product, controlled orthophotographs, can be made from photographs. With much more effort, topographic maps can be produced, perhaps only for selected regions of particular interest. However, it is quite possible to take photographs which are useful as pictures of geologic phenomena, but which have little metric value because the camera used was not designed with metric use in mind. Photography and mapmaking are certainly not synonymous, and even metric photography need not be for mapping. However, when quantitative data are needed, the photographic system should be tailored to the need.

The interlinked nature of the whole set of topics has the consequence that refinements in all topics must proceed at the same pace for optimum efficiency. In fact, it is difficult to singularly advance any of the topics without advancing some aspects of others. Just enough redundancy exists in the proposed program so that the solutions obtained can benefit from a consistency check within the total framework. This strengthens confidence in the derived quantities.

Gross quantitative statements can be made about the geodesy and cartography discipline as a whole. In terms of distance, the present knowledge of linear quantities in all the topics has an uncertainty in the range from a few hundred to a few thousand meters. The program outlined in subsequent sections should, in a few years, reduce the uncertainties by an order of magnitude to the range between 10 and a few hundred meters. Further improvements will come still later. For specific quantities, subsequent sections contain more explicit discussions of expected accuracies.

LUNAR EPHEMERIS, ORIENTATION, AND LIBRATION

Scientific Objectives

In terms of fundamental concepts, one primary objective of lunar science is to measure the position and orientation, including variations with time, of the Moon with respect to an inertial reference. These quantities are essential to an understanding of the dynamics and evolution of the Earth-Moon system and to use of the system for investigation of more fundamental problems of the solar system, astronomy, and physics.

Improvement in the lunar ephemeris, which gives the position of the center of mass of the Moon with respect to the Earth, is desirable to accomplish the following objectives:

1. To improve the accuracy of other measurements involving both the Moon and the Earth, such as (currently) the tracking of lunar satellites and the establishment of geodetic control on the lunar surface and, eventually, the use of the Earth-Moon baseline for radio interferometry on astronomical sources

2. To improve determination of ephemeris time

3. To deduce from the lunar orbit such effects as tidal dissipation

Improved knowledge of the orientation of the Moon and its variations and of the physical librations is desirable to accomplish the following objectives:

1. To fix the orientation of a selenodetic control system

2. To detect the effect of any nonrigidity of the Moon on the librations

Assuming adequate understanding of the lunar ephemeris and librations, the Moon constitutes a stable reference, competitive to high (altitudes greater than 10 000 km) artificial satellites, for use in geophysical investigations of the Earth. Some of the same techniques and observations used for lunar objectives may be applied simultaneously to measure variations in the rate and axial direction of the rotation of the Earth, to deduce the response of the solid Earth to meteorological and other disturbances.

Current Status and Unresolved Problems

Present knowledge of the lunar ephemeris is based on the Brown lunar theory using constants obtained by Earth-based observations. Recently, the Brown theory has been improved by including more terms and by updating the constants to be compatible with the International Astronomical Union standards. These results are available on tape for use in computing orbits, except for the effects of the nonsphericity of the Earth. Tapes including these effects should be available by January 1968.

The precision of the position of the Moon obtainable by the improved Brown theory (assuming perfectly precise constants) is of the order of 50 to 60 meters in range

and 100 meters in a direction perpendicular to the range. Range rate is obtainable to 1 mm/sec. However, uncertainty in the constants adds appreciably to the total uncertainty.

Recent work with grazing occultation observations has indicated the possibility of a fairly large error in declination, perhaps of the order of 500 to 750 meters. Should this work be confirmed, it would indicate the need for substantial revision to the ephemeris. Lunar Orbiter ranging data have provided strong evidence of the accuracy in range of the corrected lunar ephemeris.

Lunar orientation and its rates of change ,(physical librations) are known to about 20'' of arc (200-m position on lunar surface). This information depends primarily on Earth-based heliometer observations, fitted to lunar libration theory.

Program Plan

From the current knowledge of the lunar ephemeris and angular motions and from established instrumentation capabilities, the next programed advances should measure the range to the Moon and positions on the Moon, to within ± 10 meters, and the direction of the Moon from the Earth, to within ± 0.01'' of arc. A positional accuracy of ± 10 meters on the Moon is equivalent to ± 1.2'' of arc rotation of the Moon about its center.

These measurements can be accomplished by the instrumentation systems and procedures described in the following paragraphs.

Laser ranging to retroreflectors on the Moon. - Laser ranging to retroreflectors on the Moon is accomplished by measuring the transit time of a light pulse. In the present application, the pulse would be sent from a station of the Earth to a station on the Moon. From this station, the pulse would be reflected to an Earth station.

The instrumentation required on the Moon is a corner-cube retroreflector of about 100 in^2 weighing about 17 pounds. To optimize site selection, the delivery of the instrumentation by a manned spacecraft is preferred but not absolutely necessary. The lifetime of the retroreflector on the Moon should be at least 6 months; a lifetime as long as 20 years would be useful.

Instrumentation required on Earth is a laser capable of delivering on the order of 10^{20} photons in a pulse, a photodetector, and a telescope with a 60-inch (or greater) aperture.

A useful initial objective for range and corresponding position coordinates on the Moon (± 10 m) should be attainable with instrumentation currently in development, using one tracking station on the Earth and two retroreflectors, well separated in longitude, on the Moon. Tracking should be employed several times a month for a few months. The immediate benefits will be distinct improvements in determination of the lunar orbit and lunar librations.

A more comprehensive investigation would require further instrumentation: three well-separated tracking stations on the Earth and three reflectors on the Moon, one near the pole. Tracking should be performed daily, if possible, to obtain the maximum information on variations in the rotation of the Earth and any effects of nonrigidity of the Moon.

Orbiting camera system. - A camera system, in satellite orbit around the Moon, can be used for measuring positions on the lunar surface, provided the position and orientation of the camera at the instant of film exposure is known precisely. The position can be readily obtained from the satellite ephemeris. However, since the orientation available from satellite attitude-control systems is usually not precise enough for this purpose, the orientation must be provided. This can be accomplished by including two extra cameras to photograph the star background, as described in the section of this report on the size, shape, and topography of the lunar surface.

The primary purpose of this system is the establishment of geodetic control, but the inclusion of the stellar cameras makes possible the determination of the orientation of the Moon in a celestial reference system. The estimated accuracy attainable by the photogrammetric system is ±10" to 15" of arc in orientation and libration.

Radio transponder or transmitter. - Two separate systems are being recommended which require radio beacons on the Moon. The first system is a radar ranging system based on timing a radio pulse just as the laser ranging system times a light pulse. The second system is a radio interferometer designed to measure the direction of a beacon on the Moon. A single network of beacons on the Moon can be used for both systems, provided that each beacon is equipped with a transponder adequate for the radar ranging. The network will then, necessarily, have a transmitter for the interferometer.

The instrument to be placed on the Moon is a range and range-rate transponder which can be used by tracking networks on Earth such as the Manned Space Flight Network (MSFN) and the Deep Space Network (DSN). Such a transponder would weigh a few pounds with power and sufficient insulation to last 1 year.

The lunar equipment would be used as a transponder by the tracking systems on Earth and as a simple radio source by an independent clock interferometric system of radio telescopes. For the latter purpose, a lifetime as long as 20 years for the transmitting part of the equipment would have some value.

This application uses ground systems designed for other primary purposes and hence already available. The radio ranging should readily obtain an accuracy of ±10 meters, possibly improvable to ± 1 meter; hence, the radio ranging is secondary to the laser ranging, which has a potential of 0.1 meter. The radio interferometry is expected to attain ±0.01" of arc in direction, or ± 20 meters in the transverse component of the position of the Moon. Hence, the radio interferometry will be a valuable supplement in enabling the laser ranging to make improvements in the lunar ephemeris. The radio interferometry will be particularly valuable in determining small variations in the rotation of the Earth.

The transponders should be emplaced at a minimum of two positions which are well separated in longitude. To obtain the maximum information about the rotation of the Earth, tracking by the interferometer should be daily.

Flight hardware and schedule requirements. - In view of their light weight and passive nature, retroreflectors should be placed on all vehicles landing on the lunar surface. Similar considerations apply to radio transponders; however, the extra measures to assure a long life need only be taken for three widely separated points, as specified above.

To take full advantage of available ground facilities, both a laser retroreflector and a long-lived radio transponder should be emplaced by the earliest possible lander near the pole.

The principal hardware peculiar to the measurements recommended herein is the orbiting camera system, which requires a specific circular polar orbit and the subsequent return of film to the Earth.

Ground support facility requirements. - The necessary support by the existing radio tracking networks, MSFN and DSN, is required on a regular basis.

Lasers and photoelectric sensors will be used with 60-inch or larger telescopes located at each of three widely separated sites.

A detailed and thorough data analysis effort is required to generate plans for fully exploiting the ranging and interferometric data.

Processing and photogrammetric analysis of orbital photography is required, as described in a later section.

Recommendations

It is recommended that the capability for laser ranging to the lunar surface be established. The first-stage capability requires placement of two corner-cube retroreflectors on the lunar equator and the activation of one laser station on the Earth. The second stage requires the addition of a third reflector near a pole of the Moon and two Earth-based stations widely separated from each other and from the first station. These stations may be used concurrently for laser ranging to lunar orbiting satellites, as recommended herein.

It is recommended that a photogrammetric camera system be carried on a Lunar Orbiter which is placed in a polar orbit for a period of at least 28 days. Film return to Earth is mandatory (unless electronic readout systems can be vastly improved).

It is recommended that two or more radio transponders be emplaced on the Moon, widely separated in longitude. These transponders should be insulated or heated to last through the lunar night and to give as long a lifetime as possible.

It is recommended that there be established a radio interferometer system consisting of two (adequate) or three (preferable) stations widely separated on the Earth. These stations will be used in conjunction with the radio transponders on the Moon.

It is recommended that there be a detailed and thorough data-analysis effort to generate plans to analyze the data obtained in these several tracking systems and to exploit effectively the information contained therein.

THE LUNAR GRAVITATIONAL FIELD

Scientific Objective

The overall objective of this program is to determine the mass and the gravitational field of the Moon to the degree and accuracy required for scientific applications and for support of cartographic and mission control functions in the time period from 1970 to 1980.

Scientific applications of this information include the following: contributions to the knowledge of moments and products of inertia of the Moon; orientations of principal axes; mass and density distribution in the Moon; correlations between the selenoid and surface and geological features; geophysical implications of these correlations and implications with respect to the origin and history of the Moon; and contributions to the theory of physical librations of the Moon and to the lunar ephemeris. The information is also to be used in support of other objectives, for instance, in performing the precise orbit determination required for use with orbital photogrammetry and magnetometry.

Current Knowledge and Status

Present knowledge of the higher degree terms in the lunar gravitational field (that is, the coefficients $C_{n,m}$ and $S_{n,m}$ in the spherical harmonic expansion of the gravitational potential) is based on preliminary analyses of tracking data from Lunar Orbiter spacecraft. The various analyses currently in progress, which use tracking data from the five Lunar Orbiter flights and the anchored interplanetary monitoring platform (AIMP) flight, should provide a good determination of the lower degree coefficients and perhaps a fair determination of the coefficients through the fifth degree ($n = 5$) and the fifth order ($m = 5$).

However, it is anticipated that the available data will not allow resolution of all individual coefficients through the fifth degree and the fifth order because of correlations between various coefficients — correlations which are not resolvable with the limited variety of orbital parameters available in the present data. The requirement for further progress is for tracking data from lunar satellites with intermediate inclinations to the lunar equator (in the range from about 30° to 75") and with relatively small semimajor axes (less than 2000 km).

Program Plan

The immediate objective of the investigations is to determine the lunar gravitational-field coefficients, in the expansion of the gravitational potential, through

the fifth degree and order. This objective requires data other than that currently available. The intermediate objective is the determination of the coefficients through the 10th degree and the 10th order. More advanced objectives are the determination of coefficients through the 15th degree and the 15th order and the determination of the detailed gravitational field in limited areas (by surface gravimetry and the gravity gradiometer).

These objectives are to be accomplished through orbital and surface experiments. The orbital experiments include the following:

1. Radio tracking from Earth-based facilities (first priority)

2. Laser tracking from Earth-based facilities (first priority)

3. Radio tracking from Earth-based facilities with a transponder on the Moon (second priority)

4. The gravity gradiometer in a lunar satellite (third priority) (see appendix)

Surface experiments consist of gravimeter measurements along surface traverses (primarily as required for geological and geophysical purposes).

Instrumentation and procedures required for accomplishing the objectives include the following:

Radio tracking from Earth-based facilities. - The radio tracking technique requires Doppler and ranging transponders in an orbiting spacecraft; a receiver and transmitter in the spacecraft; a power source to achieve a minimum operation time of 1 month, with desired operation for 13 months; and use of the Deep Space Network (DSN) and MSFN tracking facilities on Earth.

Radio tracking from Earth-based facilities with a transponder on the Moon. - The spacecraft instrumentation is the same as that discussed previously, but modified to operate with a transponder located on the surface of the Moon. Doppler (and perhaps ranging) transponders must be placed on the lunar surface, with a minimum of three required (10 desired); and (with the transponders as widely spaced as possible) a transmitter, receiver, and power source is required with each surface transponder. Operating times are the same as mentioned previously. This technique also requires use of the DSN and MSFN tracking facilities on Earth.

Laser tracking from Earth-based facilities. - For the laser tracking technique, corner-cube laser retroreflectors are required on orbiting spacecraft. The weight is approximately 17 pounds for a 100-in^2 reflector, but the necessary area must be determined by a detailed study. Four to six such arrays are required if the spacecraft attitude control is not maintained, and short-term (a few days) radio tracking facilities may be required for single-purpose laser reflector satellites for orbit determination to assure laser acquisition (either a stable' oscillator for a one-way Doppler, or a transponder will serve this purpose). One to three laser tracking stations are required on Earth.

Gravity gradiometer. - This technique uses a gradiometer in the satellite and requires accurate inertial orientation of the satellite with no orientation perturbations during the measurements. The accuracyof the gradiometer should be $\pm 5 \times 10^{-10}$ gal/cm for a smoothing time of 300 seconds and $\pm 2 \times 10^{-9}$ gal/cm for a smoothing time of 15 seconds. The orbital altitude should be 30 kilometers, and orbital inclinations should cover all areas visited by surface traverse. (See appendix.) While such a system would be useful if developed, the instrument is still in the feasibility study phase.

Surface gravimetry. - Surface gravity could be measured with a gravimeter during surface traverses and at all landing sites. The geodetically useful spacing of measurements is considerably less than that required for local geologic surveys and occurs about once every 5 kilometers. A large area of the lunar surface must be uniformly sampled to provide a comparison with gravity, computed from the orbiter-derived potential. The dimension of the area is roughly indicated by the wavelength of the highest harmonic in the potential representation. If a gradiometer is eventually flown, a dense observational pattern obtained from it would allow useful measurements from smaller surface areas. The accuracy of gravimetry should be ±5 milligals, and the elevation at which measurements are made should be known to ±50 meters.

Flight instrumentation and operations. - The basic flight hardware for this program consists of transponders and laser reflectors on orbiting vehicles. Transponders should be available on the lunar module (LM), the extended lunar module (ELM), and the augmented lunar module (ALM), and these components could be used for this experiment after the basic mission is completed, provided the 30-day minimum and 3-month (or longer) desired lifetime can be satisfied.

The placing of retrodirective reflectors on these components is a particularly desirable situation, since these reflectors have no power or orientation requirements and can provide extended laser tracking data from unperturbed satellites.

Deployment of retrodirective laser reflector arrays on subsatellites or subsatellites containing transponders, from the empty bay in the service module (SM) is a promising possibility. Such satellites could have propulsion systems to achieve a desired range of inclinations and could be used in conjunction with numerous other orbital experiments.

All satellites used for providing tracking data for this experiment should have coupled attitude-control systems, so that there will be no orbital disturbances introduced by the spacecraft systems during the life of the experiment. No specific surface mobility is required; surface gravity observations should be made during traverses undertaken for other purposes, as noted previously.

Orbital requirements for the lunar satellites are as follows:

Inclination. - No precise inclinations are required, but a variety of inclinations, in the range from 30" to 75°, at 10" to 15° increments, is required.

Low-altitude orbits are most useful, with satellite altitudes in the range from 50 to 300 kilometers, implying semimajor axes of less than approximately 2000 'kilometers.

Radio tracking facilities. - Ground support equipment and facilities required consist of existing DSN and MSFN tracking facilities.

Laser tracking facilities (three desired). - The laser tracking facilities are also recommended in the section on the lunar ephemeris, orientation, and libration and can be effectively utilized for the several purposes. Provision should also be made for sufficient Doppler and range tracking coverage without unduly conflicting with operational requirements. Postmission tracking could provide this coverage.

Recommendations

The Geodesy and Cartography Working Group recommends the establishment of orbiting satellites at intermediate orbital inclinations. These satellites should be "minimum" satellites, without attitude control and with the only instrumentation being range and range-rate transponders, modified to operate with lunar surface transponders and tracking facilities on Earth.

Laser retrodirective reflectors should be incorporated on all spacecraft left in lunar orbit (LM, ELM, ALM, subsatellites ejected from the command module (CM)), to be tracked by ground instrumentation facilities developed primarily for ranging to reflectors located on the surface of the Moon.

It is recommended that the feasibility of initial acquisition of laser retrodirective reflector satellites by laser tracking instruments (perhaps by wide-beam initial tracking) without auxiliary facilities be investigated. This should be studied also for cases in which satellites ejected from the CM have propulsion systems for providing considerable change in orbit inclination.

SIZE, SHAPE, AND TOPOGRAPHY OF THE LUNAR SURFACE

Many requirements exist for quantitative definition of the size, shape, and topography of the Moon. The correlation of geodetic control accuracies with definition of the lunar ephemeris, libration, and gravity field are discussed in this report. Astronomers, geophysicists, and geologists have expressed the need for more accurate surface definition than is currently available. Imposed upon these scientific requirements are those operational requirements for surface topographic definition to support navigation, site selection, and certification. The interests of economy and efficiency dictate that all such requirements be considered in planning lunar photographic missions. These are discussed in the following paragraphs. Photographic systems are then proposed to best meet those requirements now identified.

Objectives and Requirements

Scientific objectives. - The following are the scientific objectives for lunar geodetic and cartographic investigations related to the lunar surface.

1. Determination of the physical size and shape of the Moon

2. Measurement of the topographic variations

These objectives pertain to the development of a lunar geodetic network over the entire lunar surface. The required network, derived from photographic analytical triangulation and constraints from well-determined orbits, will have identifiable positions on the surface, related to a unified coordinate system with axes in the principal axes of the Moon and with a standard error of 10 meters in the three coordinates. Consistent topographic information will then be developed for correlation with geological and geophysical information.

A quantitative comparison of the large- and medium-scale topographic features of the lunar surface with an equipotential surface is one of the strongest methods available to investigate the lunar interior. The comparison can be performed in several ways, but one example here will illustrate the essential features of the investigation. The lunar gravitational potential, as determined from tracking Lunar Orbiters, is represented in a series of spherical harmonics through some degree and order. The surface profile can similarly be expanded in surface harmonics through the same degree and order. It is important to realize that the information needed for this latter expansion is primarily accurate elevation data for the lunar topography, averaged over areas commensurate with the degree and order of the expansion. This is critically a question of geodetic control over the entire lunar surface or large areas thereof.

Given the harmonic representation of the surface profile, various geophysical models (for example, isostasy) allow a calculation of the equipotential surface implied by the model. If the calculated equipotential agrees with the observed equipotential, this is strong support for the model; if agreement is not good, a new model must be sought,

For an optimum comparison, the potential and profile information should be known to comparable accuracy. The following is a rule-of-thumb formula for the accuracy correspondence.

$$\text{profile accuracy} = \pm \frac{10^3}{\ell} \text{ meters} \qquad (1)$$

where ℓ is the degree (and order) of the harmonic expansion. For example, a profile accuracy of approximately 200 meters corresponds to a potential expansion through (5, 5). (See pp. 74-76, 1965 NASA Falmouth report.[1])

Requirements from other scientific disciplines. - No attempt has been made to compile a comprehensive list of the requirements of other scientific disciplines for information concerning the shape and topography of the Moon. However, a few examples will illustrate the range of accuracies and detail required.

The Astronomy Working Group has stated requirements for detailed topographic information on potential locations for X-ray and y-ray occultation experiments. These

[1] NASA 1965 Summer Conference on Lunar Exploration and Science. NASA SP-88, 1965.

potential locations are 50-kilometer-radius craters with relatively smooth floors and rims about 1 kilometer in height. The locations require 360° panoramic photography of the horizon (measurable to an accuracy of 1'' of arc) as seen from the site and a topographic map of the crater rim to an accuracy of approximately 10 meters.

To extend meteoroid flux measurements to larger masses, it has been proposed to survey an area of several hundred square kilometers several times with 1-meter-resolution orbital photography at 1- to 3-year intervals.

The Geology Working Group has expressed a requirement for lunar photography of potential exploration sites to 1-meter resolution for use in planning scientific activities on the lunar surface. The requirements for base maps on which to plot geological information for planning, mission operations, and postmission analyses are as follows:

1. Orthographic, Mercator, and polar stereographic projections of the whole Moon (approximately 10 sheets), 1:5,000,000 scale

2. Complete coverage of the Moon (144 sheets), 1:1,000,000 scale

3. Coverage of approximately 20 areas of interest as Apollo Applications Program (AAP) landing sites and traverses (approximately 100 sheets), 1:250,000 scale

4. Coverage of central parts of 20 areas of special interest (approximately 20 sheets), 1:50,000 scale

5. Coverage of landing sites in the central portion of AAP sites (80 sheets), 1:5,000 scale

Support of Operational Mission Requirements

Navigation. - Indispensible byproducts of lunar geodetic activities are the position and topographic information needed in support of lunar missions. Only 5 years ago, lunar spacecraft were targeted at the Moon — some unsuccessfully. By 1967, however, photographic sites for Lunar Orbiters and landing sites for Surveyors are selected and achieved with almost routine targeting precision of a few kilometers. It is probable that existing spacecraft guidance technology is inherently more accurate than our current knowledge of the locations of most lunar features in any coordinate system. Improved quidance systems and navigational techniques cannot be exploited to reduce lunar surface mobility requirements unless knowledge of desired landing-site locations improves correspondingly. Acquisition and reduction of metric photography of the Moon can afford such improvement.

Site selection and certification. - Aside from the obvious reasons for assuring crew safety and mission success, lunar landing-site analysis and selection well in advance of the mission can significantly improve the efficiency of activities on the lunar surface. The same is even more true for manned or automated surface traverse missions. Only a thorough analysis of high-resolution photography (the resolution must be three to five times better than the sizes of potential topographic hazards for the system under consideration) can provide high confidence in the operational suitability of landing sites or exploration areas. Identification and photogrammetric studies of

features of high scientific interest in the vicinity of candidate landing sites can reduce the time needed for scientific activities during the lunar surface missions and also provide important inputs to the site selection process. After the first few Apollo landings, lunar landing sites will be selected on the basis of potential scientific value.

Cartographic support for the conduct of missions. - A variety of specialized cartographic products are required for support of lunar missions. These range from small-scale flight charts used for lunar orbit operations to very-large-scale topographic plans (approximately 1:5,000 scale) used for lunar surface operations. Although needs vary from mission to mission, it will not be possible to prepare these products to the required accuracy unless metric photography is available for the areas under consideration. As the capability for extended traverses is increased, the requirement for extended area coverage of high-resolution photography (probably 1-meter resolution, or less) will correspondingly increase. There is a clear requirement to maintain the capability of obtaining such photography as additional exploration areas are identified.

Maps for general interest. - Because of the intense interest generated by the Ranger, Surveyor, and Orbiter programs, there is now a general public demand (which will increase tremendously when the Apollo missions begin) for maps of the Moon. Such maps of general interest can be compiled from information now in hand and will not affect future programs. However, it is important to make this information available so that interested members of the public can more closely identify themselves with the lunar operations.

Public demand will be best satisfied by maps of two varieties: general reference maps which present the Moon as a whole, and large-scale maps which show in detail those areas of the lunar surface in which Apollo missions are in operation.

Current Status of Coordinate Systems and the Topography of the Moon

Traditionally, the coordinate system for lunar positions has been based upon heliometer measurements using Mosting A, limb, and other selected points on the surface. These measurements were used to establish a basic selenographic coordinate system, assuming a spherical Moon. Independently, the Lunar Orbiter photographs can be used to establish a coordinate system based upon the center of mass of the Moon. This coordinate system is derived from a combination of orbital and photographic data. In this approach, camera exposure stations are determined from the Lunar Orbiter ephemerides. Subsequent photogrammetric reduction generates a system of locations on the lunar surface. The final compatibility of positions defined by these two coordinate systems is yet to be determined, but preliminary results show that differences of several kilometers may exist. Neither system meets current requirements for a lunar geodetic coordinate system.

Since 1958, several individuals at various institutions have attempted to extend and improve the positions of lunar features in a selenographic coordinate system. These analyses of Earth-based photographs represent a substantial increase in accuracy over earlier results. These results, however, suffer from scale and resolution limitations. Relative accuracies of selenographic positions obtainable from

Earth-based photography are approximately 1 and 1.5 kilometers in the horizontal and vertical components, respectively. This accuracy applies at the origin and degrades rapidly toward the limb of the Moon.

Efforts to represent the size and shape of the Moon in surface harmonics using these Earth-based results have been made by some investigators. While the representations are reasonable, certain restrictive assumptions, such as symmetry for the far side of the Moon, were necessary. Also, the probable errors of the elevations mask the real validity of the results.

The Lunar Orbiters furnished an opportunity to obtain extraterrestrial photography to attempt the establishment of a better lunar geodetic control network. However, as the Lunar Orbiter missions were not designed for broad geodetic or photogrammetric purposes, whether any overall improvement will be achieved in existing selenodetic control systems is not yet determined. Although Lunar Orbiter IV has provided extensive coverage, the high-resolution photography has an overlap of only 5 percent, limiting photogrammetric reduction. The medium-resolution photography of Mission IV has adequate overlap, but the ground resolutian is 600 to 800 meters, which is about the same as good Earth-based photography.

To date, photogrammetric control has been generated within selected sites using photography and orbital data from Lunar Orbiter I and 11. The results are internally consistent within a strip of photographs for one site. However, the adjustment of orbital and photogrammetric control from different areas to the Earth-based control indicates differences ranging from 3 to 7 kilometers. Ultimately, the standard coordinate system for lunar positions should be obtained from the combined use of orbital metric photography and orbiter positions from tracking data.

Current Status of Lunar Mapping

The following paragraphs provide a brief description of recently published lunar maps and charts currently available at scales useful for scientific analyses and lunar scientific exploration planning. These are produced for NASA by the U. S. Air Force Aeronautical Chart and Information Center and the U.S. Army Map Service.

Lunar charts prepared from telescopic photographs. -

Lunar Astronautical Chart (LAC) series (1:1, 000,000 scale): The LAC series of lunar charts will consist of 44 sheets covering most of the visible face of the Moon. This chart series is prepared from telescopic photography and visual observations, supplemented in localized areas by shadow measurements to provide relative differences of elevation. Position and elevation uncertainties of features shown on this chart series are in excess of 1 kilometer. The current status of chart production in the LAC series is illustrated in figure 1, with completion of the series expected in late 1967.

Apollo Intermediate Chart (AIC) series (1:500, 000 scale): The AIC series of lunar charts consists of 20 sheets covering the near-side equatorial zone of the Moon between ±7-1/2° lunar latitude and ±50° lunar longitude. Like the LAC series, this chart series is prepared from telescopic photographs and visual observations (supplemented in small areas by Ranger data). Position and elevation uncertainties of features shown

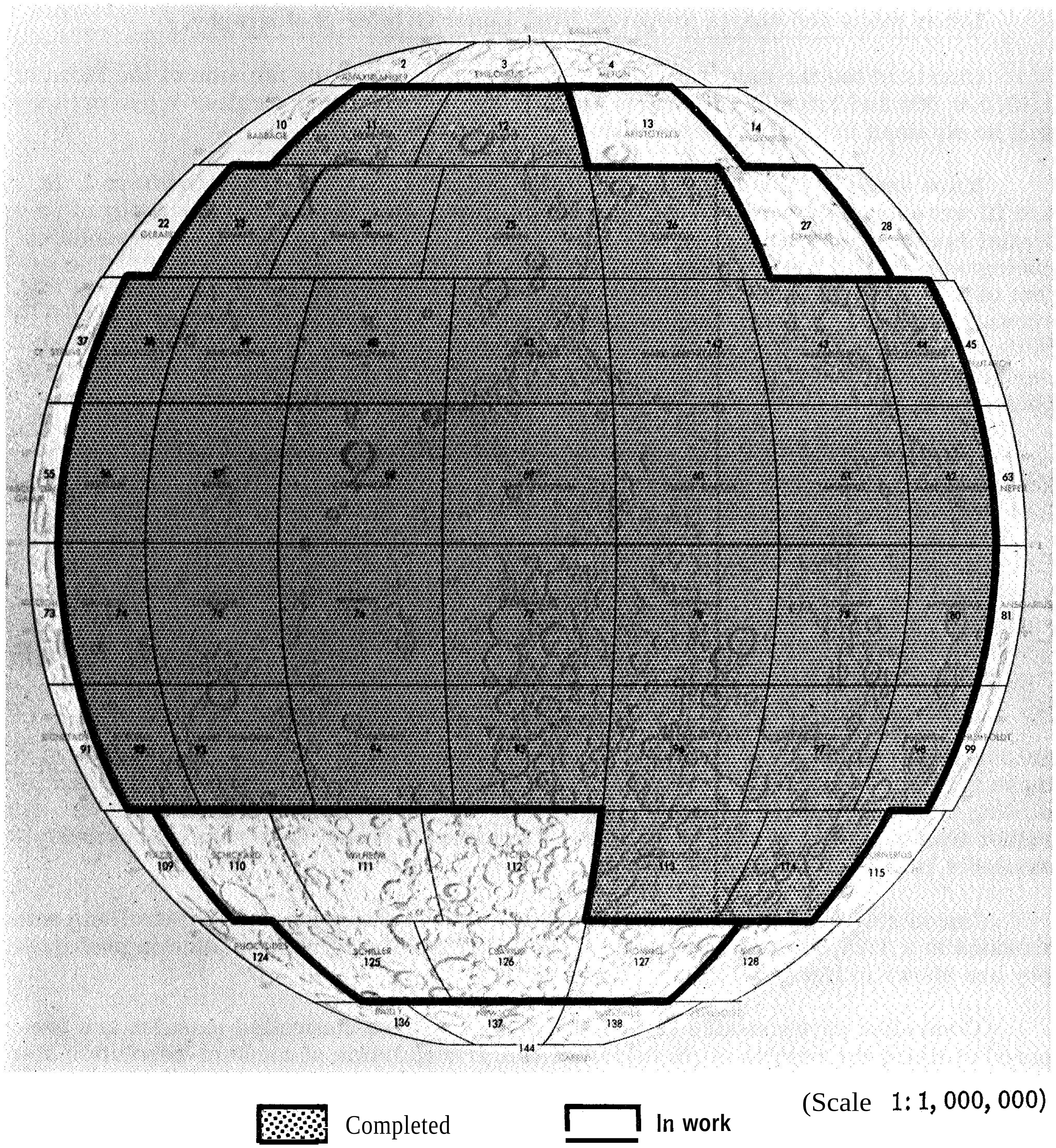


Figure 1. - Lunar chart index, status as of July 1967.

on this chart series are in excess of 1 kilometer. The status of chart production in the AIC series is illustrated in figure 2.

Lunar maps and charts prepared from Lunar Orbiter photography. -

Charts of the far side of the Moon: Charts of most of the far side of the Moon at 1:10, 000,000 and 1:5, 000, 000 scales are now available. Lunar Orbiter V photography will be obtained for most of the missing areas.

Maps and photomosaics (1:100, 000 and 1:25, 000 scales): Lunar Orbiters I, II, and III were used primarily to obtain medium- and high-resolution photography of potential Apollo landing areas near the lunar equator. The extent of medium-resolution photography (8 to 15 m) obtained on these missions is illustrated in figure 3. The extent of high-resolution coverage (1 m) obtained of potential Apollo landing sites is shown in figure 4. Useful maps or photomosaics at a 1:100, 000 scale can be prepared of those areas covered by medium-resolution photography; and useful maps and photomosaics at 1:25, 000 scale can be prepared from those areas covered by high-resolution photography.

It should be realized, however, that these products do not meet conventional map accuracy standards usually imposed on products at these scales. Their utility is limited to those investigations that can be accomplished within the following accuracy.

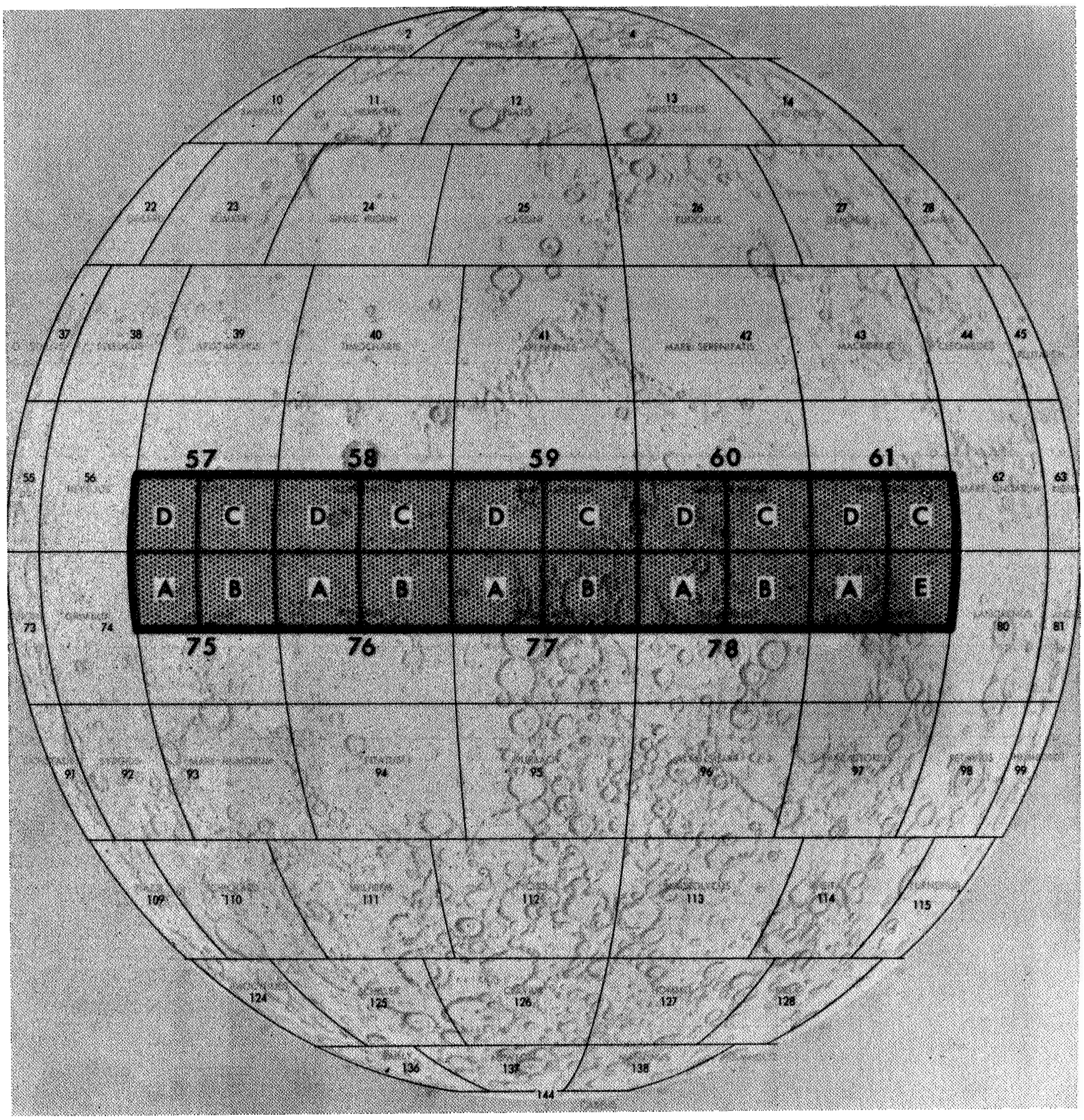
Relative uncertainties of positions and elevations within contiguous mapped areas are approximately 150 and 300 meters, respectively. Uncertainties of elevations with respect to a lunar mass-centered coordinate system are on the order of 500 meters, These uncertainties apply to products at both 1:100, 000 and 1:25, 000 scales since the same photogrammetric data are used in the preparation of both.

Uncontrolled photomosaics (1:100, 000 scale): Uncontrolled photomosaics are produced on a quick-response basis to provide an overall view at a common scale of those areas photographed by the medium-resolution camera. The rectification and scaling of the photography is done by map matching or use of mission photographic data rather than by photogrammetric means. The extent of those photomosaics currently available is shown in figure 5(a).

Uncontrolled photomosaics (1:25, 000 scale): The locations of uncontrolled photomosaics at a 1:25, 000 scale prepared from Lunar Orbiter II high-resolution photography are shown in figure 5(b).

Controlled photomosaics (1:100,000 scale): These controlled mosaics are prepared utilizing the results of photogrammetric triangulation of medium-resolution stereophotography. The current status of these photomosaics is shown in figures 6(a) and 6(b).

Topographic maps (1: 100,000 scale): Contoured topographic maps at a 1:100, 000 scale are currently being produced from Lunar Orbiter I and II medium-resolution stereophotography. The maps will be produced with shaded relief rendition of surface topography. The current status of production of these maps is shown in figure 7(a).



Completed

(Scale 1: 500,000)

Figure 2. - Apollo intermediate chart index, status as of July 1967.

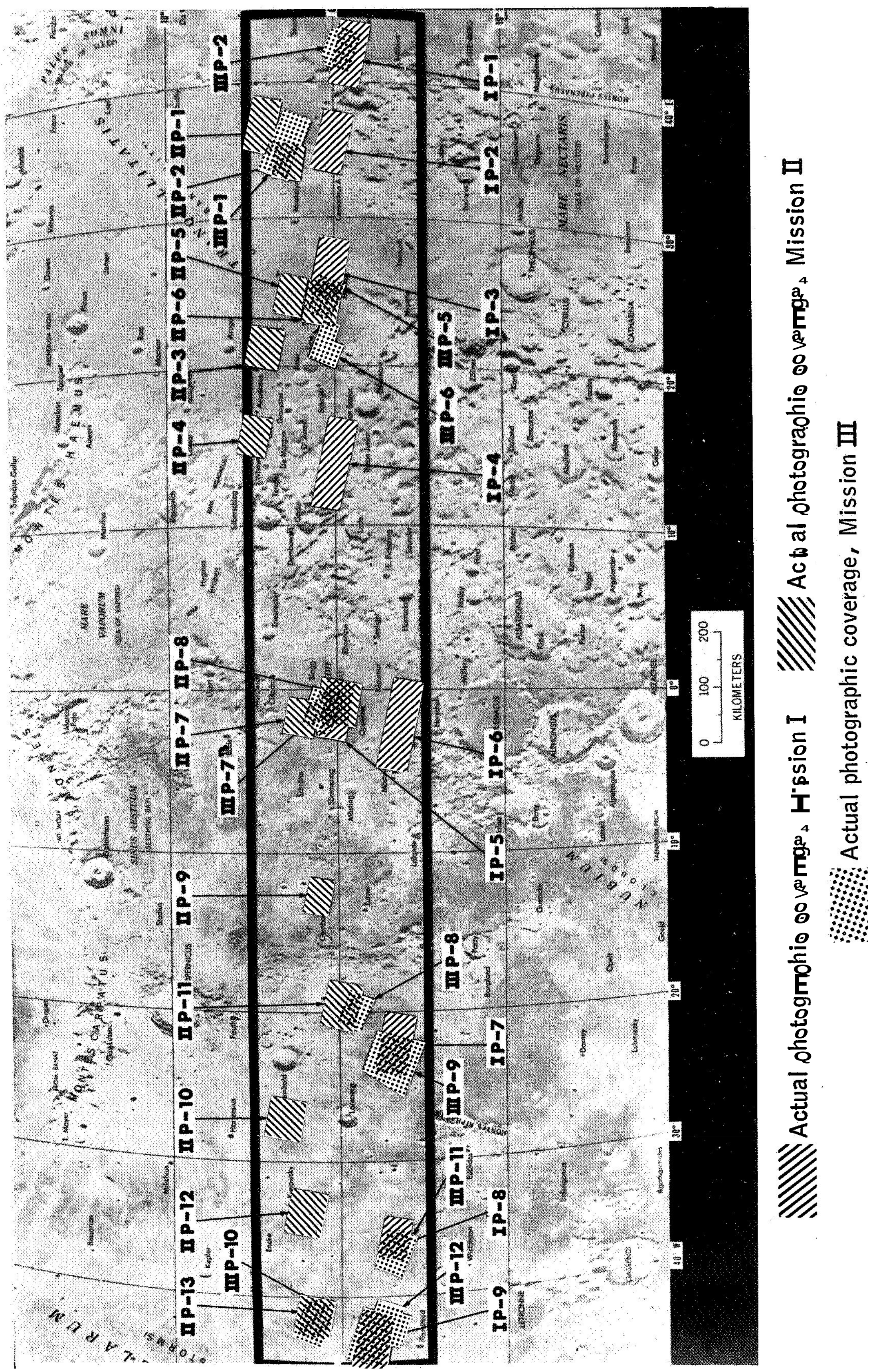


Figure 3. - Sites from Lunar Orbiter Missions I, II, and III.

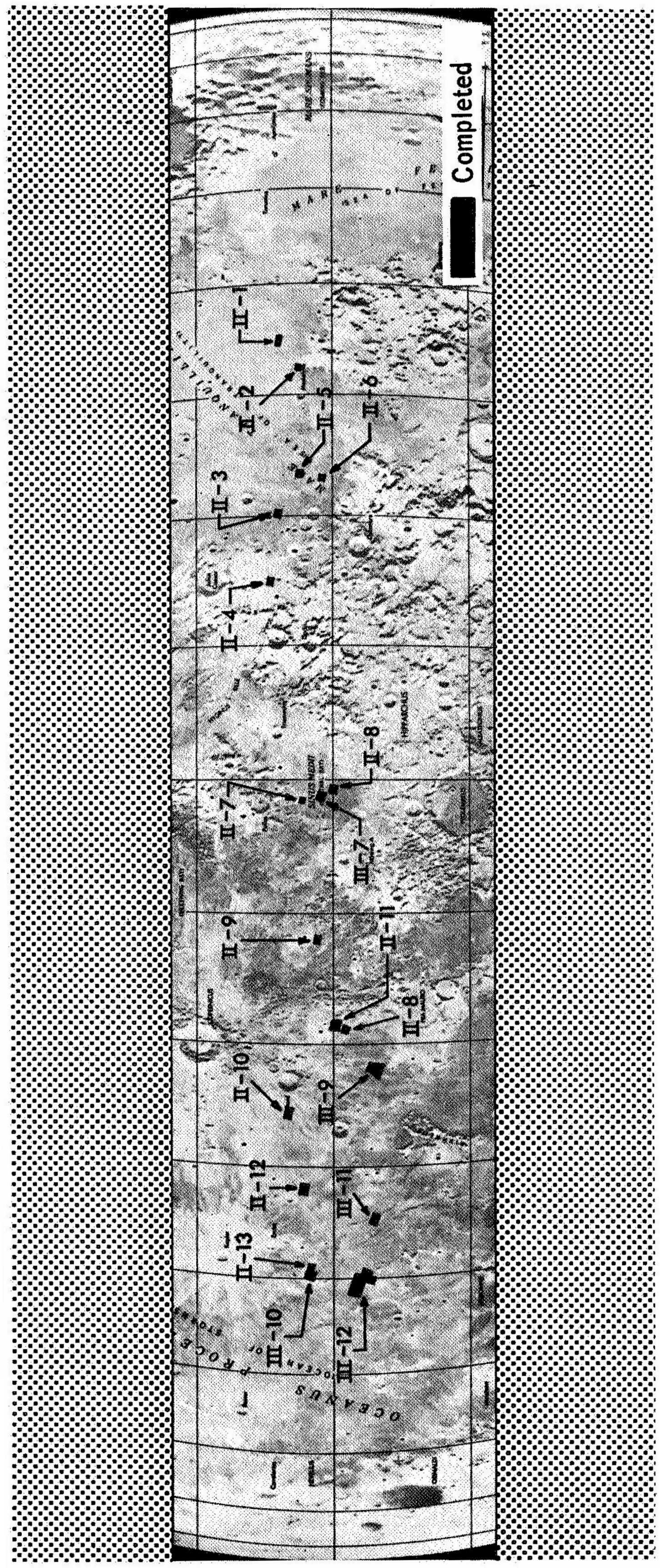
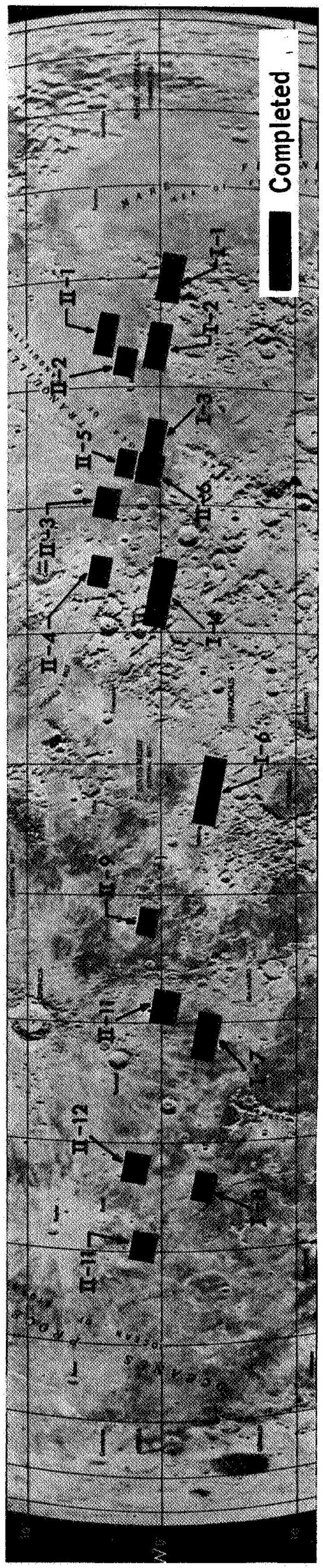
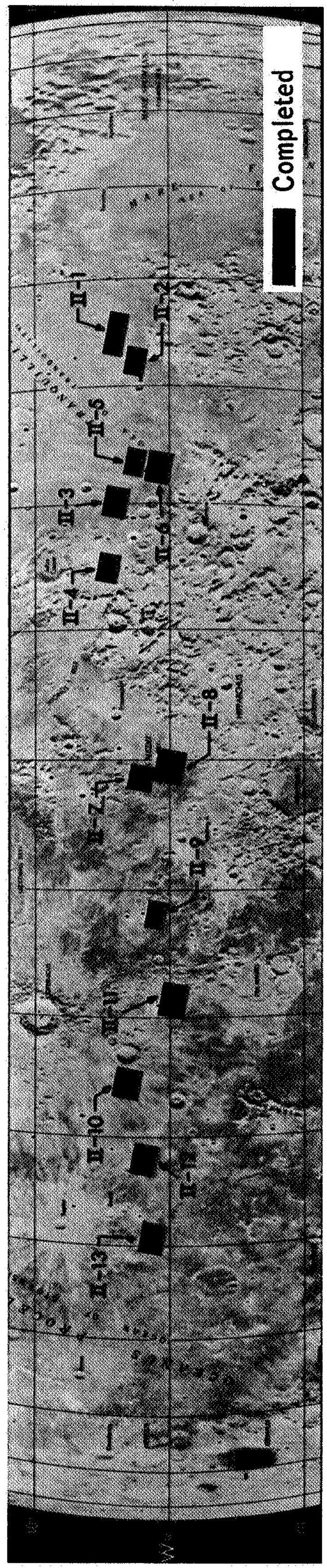


Figure d - High resolution photographic coverage of Apollo landing sites, as of July 1967.

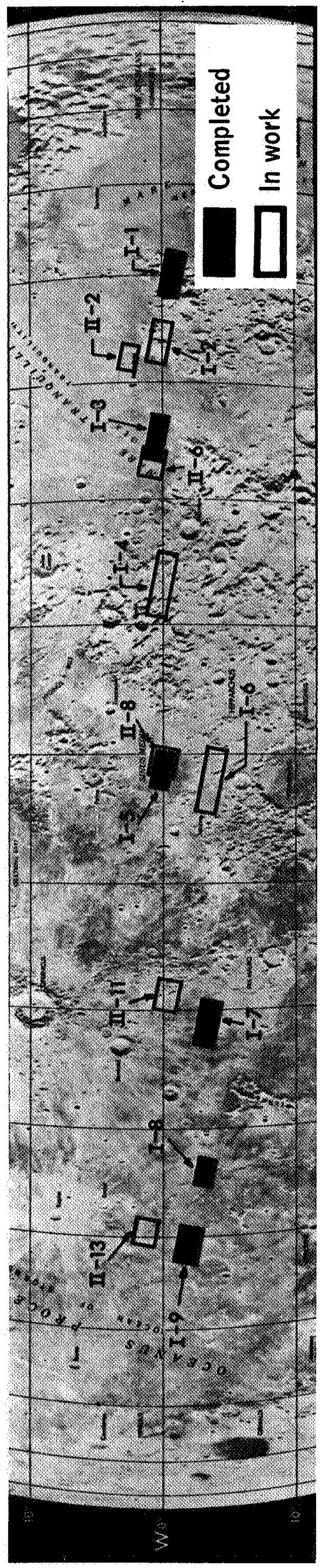


(a) Scale 1:100, 000

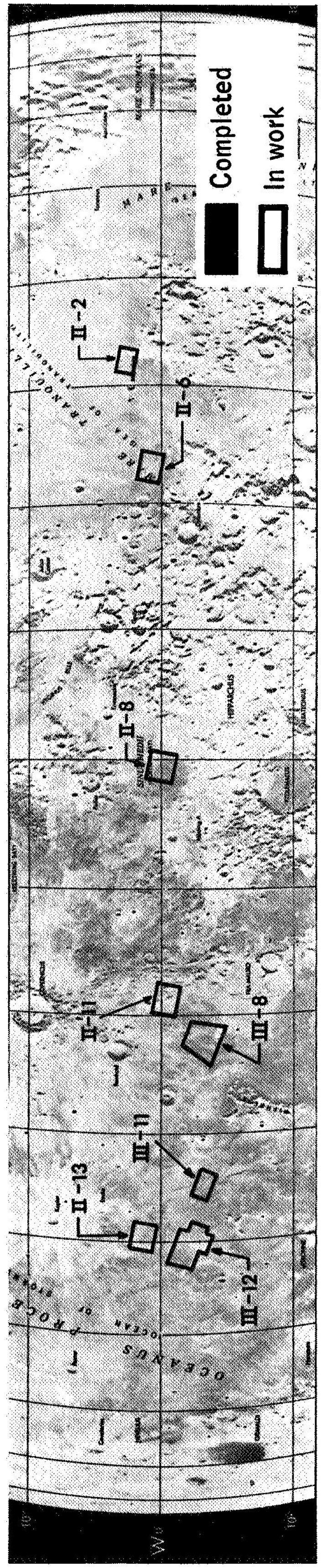


(b) Scale 1:250 000

Figure 5. - Lunar photomosaics (uncontrolled), status as of July 1967.

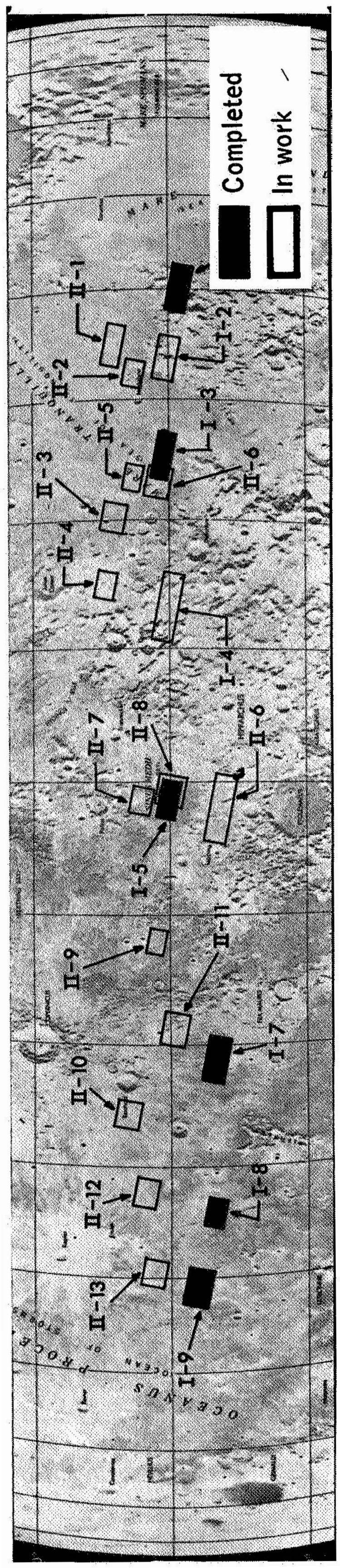


(a] Scale 1: 100, 000

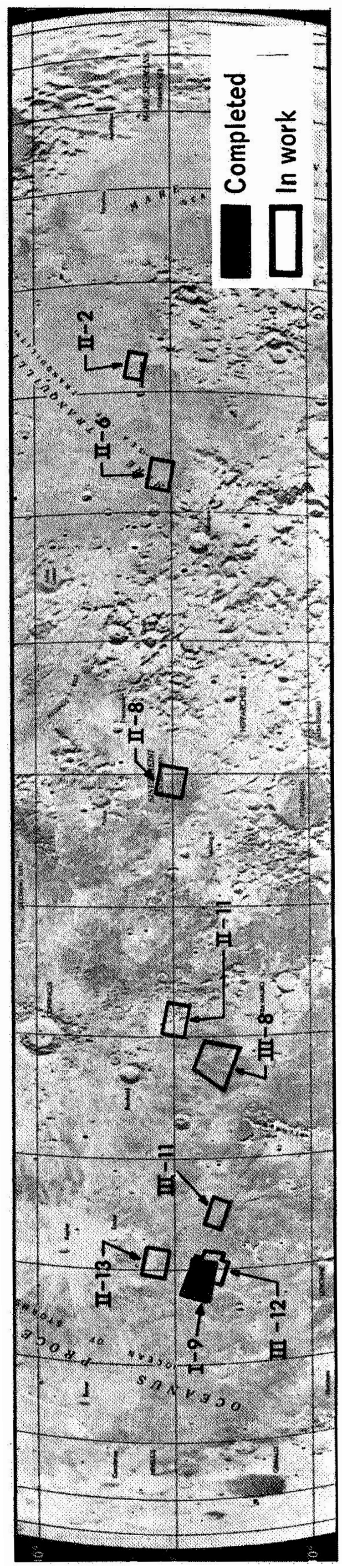


(b) Scale 1: 25, 000

Figure 6. - Lunar photomosaics (controlled), status as of July 1967.



(a) Scale 1: 100, 000



(b) Scale 1: 25, 000

Figure 7. - Lunar maps (TOPO), status as of July 1967.

Topographic maps (1:25, 000 scale): Contoured topographic maps at a 1:25, 000 scale are currently planned for those areas indicated in figure 7(b).

Lunar Orbiter III products: The Lunar Orbiter 111 photography primarily covered areas previously photographed by Lunar Orbiters I and 11 to obtain additional information in potential Apollo landing areas. Studies are currently in progress to determine the degree of improvement that can result from the additional materials.

Lunar Orbiter IV products: Lunar Orbiter IV obtained nearly complete monoscopic coverage of the near side of the Moon at 60- to 100-meter resolution (fig. 8) and nearly complete stereo coverage at 500- to 800-meter resolution. Studies are in progress to determine those useful products that might be prepared from this photography.

Program Plan

Photography from Lunar Orbiters I to V is the only cartographic source material available until the Apollo missions. The following sequence of actions would exploit this material to the limit of its accuracy and content.

1. Study in detail the anomalies of reported camera exposure station positions and determine the best possible exposure station coordinates for all missions.

2. Continue the mensuration for triangulation of all medium-resolution coverage from Missions I, 11, 111, and V; but delay the computations until a final set of exposure station coordinates are available.

3. Complete controlled mosaics at a 1:100, 000 scale from medium-resolution photography and mosaics at a 1:25, 000 scale from high-resolution photography of Missions I, 11, and 111.

4. Evaluate the orbital tracking data as the fundamental control for both mosaics and maps as an alternative to the Department of Defense (DOD) control net based on observations from Earth.

5. Adopt a standard specification for designating contours on the lunar surface maps.

6. Complete the contoured and relief shaded maps at 1:100, 000 and 1:25, 000 scales from the medium- and high-resolution photography from Missions I, 11, and III, according to the best control system and contour specification.

7. Prepare controlled mosaics and contoured, shaded relief maps for the scientific sites photographed by Orbiter V. The anticipated resolution from the medium-resolution camera is compatible with scales of 1:250, 000 to 1:1, 000, 000 and from the high-resolution camera with scales of 1:50, 000 to 1:250, 000.

8. Determine the feasibility of compiling orthophotographic maps from medium-resolution Orbiter photographs.

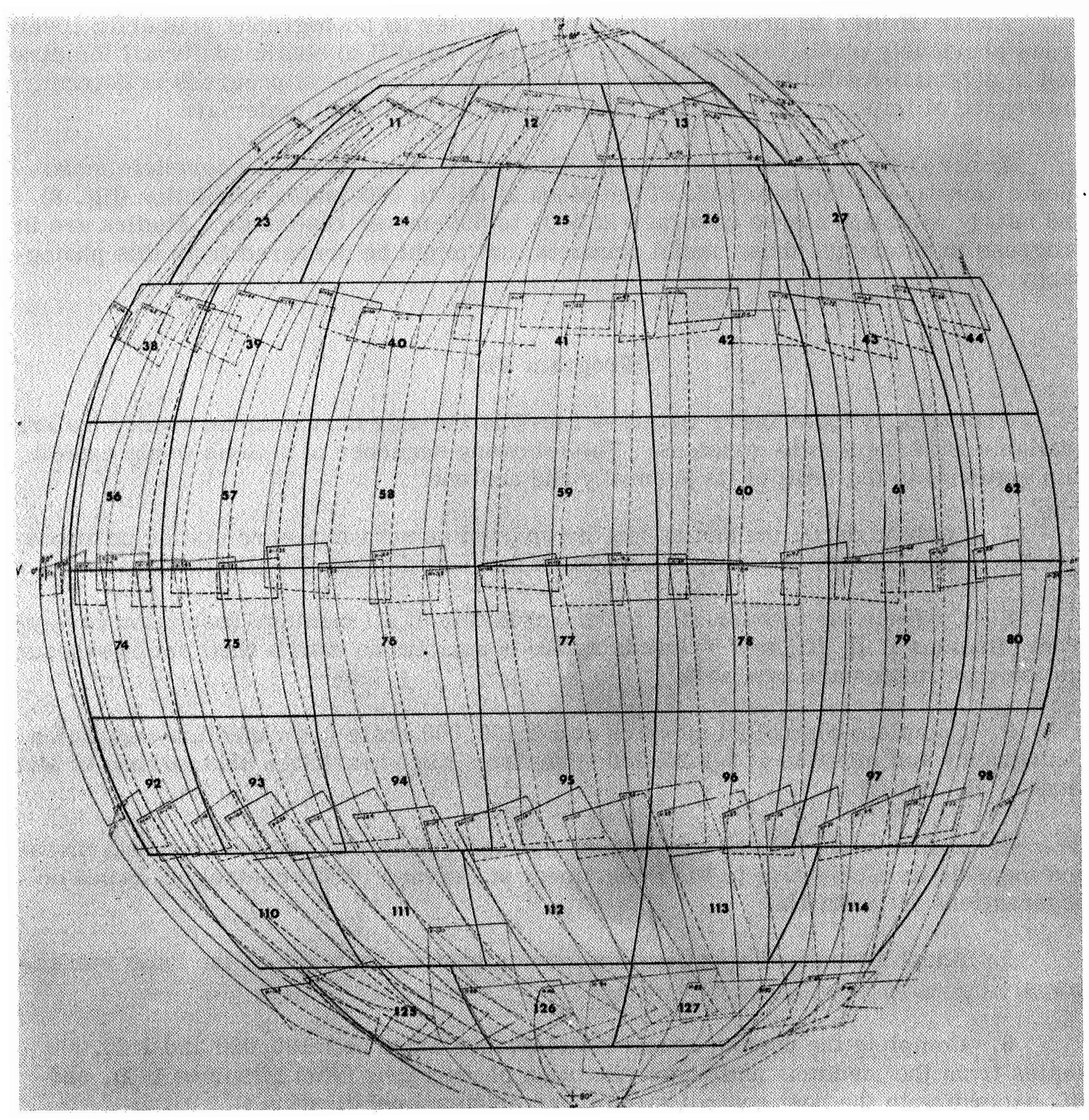


Figure 8. - Lunar Orbiter IV earthside high resolution photography keyed to LM *lk.*

9. Prepare a photographic atlas of all Orbiter IV and V far-side photographs. The medium-resolution photography should be published at the scale of the specialized ground reproduction equipment for the Lunar Orbiter program; the high-resolution photography should be brought to standard scales of 1:4,000,000 on the front side and 1:8,000,000 or 1:10,000,000 on the far side.

10. Establish the feasibility and accuracy obtainable in triangulating a lunar surface control network from either or both the medium- and high-resolution far-side photography of Orbiters IV and V. If an accuracy of 500 to 1000 meters in planimetric position is possible, then compute such a control network.

11. If the control network proves feasible, prepare controlled photomosaics at a 1:2,500,000 scale from Mission IV high-resolution near-side photographs and mosaics at a 1:5,000,000 scale of the far side from Missions IV and V.

Geodetic Camera Systems

The Working Group has reviewed a number of feasible camera systems which would more nearly satisfy both a geodetic requirement for 10-meter positional accuracy and the cartographic requirement for synoptic maps of the entire lunar surface and accurately positioned maps for detailed study sites. All candidate systems were carefully reviewed in terms of their mensurational capability, orbit restraints, number of photographs produced, film weight required, and so forth. Two alternate vertical camera systems emerged: a 12-inch-focal-length system and 6-inch-focal-length system. The characteristics of these systems are presented in table I:

TABLE I.- CHARACTERISTICS OF THE GEODETIC CAMERA SYSTEMS

Item	6-inch system	12-inch system
Focal length, mm	152	305
Format (length times width), mm	230 × 230	370 × 230
Overlap along flight, percent	55	55
Orbit altitude, km	93	93
Lens-film resolutian, mm	0.018	0.020
Photograph scale	1:612,000	1:306,000
Lunar surface resolution, m	10	6
Stereo model (length times width), km	63 × 140	50 × 70
Position accuracy, m	17	8
Elevation accuracy, m	18	11
Content for map scale	1:100,000	1:50,000
Control for map scale	1:50,000	1:25,000
Contour interval obtainable, m	50	30
Frames for 100-percent coverage	6000	14 700
Film weight for 100-percent coverage, lb	82	322

Either system requires two stellar cameras of 6-inch focal length, 60- by 60-millimeter format on 70-millimeter roll film, and a 76-millimeter aperture. The two stellar cameras together would consume 14 pounds of film in support of the 6-inch metric camera or 34 pounds in support of the 12-inch camera. In addition, a vehicle clock capable of being related to ephemeris time with an accuracy of 0.001 second is required. Finally a pulsed laser altimeter capable of ±2.5-meter accuracy is required. The clock and altimeter readings should be synchronized with the camera exposure and should be recorded in a data block on the film.

In view of the weight of film required, particularly for the 12-inch camera system, there is a natural inclination to suggest that the photography be transmitted back to Earth rather than physically returned. The Geodesy and Cartography Working Group is opposed to photograph transmission as a substitute for physical return. Experience with the Lunar Orbiter photography has demonstrated that while resolution may be maintained through transmission, geometric integrity is seriously degraded. All three organizations measuring Orbiter II photographs have achieved no better than 0.030-millimeter standard error in recovering the coordinates of images on the Orbiter photography; this is compared with the 0.005-millimeter standard error customarily obtained in comparable measurements of the actual film. This means that to obtain comparable precision in ground dimensions, the scale of the photography would have to be increased by a factor of 6 which would impose impractical focal lengths and film formats. Extremely low altitudes with a consequent increase (36 times) in the number of photographs would alternatively be required. In addition to the gross decrease in mensuration ability, the division of the record into a large number of scanned segments imposes a tremendous problem in data reduction. In the triangulation of a single 16-photograph strip of Lunar Orbiter photographs, it has been found necessary to make over 12 000 separate point-coordinate measurements to remove the nonlinearities caused by the transmission system, to tie the individual framelets together in a unified photograph frame, and to provide the required geometrical distribution. This is to be compared with approximately 400 point measurements which would be the maximum required on the same number of recovered photographs, yielding a sixfold improvement in accuracy.

Site Evaluation Camera System

The 93-kilometer circular polar orbit is optimum for normal field-of-view cameras to provide continuous coverage at the lunar equator to obtain complete Moon photography in a 28-day mission with a minimum number of photographs. At this altitude, consecutive orbital passes are approximately 33 kilometers apart as they cross the equator.

For a site evaluation camera to have the capability of photographing a location anywhere on the surface of the Moon, it should have a lateral coverage of at least 33 kilometers. This dimension is also compatible with the size of area required for operations on the lunar surface. It may be noted that even at zero altitude, the equatorial motion is still 30.5 km/orbit, so that any camera system must be able to cover at least 31 kilometers if it is to be capable of photographing any location within a single 28-day mission.

It is considered most desirable to obtain the site evaluation photography from the same mission which acquires the geodetic and synoptic photography. Two twin convergent camera systems which probably could be developed to accomplish this are listed in table II.

TABLE II. - CHARACTERISTICS OF THE TWO CAMERAS USED IN SITE EVALUATION

Characteristics	Frame system	Panoramic systems
Focal length, mm	600	600
Format (length and width), mm	115 x 230	115 × 230
Panoramic sweep angle, deg	--	22
Altitude, km	93	93
Camera tilts, deg	± 20	± 20
Total convergence, deg	40	40
Nominal photo scale	1:156,000	1:156,000
Overlap, percent	100	100
Lens-film resolution (static), mm	0.010	0.007
Lunar surface resolution,[a] m	1.9	1.2
Stereo model (length times width), km	19.5 × 36	19.5 × 36
Position accuracy, m	0.8	2.0
Elevation accuracy, m	1.0	1.0
Number of exposures per site	16	16
Film weight per site, lb	0.122	0.122

[a]Assuming 25-percent degradation due to dynamic response.

The fundamental difference between these systems is that the panoramic cameras can provide higher ground resolution at the expense of positional accuracy and increased complexity of camera and data reduction equipment.

A third alternative is to fly a 600-millimeter panoramic system at a nominal altitude of 50 kilometers. The panoramic sweep angle would need to be increased to

40° (which is feasible) to provide the capability of obtaining site photography anywhere on the Moon in a single 28-day mission. The surface resolution would be increased to about 0.6 meter, and the ability to discriminate elevation differences would be increased to about the same number. The disadvantage is that the system would not be flown at the optimum altitude for the geodetic synoptic photography.

Recommendations

1. It is recommended that work begin immediately to space harden a 6-inch-focal-length metric mapping camera system for lunar use. Little, if any, development is required: only minor modifications to the workhorse mapping camera that has been in use more than 20 years and the adaptation of cameras for stellar photography.

2. It is recommended that development be initiated to provide the 12-inch-focal-length metric mapping camera desired to yield ultimate lunar positional accuracies of 10 meters.

3. It is recommended that cameras in the lunar orbiting CM on early Apollo flights be thoroughly calibrated and of metric quality. Stereophotography obtained from lunar orbit can then be reduced photogrammetrically and, hopefully, provide early improvement in our knowledge of the shape of the Moon.

4. It is recommended that the capability for laser altimetry from lunar-orbital satellites be vigorously developed. Altitude measurements and orbital photography can improve our knowledge of the size of the Moon and provide an independent check on the data obtained from orbit determination programs.

5. It is recommended that development of a 24-inch, convergent, panoramic camera system be studied as a means of obtaining high-resolution photography of potential exploration areas. The advantages and disadvantages of this approach should be weighed against a 24-inch (Lunar Orbiter type) convergent frame camera.

SUMMARY AND RECOMMENDATIONS

Principal Recommendations

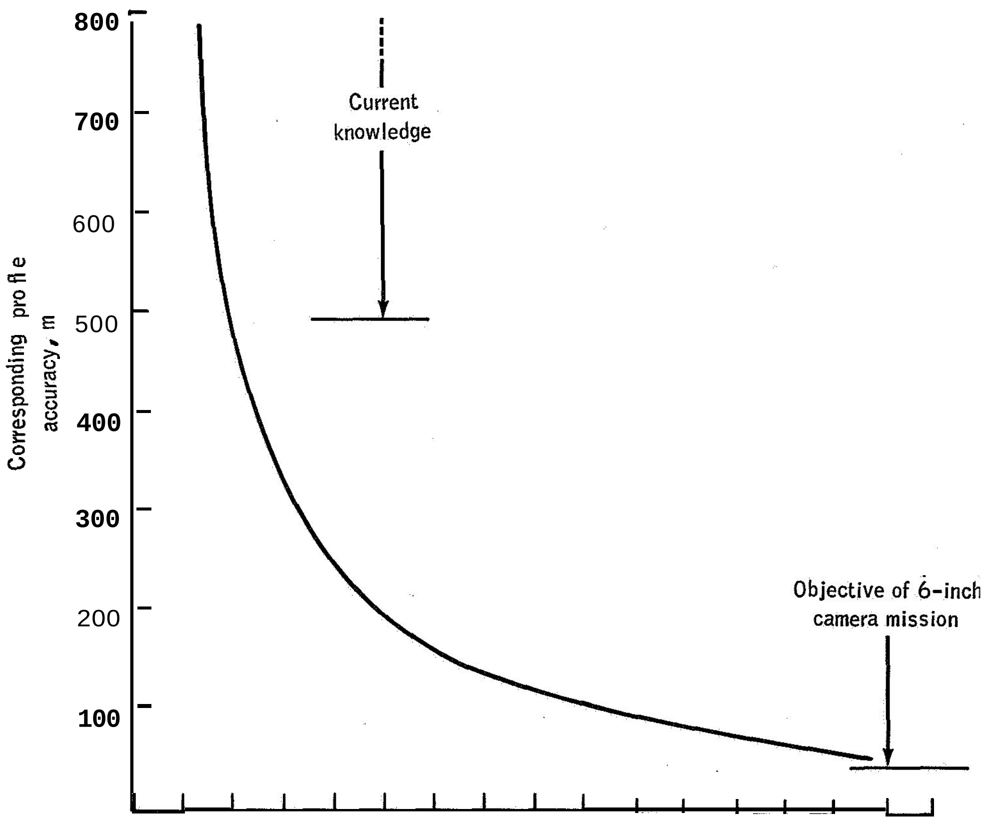
Further improvement of the lunar ephemeris is an important objective which should be pursued. Radio tracking of Lunar Orbiters is presently the best source of data. Laser ranging to reflectors on the lunar surface will become important, and implementation of this technique should continue with high priority. The use of radio transponders placed on the lunar surface should also continue. Independent clock radio interferometry between distant radio telescopes on the Earth is a very promising but unproven new concept for accurately measuring angles to radio transmitters on the lunar surface; this should be investigated in depth as soon as possible and implemented when practical.

The motion of the Moon about its center of mass should be measured by the same ground instruments and lunar surface aids which are used to determine the ephemeris.

Adaptation of independent radio interferometry is particularly important for this objective. Lunar orientation determined during photographic missions by Lunar Orbiters may provide a valuable spot check of continuing measurements from Earth.

Determination of the gravitational field of the Moon should continue beyond the present (5, 5) spherical harmonic representation, with a (15, 15) representation as an objective by 1975. Further radio tracking of Lunar Orbiters in different inclinations is a proven technique which is certain to yield improved results. Consideration of this objective should be important in mission planning *so* that adequate orbital intervals are obtained unperturbed by spacecraft maneuvers and so that appropriate ground tracking is scheduled. If orbiters for other missions do not provide the necessary diversity of orbit inclinations, simple subsatellites for this purpose should be launched from Apollo Applications Program missions. The development of laser tracking techniques for Lunar Orbiters should be undertaken particularly to insure tracking over many years. A gravity gradiometer, if proved feasible, may allow measurement of very short wavelength lateral variations of the gravity field.

The most serious deficiency in available knowledge of the lunar surface profile is adequate geodetic control over the total Moon or major fractions thereof (fig. 9).



To remove this deficiency, a metric camera should be flown in a 28-day polar mission around the Moon and the film returned to Earth. A long-focal-length camera should also be carried as a complementary system to obtain high-resolution photographs of selected areas of scientific or operational interest. A laser altimeter should be developed for lunar applications either as an auxiliary instrument with the camera systems or for independent use.

Summary Charts

Tables III, IV, and V summarize geodetic and cartographic objectives and the instrumentation which might be used to achieve them.

Recommended Supporting Research and Technology

It is recommended that vigorous research and development programs be conducted on the following items in support of geodetic and cartographic science:

1. Lightweight, highly reflective, omnidirectional retroreflector arrays to be deployed in lunar orbits

2. Small, long-lived radio transponders/transmitters to be deployed in lunar orbits

3. Small, long-lived radio transmitters to be deployed on the lunar surface

4. Gravity gradiometer for use in lunar orbit

TABLE III. - SYSTEMS TO MEASURE THE LUNAR EPHEMERIS, ORIENTATION, AND LIBRATIONS

System	Instrument at the Moon	Ephemeris	Orientation and libration	Advantages	
Laser ranging	3 retroreflectors on the Moon	Present, 100 m Easily, 10 m Ultimate, 1 to 0.1 m	Present, 20" of arc (200 m) Easily, 1" of arc (10 m) Ultimate, 0.1" to 0.01" of arc (1 to 0.1 m)	Passive Long lived Under development Approved experiment High ultimate yield	
Radio transponder	3 transponders on the Moon	Easily, 10 m Ultimate, 1 m	Easily, 1" of arc (10 m) Ultimate, 0.1" of arc (1 m)	Easy adaptation of existing systems Ground stations exist	Limited life or extra weight to survive lunar night
Independent radio interferometry	Transponders on the Moon	Present, 0.1" of arc (200 m) ultimate, 0.01" of ar (20 m)	Present, 200 m Ultimate, 20 m	Easy adaptation of existing systems	Lunar landing required
Celestial reference (pole)	Camera on the Moon		Present, 30" of arc (200 m) Easily, 5" of arc (40 m) Ultimate, 1" of arc (8 m)	Direct measurement	Manned landing required Development required
Orbiting camera system	2 cameras in orbit around the Moon		Easily, 10" of arc (80 m)	Combines with other missions No landing needed	Development required

TABLE IV. - SYSTEMS FOR DETERMINATION OF THE GRAVITATIONAL FIELD OF THE MOON

Method	Instrument	Objectives	Advantages	Disadvantages
Radio tracking from Earth-based facilities (no transponder on Moon)	Transponders (Doppler and range) in lunar satellites (semimajor axis, 2000 km; equatorial and polar orbits)	Immediate: Precise coefficients through $C_{5,5}$ and $S_{5,5}$	Proven method Existing spacecraft and ground instrumentation	Requires a number of satellites to be launched and tracked
	(Approximately 4 additional inclinations in range 80° to 75°)	Intermediate: coefficients through $C_{10,10}$ and $S_{10,10}$		
	(Approximately 4 additional inclinations in same range)	Ultimate: coefficients through $C_{15,15}$ and $S_{15,15}$		
Laser tracking from Earth-based facilities	Laser retroflectors on lunar satellites (inclination and semimajor axis requirements as above)	Ultimate: coefficients through $C_{15,15}$ and $S_{15,15}$	Passive, easily instrumented, long lived Independent ground tracking systems	Possible problem of initial acquisition
Radio tracking from Earth-based facilities (transponders on Moon)	Doppler and range transponders on lunar surface (3 minimum, 10 desired and in lunar satellites	Ultimate: coefficients through $C_{15,15}$ and $S_{15,15}$ Position of points on lunar surface: present, 1000 m easily, 100 m ultimate, 10 m	Provides diversity of tracking geometry May reduce number of satellites required Ranging helps separate effects of lunar ephemeris and aids in measurement of lunar librations	Requires development of surface systems, which must operate for 1 to several months
Gravity gradient	Gradiometer on lunar satellite	Higher harmonics of gravity field; detailed field to 200 km in scale (perhaps as good as 5- to 10-km scale)		Must be developed Requires specially stabilized spacecraft
Surface gravimetry	Gravity meter on surface and on traverse vehicles	Detailed gravity in limited locations; confirmation of gravity gradient measurements		Need to cover large areas for confirmation of and correlation with satellite gravimetry

TABLE V. - SYSTEMS TO MEASURE THE SIZE AND SHAPE OF THE TOPOGRAPHIC SURFACE OF THE MOON

(a) Geodetic frame camera

Focal length, in.	Surface resolution, m	$\left(\sigma x^2 + \sigma y^2\right)^{1/2}$, m	σh, m	Map content	Map control	Contour interval, m	Frames for 100-percent coverage	Film weight, 100-percent coverage, lb
12	6	8	11	1:50,000	1:25,000	30	14 700	32
6	10	17	18	1:100,000	1:50,000	50	6 000	8

(b) Twin convergent panoramic cameras

Focal length, mm	Surface resolution, m	$\left(\sigma x^2 + \sigma y^2\right)^{1/2}$, m	σh, m	Nominal photoscale	Exposures per site	Film weight per site, lb
600	1.2	2.0	1.0	1:156,000	16	0.122

(c) Stellar camera (two required)

Focal length, in.	Format, mm	Aperture, mm	σ roll, in.	σ pitch, in.	σ yaw, in.	Film weight	Film weight
6	60 × 60	76	3	15	3	14 lb required for 12 000 exposures if used with 6-in. geodetic camera	34 lb required for 29 400 exposures if used with 12-in. geodetic camera

APPENDIX

REQUIREMENTS FOR LUNAR SATELLITE GRAVITY GRADIOMETER

The accuracy of 25×10^{-10} gal/cm for a smoothing time of 300 seconds stated in the 1965 NASA Falmouth Report[1] was based on a single consideration: that the minimum accuracy acceptable should be that which enables comparison of the field obtained from the gradiometer with that obtained from orbital perturbations.

The comparison criterion permits a rather long smoothing time. However, for application to geophysical problems, obviously as short a smoothing time as practicable is desirable. This smoothing time would be essentially the orbital time corresponding to the smoothing distance unavoidable because of the altitude of the satellites.

Assume for convenience that this smoothing distance is 30 kilometers, or 1" of arc; the corresponding smoothing time is about 18 seconds.

The rms gravity anomaly change in 1" of arc on Earth is about 522 milligals. If the small-scale gravity anomalies on the Moon have the same ratio to those predicted from the Earth by equal stress implication as the low-degree harmonics determined from Orbiters, they will be about four times as great. Gravity anomaly change per kilometer will then also be about four times as great, or about ±90 milligals/30 km, equivalent to a gradient of about $\pm 3 \times 10^{-8}$ gal/cm.

Assuming that the error should not be more than about one-fifteenth of the quantity measured, an accuracy of $\pm 2 \times 10^{-9}$ gal/cm for a smoothing time of 15 seconds seems appropriate.

Feasibility studies since 1965 indicate that the desired accuracies have a reasonable hope of attainment only if the satellite is unmanned and maintained in an inertial orientation.

A more intensive development effort, including hardware experimentation on the two or three most promising techniques, should be undertaken as soon as practicable.

To distinguish anomalous variations in the vertical gradient from the central term, the accuracy of knowledge of the radial coordinate of the satellite needs to be ±10 meters.

The orbit should be at minimum safe altitude (approximately 30 km) and at the lowest inclination covering all areas to be covered by geophysical traverses of more than 50 kilometers extent.

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[1]Results of the conference were published as NASA 1965 Summer Conference on Lunar Exploration and Science. NASA SP-88, 1965, pp. 66-67.

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CHAPTER 8

REPORT OF
LUNAR ATMOSPHERES WORKING GROUP

TABLE OF CONTENTS

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INTRODUCTION

Although the lunar atmosphere is known to be exceedingly tenuous, knowledge of its density and composition should provide valuable information concerning the lunar interior chemistry and radioactivity, the possible volcanic processes, and the chemical and isotopic compositions of the solar wind. Because the lunar atmosphere is so tenuous, it is particularly susceptible to contamination from flight operations, which could confuse, or even destroy irrevocably, the record accumulated during the existence of the Moon. It is, therefore, imperative that atmospheric observations be made as early as possible in the lunar exploration program.

So far, only upper limits of the lunar atmosphere density have been established by various observational methods, differing significantly in sensitivity. While optical measurements indicate a density less than 10^{-6} that of the atmosphere of the Earth, a more stringent upper limit has been set by the observation of radio star occultations. This method allows the electron concentration to be deduced from the refractive index of the lunar ionosphere. Early measurements of this type lead to estimated electron concentrations and, therefore, to ion concentrations not in excess of 10^3 cm^{-3}. The neutral gas densities may be inferred from these results, if the degree of ionization prevailing in the lunar atmosphere can be assessed. Earlier estimates of 10^{-3} for this ratio, based upon the degree of ionization at the peak of the terrestrial ionosphere, lead to very low estimates of the lunar atmospheric density, 10^6 cm^{-3}.

The estimates appear unrealistic since the rapid loss of ions by surface neutralization and solar-wind sweeping may reduce the degree of ionization by orders of magnitude. For a steady ionosphere, an ionization rate of about 3×10^{-7} sec^{-1}, with a time of approximately 3×10^2 sec between collisions with the surface, gives a fractional ionization of 10^{-4}. If the solar wind impinges directly onto the lunar surface, the ions will be rapidly swept back to the surface, further reducing the degree of ionization to approximately 10^{-8}, Using a recently obtained upper limit for the lunar ionosphere electron concentration of 20 cm^{-3} implies a neutral gas density upper limit of 10^5 cm^{-3} for a fractional ionization of 10^{-4}, and 10^9 cm^{-3} for a fractional ionization of 10^{-8}. Thus, the surface pressure may be lower than 10^{-11} torr and the total mass of the atmosphere lower than 100 metric tons.

POSSIBLE SOURCES OF LUNAR ATMOSPHERE

There are several possible sources that could contribute to the lunar atmosphere.

Residual Original Atmosphere

No realistic statements can be made on the composition and abundance of a possible primitive lunar atmosphere. But whatever the composition may have been, light and moderately light gases, including argon, must have long *ago* been depleted from the lunar atmosphere by thermal escape, even though the surface temperature of the Moon was no higher than at present. Constituents (xenon and krypton) which are too heavy to be removed by thermal escape may be subject to removal by other mechanisms, such as interaction with the solar wind. Consequently, the residual primitive atmosphere cannot be regarded a likely constituent of the present lunar atmosphere.

Volcanism and Release of Gases From Rocks and Magma

Such gases as noble gases, water, carbon monoxide, carbon dioxide, sulfur dioxide, hydrogen sulfide, and ammonia may be continually or intermittently released by lunar volcanism and from rocks and magma. So far, observations indicate that about three visible events which can be interpreted as gas release from the Moon occur each year. The molecular gases can be broken down photochemically, which will increase the number of possibilities. The lighter components should escape fairly quickly. No quantitative estimates can be made at this time.

Solar-Wind Accretion

The solar wind should contribute to the lunar atmosphere, but the magnitude of the effect depends upon the degree to which the solar wind actually impinges on the lunar surface and upon the degree to which the flow can be deviated (by magnetic fields) so that it does not strike the surface. If the solar wind impinges directly on the lunar surface, as appears likely from observations by the anchored interplanetary monitoring platform (AIMP) (Explorer 35), an input of about 50 g/sec (4 tons/day) is contributed to the lunar atmosphere. The input of gases heavier than helium would be about 0.5 g/sec, on the assumption that the composition for the solar wind is the same as that for the solar surface. However, the assumption may not be valid.

Meteoric Volatilization

The impact of meteorites on the lunar surface will vaporize meteoritic and lunar surface material, each event creating a transitory contribution to the atmosphere. The high frequency of impacts makes this source a relatively steady one. The source strength is not likely to exceed a steady input into the atmosphere of 3 g/sec. Infrequent comet impacts can deposit large quantities of volatiles on the lunar surface.

Meteoric gas sources, as well as some volcanic sources, might best be identified in conjunction with seismic data. To distinguish between such localized sources, as well as to locate these sources, it is important to conduct simultaneous atmospheric and seismic measurements.

ESCAPE TIMES IN THE LUNAR ATMOSPHERE

The steady-state concentration of various atmospheric constituents is determined by rates of supply and by rates of escape. It is important, therefore, to know the escape time with some certainty. Several escape mechanisms have been suggested, with widely varying rates. The best known is the thermal escape, first discussed by Jeans. For atoms of low mass number (<25), the thermal escape mechanism gives a useful upper limit to the escape time, which becomes increasingly unrealistic for higher mass numbers because of more rapid escape by other mechanisms.

In addition to thermal escape from the gravitational field of the Moon, the escape of atoms which have gained kinetic energy in collisions with solar-wind ions and a variety of ionic escape mechanisms must be considered. Because of uncertain assumptions, the escape times are quite difficult to estimate and it is important to devise an experiment to measure escape time. It is likely, however, that thermal escape dominates for the lightest gases (certainly for H and He), while ionic escape may be the fastest for the heaviest gases, such as krypton and xenon.

ESTIMATES OF CONCENTRATION

For planning purposes, it is useful to develop lower limits for atmospheric densities based only on solar-wind input, to neglect other inputs, and to use best estimates on escape. The near-surface concentration for the i^{th} species is given by $N_i = \frac{J_i T_i}{4H_i}$ where T_i is lifetime on the Moon and H_i is the scale height (table I). The solar-wind flux J_i is calculated using the table of solar abundances by Aller.

Owing to the weak lunar gravity, an upward flux of hydrogen and helium should be flowing away from the surface at the densities indicated in table I. Measurements from a lunar orbiter could verify the existence of such a flow.

The ion concentration can be estimated by comparing the rate of ionization of the neutral atoms, through the processes of photoionization and charge exchange, with the rate of ion removal by recombination (mainly on the lunar surface) and by ionic escape.

Even though the thermal ion density is believed to be very low, it should nevertheless be measured. The appropriate instrument is an ion mass spectrometer. The most useful location would be near the lunar equator. The most interesting measurements relate to the difference between the illuminated and dark side of the Moon and to

TABLE I - PARAMETERS AND CONCENTRATIONS FOR ATMOSPHERIC CONSTITUENTS

Parameter	Gases					
	Hydrogen	Helium	Neon	Argon	Krypton	Xenon
Scale height, cm	2×10^{8}	5×10^{7}	10^{7}	5×10^{6}	2.5×10^{6}	1.5×10^{5}
Thermal escape, 400° K; lifetime, yr	–	–	42	10^{8}	10^{24}	10^{41}
Best estimate lifetime, sec	1.4×10^{3}	10^{4}	10^{7}	10^{7}	10^{7}	2×10^{7}
Solar-wind input flux, cm^{-2} sec^{-1}	3×10^{8}	3×10^{7}	1.5×10^{5}	2×10^{3}	4×10^{-1}	3×10^{-2}
Surface concentration, cm^{-3} . . .	4×10^{3}	6.0×10^{3}	1.6×10^{5}	4×10^{3}	6×10^{-1}	4×10^{-1}

a possible enhancement in the vicinity of the terminator. The thermal ion measurements should be correlated with those of suprathermal ions and with measurements of the magnetic fields.

CONTAMINATION RESULTING FROM LUNAR EXPLORATION

Manned and unmanned exploration of the Moon will contribute significant sources of contamination to the lunar atmosphere and surface. In view of the small total atmospheric mass (perhaps as small as 100 metric tons), the foreign materials introduced in a single mission will amount to a significant fraction of the ambient atmosphere on either manned or unmanned missions. The amount of gas released during a Surveyor landing is approximately 0.5 ton, while the command and service module/lunar module (CSM/LM) combination dumps approximately 20 tons of gas into the lunar atmosphere. The contamination takes place on a lunar scale and on a local scale near the landing site. The amount of material released locally by systems such as the LM cooling system, fuel venting, and astronaut suit cooling system, and by suit leaks is small compared with the total amount of gas released by the CSM/LM exhaust; however, the proximity of the LM and astronauts to the various measuring instruments intensifies the effect of the contamination on such measurements.

Contamination On A Lunar Scale

The major sources of large-scale contamination are contributed by the exhaust products released during the injection of the CSM/LM into lunar orbit, the LM descent, the LM ascent, and the CSM transearth injection. The major constituents of the exhaust products and their estimated mass fractions are calculated to be as follows: N_2, 0.45; H_2O, 0.31; CO, 0.13; CO_2, 0.079; H_2, 0.013; OH, 0.013; however, the composition of these gases, especially of free radicals, may be modified by various mechanisms during their stay in the lunar atmosphere and by interaction with the surface.

The exhaust exit velocity of the CSM during lunar orbit injection is on the order of magnitude of the lunar escape velocity; hence, it may be expected that a major portion of this gas will escape directly from the lunar atmosphere.

Studies have shown that about 90 percent of the LM descent exhaust will be lost to space. The remaining 10 percent, amounting to about 1 metric ton, will strike the surface and be adsorbed or reemitted after accommodation to the surface temperature.

If the adsorptive properties of the lunar surface are such that all impinging particles are reemitted instantaneously, then diffusion calculations show that in the touchdown region (30 to 300 meters away) during the first 24 hours, H_2O, N_2, CO_2, and CO will contribute partial pressures of 10^{-11} torr (5×10^5 particles cm^{-3}). The compounds NO and OH potentially contribute initial partial pressures of 10^{-12} torr. Other exhaust constituents such as atomic and molecular oxygen will be present in detectable amounts only during the first few hours. Water vapor will remain in detectable

amounts for approximately 2 days, but N_2, CO_2, and CO will remain for approximately 7 days. The atmospheric contamination should also be detectable a considerable distance from the touchdown point, provided molecules are not quickly adsorbed by the lunar surface. For example, 2700 kilometers away from the touchdown point, the partial pressure of molecular nitrogen could increase to a maximum of 3×10^{-13} torr about 28 hours after touchdown.

The results stated were calculated assuming a negligible surface adsorption coefficient. If the surface is assumed to adsorb all impinging particles with no subsequent release, then clearly, no atmospheric contamination will be observed.

Exhaust constituents such as water vapor, carbon monoxide, and hydroxyl ions are likely candidates for surface adsorption, while molecular nitrogen and the noble gases are less likely to be adsorbed. In reality then, the surface near the touchdown will adsorb some fraction of the exhaust gas and exponentially release this gas over a period of time. For example, at the time of LM ascent approximately 0.5 ton of fuel will strike the lunar surface, exposing the Apollo lunar surface experiments package (ALSEP) instrumentation to a dynamic pressure of about 2×10^{-4} torr for about 20 seconds. If only a small fraction (1 percent) of this exhaust is adsorbed on the lunar surface and exponentially released with a time constant of 10^6 sec, detectable amounts of contaminant materials may remain for 10 days.

The injection of the CSM into transearth orbit requires an expenditure of approximately 5 tons of fuel. The resulting exhaust will be almost stationary with respect to the Moon and should fall to the surface. Because this material will be spread over a large portion of the lunar surface, the resulting contamination in the vicinity of the ALSEP will be small compared with the contamination arising from the LM ascent stage.

Local Sources of Contamination

A contamination source of major concern is water vapor expelled from the astronaut pressure suits. The water will contain small amounts of iodine and will be released at a rate of approximately 0.3 gram sec^{-1} from an area of the suit near the back of the neck. At 1 meter from the neck location (approximately the distance to the hands of the astronaut) the expelled water vapor will give rise to a water vapor pressure of about 10^{-4} torr, corresponding to a deposition rate of 1.6×10^{-6} gram sec^{-1} cm^{-2} or about 2 monolayers sec^{-1}. This rate could be significantly reduced by directing the vapor upward and away from the astronaut working area and still further reduced by a supersonic expansion in a rocket nozzle pointed upward.

Less intense deposition can be expected from pressure suit leaks (2.5 milligrams sec^{-1}) and from the LM cooling and fuel venting system. Contamination from the LM systems may, again, be considerably reduced if the water vapor and the fuel are supersonically expanded before expulsion from the LM.

Advanced missions, foreseen in the Apollo Applications Program (AAP), include a variety of roving and flying vehicles. These will certainly contribute to contamination. In the absence of definitive engineering plans, no quantitative statements on the effect of such contamination can be made at this time.

The adsorptive properties and the quantitative features of gaseous diffusion about the lunar surface will be a major consideration for determining the effect of contamination and the course of future investigation of the lunar atmosphere.

Precision measurements conducted on the Moon on the behavior of the existing atmosphere and artificial components (exhaust products or controlled release experiments) should provide a unique overall picture of the surface properties. These measurements should be complemented by an experimental determination of the adsorptive properties of various materials expected to be present on the lunar surface, and theoretical investigations of gaseous diffusion about the lunar surface should be completed as early as possible.

Controlled Sources of Contamination

Numerous questions are certain to arise once lunar atmospheric data are available; for example, certain expected atmospheric constituents may be absent, while other constituents may be observed which are unexpected. Therefore, to understand the detailed behavior of the lunar atmosphere requirements for the release of controlled amounts of specific volatiles must be met. Even in the remote case that no detectable natural atmosphere exists (such as, below ~100 particles cm^{-3}), unique information can be obtained about the surface characteristics by experimental release of volatiles. It seems feasible to design equipment to detect as little as ~10 particles cm^{-3} of a gas, which corresponds to complete dispersal into a temporary atmosphere of only about 1 kilogram of material, regardless of the molecular weight.

INSTRUMENTATION SUITABLE FOR LUNAR ATMOSPHERE STUDIES

The following is a summary of commercially available ionic-type total pressure measuring gages and high-vacuum residual gas analyzers. The devices cited are not flyable, but are indicative of the present state of development. The study involves approximately 50 instruments; while not intended to be complete, such a number should be a reasonable cross section.

Commercial Ionization-Type Total Pressure Gages

All information presented here is predicated upon the statements of the manufacturer and is not intended to imply independent experimental confirmation. As is well known, the Bayard-Alpert gage has a practical limitation of about 10^{-10} torr. There are numerous manufacturers of these devices. Modulation of the ion current arriving

at the collection has been utilized to compensate for the X-ray limit so that pressure measurements in the upper 10^{-12} torr region are possible. Gages claimed to be more sensitive make use of increased ionization path length, removal of thermionic filaments, suppressor grids for minimization of photoelectrons leaving the collector (whatever the cause), or prevention of line-of-sight capability between the source of the ion generation and the ion collector. A commercial version of the Redhead cold-cathode ionization gage has a claimed detection capability of 10^{-13} torr. The helmer gage is comparable to this, according to published statements. A pressure detection limit of 10^{-12} torr is claimed for the Schuemann gage, which uses a photoelectron suppression grid in front of the collector.

Two advances in the present state of the art of ionic total pressure measuring devices should include adaptation of electron multipliers as ion detectors and increased reliability of ionization initiation in cold-cathode magnetron-type gages.

Commercial Residual Gas Analyzers

Since the nature of residual gas analyzers must be such that the ion analyzing device must possess a small volume, a survey was made to evaluate the present state of the art for measuring the composition of the lunar atmosphere. In general, those analyzers using electrometer ion detection are limited to 10^{-10} to 10^{-11} torr partial pressure (N_2), whereas those using electron multipliers are claimed to be capable of 10^{-13} to 10^{-14} torr. A notable exception is the coincidence mass spectrometer wherein an ultimate partial-pressure sensitivity of 10^{-16} torr is claimed. The types of residual gas analyzers that appear most favorable for lunar atmosphere neutral molecule analysis are magnetic deflection, monopole mass filter, quadrupole mass filter, and coincidence mass spectrometers, all of which should utilize electron multipliers for ion detection. The first three types could also be used for ambient thermal ion compositional analysis. A definite need exists for the removal of the thermionic emitter from the ion generation region of the neutral mass spectrometer and for the inclusion of a cold source of ionizing electrons.

In general, the various types of mass spectrum analyzers are not readily scanned from a mass number of 1 to a high mass range without some switching technique. Instruments working on the time-of-flight or monopole-quadrupole principles are an exception to this restriction. In general, a mass spectrometer possessing high sensitivity will have low resolution and slow mass scan.

Miniaturized Mass Spectrometers

Because of the unknown and extremely tenuous nature of the lunar atmosphere, mass spectroscopy appears to be the only method which has the necessary sensitivity and versatility for studying the composition. Various types of mass spectrometers have been used in the laboratory for gas analyses. Included in the list are single- and double-focusing magnetic deflective instruments, time-of-flight instruments, quadrupole and monopole mass filters, omegatrons, and cycloidal magnetic instruments.

Each instrument has special features and strongpoints. Some have been flown in sounding rockets or satellites, and experience has been gained in miniaturizing and ruggedizing the equipment and in returning data to ground by telemetry.

Of the various types proposed for flight applications, the greatest experience has been gained with simple sector magnetic spectrometers. The demonstrated performance of the class of instruments is good enough that, with a minimum of effort, existing models could be adapted for lunar investigation. Some 22 sector magnetic spectrometers have been flown on Aerobee sounding rockets. The results obtained in the early flights and some descriptions of magnetic deflection instruments have been published. Further details and specifications pertaining to the suitability of such instruments for lunar investigations are given in the following discussions.

Ions are produced by bombardment of the gas to be analyzed by electrons emitted from a heated filament. The ions formed are accelerated and directed between the poles of a 90" sector permanent magnet. Mass spectra are obtained by varying the ion accelerating voltage. If a large mass range is to be covered, the range of accelerating voltage required will be excessive. Therefore, it is more convenient to employ two collectors at different radii.

Readings can then be obtained simultaneously for the high and low mass ranges. For example, with instruments of the general type flown, one collector can cover the mass range of 1 to 10 amu while the other covers the range of 10 to 100 amu, as the ion accelerating voltage decreases from 1000 to 100 volts.

In the most recently flown sector magnetic spectrometer instruments, ions are produced by a 100-μA, 75-eV beam of electrons. The main defining slit for ions leaving the source has dimensions of 0.1 by 0.010 inch. The heavy mass-collector slit has a width of 0.050 inch, and the radius of curvature of the ions reaching the heavy mass collector is 1.5 inches. The light mass-collector slit has a somewhat greater width than the heavy mass-collector slit, since only modest resolution is required.

The sensitivity of the instrument is such that for the N_2 mass 28 peak, 3×10^{-5} A/torr reach the final collector. By increasing the electron ionizing current, this sensitivity can be raised by a factor of 10 at the expense of some linearity for pressures above 10^{-5} torr. Since pressures expected at the Moon are far below this figure, an operating sensitivity for N_2 of 10^{-4} A/torr can be safely assumed. Under these conditions, the resolution is such that at mass 50 a peak at one mass number will not contribute more than 1 percent of its intensity at an adjacent mass number. At lower masses the overlap is even more favorable. Hence, a study of the isotopic composition of lunar argon would be entirely feasible. While the resolution decreases with increasing mass, a measurement of approximate isotopic compositions for Kr (as Kr^{+}) and Xe (as Xe^{++}) should be possible. With electrometer tube amplifiers such as are in use today, currents of 10^{-14} A can be detected. Hence, without extensive modifications, partial pressures as low as 10^{-10} torr can be detected with instruments already flown on sounding rockets.

If an electkon multiplier is used as a detector, considerably improved sensitivity can be obtained. As a practical matter, electron multiplier gains of 10^5 or more are reasonable. With a gain of 10^5, currents of 10^{-19} A (approximately 1 ion sec^{-1}) can be detected. For the instrument described, this gain corresponds, in the case of N_2, to a pressure of 10^{-15} torr. The background current for a good multiplier is equivalent to about 1 count sec^{-1} or less. The measurements are not limited to their low current. However, the measurement of currents as low as 1 ion sec^{-1} requires either pulse-counting techniques or sufficiently long integration times to resolve statistical fluctuations.

In practice, the effective sensitivity attainable depends on the time available for a spectral scan. For scan times of a few minutes, it would appear that sensitivities of the order of 10^{-13} or 10^{-14} torr could readily be obtained.

Of practical importance in operating mass spectrometers at high sensitivities is the question of residual impurities in the instruments themselves. Laboratory experience shows that slight traces of CO (mass 28), H_2O (mass 18), and other impurities may remain even after extensive baking and outgassing. The exact amounts of the impurities remaining depend upon the exposure history of the instrument. Accordingly, care must be exercised in applying sensitivity figures to any particular situation.

An instrument constructed along the general lines discussed previously would not weigh over 10 pounds, excluding support structure or thermal control, and would consume less than 10 watts. In spite of the use of magnets, the stray magnetic field in the vicinity can be reduced to low values as the magnetic circuits are nearly closed.

As mentioned at the beginning of this section, many types of mass spectrometers have been used in the laboratory, but the greatest experience with instruments under flight conditions has been obtained with magnetic deflection instruments. Quantitative data are available which make possible an evaluation of the suitability of such instruments for lunar investigations. Among other instruments for which flying experience has been gained and which show promise of meeting the performance characteristics discussed above are the monopole and quadrupole mass filters. Further experience with these or other instruments may show that one of these may be preferable in the long run.

Instrumentation for Subsurface Gas Detection

The finely divided lunar surface materials may hold a great quantity of gas by surface adsorption. In many areas, there is likely to be a steady percolation of gases upward through the lunar rubble. Although the gas that is released at the surface may rapidly escape from the lunar atmosphere, there could be a great quantity of lunar gas below the surface. One means of detecting this gas would be to insert a probe into the loose surface material and mildly agitate or heat the material. The probe could be inserted into suspected vents which may be present in various types of features such as rills or crater bottoms. The gas could be detected by a mass spectrometer, and the results would be of geochemical significance. The upper mass range

of the spectrometer should at least include mass 50, preferably mass 150 if possible.

An example of an instrument would be a 1-meter-long probe of stainless steel that could be provided with an electrically heated (10° to 300° C above ambient) penetrating point that could be removed or opened for above-surface activities. An adjustable opening near the spectrometer end would permit the release of gas if the pressure at the probe tip is greater than 10^{-5} torr, thereby increasing the dynamic range. Total pressure could be indicated by the level of signal in the earphones, while the mass of the major component or a rough spectrum is displayed on the spectrometer package.

The main problem in the use of such a probe would be the high level of contamination, especially of water vapor, near the astronaut. The capacity of the instrument to detect subsurface water vapor would be limited; however, the ability to detect other gases would not be seriously compromised. This problem could be minimized if the water vapor vent on the astronaut's backpack were directed upward and perhaps modestly expanded in a rocket nozzle. Another helpful approach might be to shut off the water release for a few seconds at critical times in the use of the probe.

Another opportunity for the examination of subsurface gas will arise with drilling operations. The lunar drills presently being considered have no provision for gas collection. Measurements of gases from drill holes would be of substantial value in the geochemical understanding of the Moon; therefore, attention should be given to this fact in developing drilling technology.

SITE SELECTION FOR ATMOSPHERIC DETECTORS

Observation of atmospheric fluctuations at a single site would present many ambiguities in interpretation since the ambiguities might arise from fluctuating gas sources, tenuous "winds" driven by surface thermal gradients, equipment malfunctions, et cetera. It is desirable therefore to emplace atmospheric monitors at different sites so that the data can be correlated to check each interpretation. To locate a lunar gas source, for example, the sites should be located in such a way as to allow triangulation on the source; thus, at least three monitoring sites are desirable (preferably four) if the baselines are large (that is, comparable to the lunar radius). The largest gas vent need not be associated with the largest crater or some other prominent feature; thus, triangulation nets of atmospheric monitors are essential to locating such geophysically important sites. It follows that the entire lunar surface should be searched for such gas sources, and therefore stations on the far side will ultimately be required unless the Earth side stations rule out any activity whatsoever.

RECOMMENDATIONS

Supporting Research and Technology Recommendations

The following recommendations are given in order of priority.

Development of high-sensitivity miniaturized mass spectrometers. - As an item of first priority, it is recommended that tests and adaptations of magnetic deflection instruments for lunar investigations be conducted.

As an item of second priority, it is recommended that development and testing of monopole and quadrupole mass filters suitable for lunar atmosphere investigations be encouraged. These instruments have certain features which, in the long run, may make them as desirable, or more so, than the more fully developed and demonstrated magnetic deflection instruments.

Finally, but of third priority, it is recommended that further development and testing of coincidence mass spectrometers be conducted. Theoretically, such instruments have a very favorable signal-to-noise ratio and, accordingly, may be of considerable value in studying the composition of a very tenuous atmosphere such as will be encountered on the Moon.

Prior to the advent of the space program, there was little incentive for having high-performance, miniaturized, lightweight, and rugged mass spectrometers. The availability of sounding rockets and satellites for the study of the composition of the upper atmosphere of the Earth led to the development of several types of instruments. Only in the case of the magnetic deflection instrument has the development and application been carried so far that, with a minimum of modification, the instrumentation can be applied directly to the problem of the measurement of the lunar atmosphere.

Mass spectrometer handtool probe. - It is recommended that development of a hand-portable probe be performed for measurement of gases that might be released from vents or from subsurface materials. This equipment would consist of a mass spectrometer attached to a probe that can either be directed at a suspected vent or be inserted by hand into the surface. For the latter purpose, the probe should have a built-in heater to promote the release of adsorbed gas. A large dynamic range is desirable since the pressure in a vent could be quite large compared to ambient. Direct, albeit rough indication of the total density and spectrum should be available to the explorer, with more detailed data being telemetered as appropriate (for example, for return to Earth or to a command station).

Nonthermionic ionizing electron sources for mass spectrometry. - It is recommended that research and development be performed on nonthermionic sources of electrons and that the resulting devices be evaluated relative to the adaptation to mass spectrometric ion sources.

Serious alteration of the virgin gas composition occurs when a thermionic ionizing electron source is used in a mass spectrometer applied to the analysis of ambient gases at 10^{-6} to 10^{-9} torr. The main causes may be traced to those associated with thermal gaseous effects, gettering action, and other chemical interactions resulting in insulating deposits elsewhere. When the examination of ambient atmospheres of 10^{-10} to 10^{-15} torr is considered, the perturbation caused by the electron emitter in a mass spectrometer becomes increasingly more important. Several approaches which eliminate the thermionic electron source are described in the literature: field ionization devices; the various types of electron multipliers; and electrostatic field junction,

solid-state devices. The cold-cathode device (magnetron) is an ion source and can be used without a separate electron source. All these approaches should be comparatively evaluated relative to the application to mass spectrometer ionizing sources. The magnetron field discharge source might be incorporated with monopole-quadrupole m/e analyzers. This is possible because of the heterogeneous energies of ion formation and the ability of these analyzers to accept a wide range of ion velocities coincident with the axis of symmetry. Electron beam outputs from electron multipliers and solid-state junction emitting devices may be applied to any m/e type analyzer as a source of ionizing electrons for ion generation. The output from these may contain electrons with a wide energy distribution; but if this energy distribution does not change with time, cracking patterns will remain constant and provide mass spectrometric calibration relative to different molecular species.

Low-current detectors for mass spectrometers. - It is recommended that development of electron multipliers or other very-low-current detectors be undertaken.

The mass spectrometer, which will be the key instrument in studying the composition of the lunar atmosphere or other tenuous atmospheres, requires a very sensitive current detection device. For example, for an atmosphere of 10^{-12} torr, typical ion currents in mass spectrometers are of the order of 10^{-16} A (about 1000 ions sec^{-1}) which is below the range of conventional electrometer-type amplifiers. Electron multipliers are used either as detectors to count the individual ions arriving at the detector or as preamplifiers in conjunction with electrometer amplifiers operating as current integrating devices.

While some marginally satisfactory electron multipliers are available, there is actually no satisfactory multiplier at hand which combines high gain, reliability, compactness, bakeability, and the ruggedness needed in flight applications. Most multipliers in existence were developed for other purposes; hence, the overall performance falls far short of what the state of the art permits if an electron multiplier were developed primarily for mass spectrometer use.

Pressure gages for operation at less than 10^{-12} torr. - It is recommended that pressure gages for determination of pressures below 10^{-12} torr be developed.

Present field ionization (magnetron) devices are capable of reliable measurement of gas pressure to a lower limit of 10^{-12} torr. Certain designs exhibit a performance deficiency in the lower limit of this pressure range, such as onset of nonlinearity of response. A need exists for an extension of low-pressure measurement below the 10^{-12} range.

If a field ionization technique is used, an increased reliability of ionization initiation is needed. At these low pressures, consideration should be given to minimizing internal gage outgassing which results from ion or electron bombardment and to minimizing the tendency of the gage to act as an ionization pump. Both phenomena tend to falsify the correct ambient reading. A significant innovation will be required to advance the technology beyond the present state of the art.

Diffusion studies and development of sample gas-release experiments. - It is recommended that theoretical investigations of the lunar diffusion problem (including the effects of surface temperature variations, surface obstacles, and removal of the diffusion gases by various escape mechanisms) be conducted as early as possible.

Hardware concepts for controlled sample gas-release studies on the lunar surface should also be developed. Sample gas-release experiments conducted on the lunar surface can be used to verify theoretical diffusion studies and to determine quantitatively the magnitudes of various escape processes.

Gas released on the lunar surface will diffuse away from the source in a mode similar to girdle waves on a sphere, with a velocity of propagation characteristic of the molecular weight of the diffusing species. A complete understanding of this process may' improve the ability to locate impulsive gas sources. The quantitative features of gaseous diffusion about the lunar surface will be a major consideration for determining the escape rates and composition of lunar atmosphere gases and the locations of sources contributing to the atmosphere.

Adsorption studies relating to the lunar surface. - It is recommended that experimental studies on adsorptive properties of lunar-like surfaces be implemented immediately along the following lines: (1) adsorption studies on a great variety of mineral surfaces on a relatively short time scale and at moderately low background pressures (10^{-8} to 10^{-9} torr) to obtain a broad knowledge of the basic physical and chemical interactions occurring between various gaseous species in the exhaust products of lunar vehicles and lunar-like surfaces; (2) exposure of macroscopic surfaces in relatively large chambers to gas sources of finite duration to study the dynamic equilibrium between adsorption and desorption; and (3) similar experiments with the addition of sputtering and other likely environmental parameters to determine the effects of the latter processes on the adhesion of gases to surfaces of various textures.

The behavior of the ambient lunar atmosphere is governed by interaction with the surface, mainly to the extent that the surface acts as a thermal reservoir and as an agent for neutralization of solar-wind ions. However, the balance between adsorption to the surface and desorption from the surface will play a decisive role in the dispersion of gas clouds from transient sources. Sputtering of the lunar surface by solar-wind ions may significantly affect the adsorptive properties of the lunar surface. Present quantitative information on interaction of gases with nonmetallic surfaces is, however, exceedingly poor. Precisely this knowledge is needed for a realistic assessment of atmospheric contamination near landing sites after touchdown and for separation of transient effects from local and lunar-scale atmospheric data obtained at later times.

Operational Recommendations

The following recommendations should have some impact on operational plans or hardware items. The first recommendation has higher priority than the rest; otherwise, priority is not indicated by the order of presentation.

Installation of a mass spectrometer on the Moon at the earliest possible time. - It is recommended that a mass spectrometer be flown at the earliest possible time: (1) preferably before Apollo, (2) during Apollo if feasible, but (3) as soon after the

first Apollo lunar landings as possible if any geophysically meaningful atmospheric composition measurements are to be made.

The composition and density of the lunar atmosphere are of fundamental importance in evaluating the nature of lunar degassing processes. The cold-cathode total pressure gage presently scheduled for the ALSEP will provide data concerning the density of the lunar atmosphere but does not provide information concerning the composition. The composition and a precise measurement of the surface atmospheric densities can only be obtained with a mass spectrometer.

A true identification of the primary lunar atmospheric constituents will be hampered by the exhaust gases from the Apollo LM landings and unmanned soft landers. Contamination by vehicle exhaust gases will become increasingly serious as more lunar landings are performed.

Mass spectrometer in early ALSEP. - It is recommended that serious consideration be given to the inclusion of a high-sensitivity mass spectrometer to measure ambient gases and rate of disappearance of rocket gases from the Moon if the opportunity for substitution of instruments in early ALSEP packages can be developed. It is important that this be done before the quantity of contaminant gases carried to the Moon by vehicle systems becomes significant by comparison with the natural atmosphere.

Mass spectrometers in later ALSEP. - It is recommended that a high-sensitivity mass spectrometer be included in any additional or modified ALSEP (beyond No. 4) to measure ambient gases and rate of disappearance of rocket gases from the Moon. If three packages can be suitably located, the opportunity exists to triangulate on gas sources that can be detected at the packages, thus providing the information needed to guide an astronaut or unmanned vehicle to the gas-release site.

Lunar satellites. - It is recommended that a vigorous program of atmospheric measurements be conducted from lunar orbiting satellites.

Satellite measurements are a natural complement to lunar surface observations and provide: (1) continuous long-term monitoring of the lunar atmosphere, including its spatial and temporal variations; (2) enhancement of the effective sensitivity of composition probes for minor constituents by long-term repeated scanning of the mass spectrum; (3) early access to the atmosphere on the far side without requirements for additional communication links to Earth; (4) access to regions above the poles; and (5) detection of localized or impulsive sources of gases emanating from surface locations distant from landing sites, including monitoring of the diffusion and escape of controlled gas releases.

Sensitive mass spectrometers and other low-density detectors should be flown at the lowest feasible altitude (on the order of 30 km or less) to be effective in sampling the lunar atmosphere. To insure their proper operation in a clean, undisturbed environment, these instruments should be mounted on unmanned vehicles. Satellite studies of the lunar atmosphere should proceed along the following lines.

Lunar orbiter: The expansion of activity during Apollo and AAP will contaminate the ambient lunar atmosphere to an unknown degree. Therefore, it is urged that a

mass spectrometer be flown on a lunar orbiter vehicle, prior to the first Apollo launch. This may offer the last opportunity to observe the lunar atmosphere in a relatively pure state. Moreover, results of such an early survey may be invaluable in the definition of plans and the development of instrumentation for AAP. The lunar orbiter vehicle offers the additional advantage of high maneuverability and attitude control. It appears feasible that mass spectrometers of sufficient sensitivity can essentially be taken off the shelf and be readied for flight within a year. Timely incorporation into the present lunar orbiter payload should not pose an insurmountable problem.

Lunar subsatellites: Subsatellites could be injected from the CSM into precision orbits. The requirements on this type of vehicle would be a low level of outgassing and a nearly circular low-altitude orbit, with a perilune not greatly in excess of 30 to 50 km. Two classes of payloads may be envisioned: a neutral mass spectrometer as principal payload and a heavier package which, in addition to the mass spectrometer, may include a sensitive pressure probe as a backup experiment and ion detectors of various kinds. The payload may be complemented by experiments in other areas of lunar studies. Attitude control is highly desirable to control ram effects. Launch intervals should not exceed the projected lifetimes of the orbiters to insure continuous monitoring of lunar outgassing activities and of the effect of Apollo and subsequent operations on the lunar surface. In view of past experience, biannual launches starting in 1971 appear to meet this requirement.

Advanced unmanned lunar satellites: These would be advanced satellites of the lunar orbiter type. Such satellites would serve to back up and complement the subsatellites within the framework of the AAP. The general requirements on their operation are the same as those for subsatellites.

Manned orbiters: In view of the near-vehicle contamination, the manned lunar orbiters, envisioned for the AAP, may not be suitable for atmospheric studies, although the feasibility of optical methods (for example, resonance scattering) should be examined.

<u>Inclusion of mass spectrometers in payloads with seismic detectors</u>. - It is recommended that mass spectrometers be emplaced together with seismic detectors, if feasible. An analogous situation has existed for years in the planning of interplanetary probes where simultaneous measurement of plasma flux and magnetic fields has proved to be essential. Impulsive gas sources might be attributed to several possible processes, such as meteoric impact, volcanism, and sporadic outgassing. Correlation of atmospheric and seismic data would provide important information for the interpretation.

<u>Triangulation nets of atmospheric monitors for location of gas sources</u>. - It is recommended that atmospheric monitors be arrayed in triangulation nets, to provide information on the location, magnitude, and duration of gaseous emissions from natural and artificial gas sources. These monitors should measure the mass spectrum and total pressure. In this way, suggested sites such as Aristarchus may be verified as gas-producing sources well in advance of direct exploration; furthermore, gas vents that are not topographically prominent may be located. Lunar surface adsorption and accommodation parameters could also be determined by such nets.

A large range in the baseline distance between monitors in such nets is desirable. The location of general areas of activity will require monitor baseline distances on the order of 1000 to 2000 km, while nets with 25-km baseline distances might be used to pinpoint specific sources.

Mass spectrometer handtool for location of lunar gases. - It is recommended that a mass spectrometer handtool be used to explore for subsurface gas and/or gas release at the surface. Large gas flows could exist at the lunar surface, yet be unnoticeable without suitable instruments. Such flows could result from volcanism, hydrothermal activity, or sublimating subsurface volatiles (for example, ice); therefore, the gas flows would be of great geophysical and atmospheric importance. The lunar explorer should, therefore, have available a sensitive portable detector for such gas sources that would be capable of giving at least a rough indication of total density and composition. Such an instrument would enable the lunar explorer to trace rapidly and investigate gas flows and infer their probable origin, which in turn would suggest the feasibility and course of further investigations (for example, drilling, change in tranverse routing, et cetera).

Modular ALSEP. - It is recommended that future ALSEP stations be designed to allow a substantial degree of flexibility to react to new opportunities opened up by new developments or discoveries on the Moon. A modular concept to permit accommodation of new instruments with minimum disturbance of the basic ALSEP system would greatly facilitate such flexibility.

Specifically, the number of candidate experiments for a particular ALSEP mission is expected to exceed the number that can be accommodated on that mission. Flight assignments for the mission should be made as close to flight time as practicable to reflect the state of knowledge at that time. The experiments would, therefore, be built to meet a standard ALSEP electrical interface and a suitably small choice of mechanical interfaces. This requires that the ALSEP central station have a suitable number of standard electrical experiment plug-in stations and a central data processor assigning experiment data rates under control of a stored program. The processor control program could be stored prior to flight or preferably on command from Earth. Remote reprograming is particularly desirable, as it permits real-time assignment of experiment data rates in response to acquired data.

Escape and diffusion experiments. - It is recommended that the gas escape and diffusion experiments by controlled gas release at the lunar surface be conducted.

To obtain experimental information on escape time for various gases, one should release, impulsively, a known amount of the gas at a known time and position. An array of mass spectrometers, or an orbiting mass spectrometer, will first observe the characteristics of an atmospheric buildup to obtain useful information on the diffusion parameters of the gas. After a quasi-steady-state distribution is reached on both the dayside and nightside, a slow decay in intensity follows from which the lifetime in the atmosphere can be deduced. Interpreting observations of the lunar atmosphere and deducing input and exhalation rates then become easier.

Reduction of water vapor release from portable life support systems. - It is recommended that water vapor, evolved from the backpack portable life support system (PLSS), should be directed upward and away and, if possible, supersonically expanded away from the working area around the astronaut. The present configuration of the

PLSS heat-exchanger plate produces a contribution of 10^{-4} torr equivalent water vapor pressure in the region of the hands of the astronaut. Such a condition will be undesirable for in situ mass spectrometer measurements and sample collection.

Inventory of volatiles deposited on the Moon. - It is recommended that a continuous inventory of all volatiles deposited on the Moon be implemented.

It is obviously important to minimize contamination produced in the process of lunar exploration in order to measure the lunar atmosphere. Since contamination is inevitable, consideration should be given to tagging techniques; for example, isotopic techniques. In any case, all volatiles and gases that have been and are being introduced into the lunar atmosphere should be recorded; also the amount, composition, date, and place of release should be recorded. This is especially important for the more exotic substances; for example, it appears that the cooling water from astronaut operations will contain iodine, that the LM vehicle will be pressurized with helium, and so forth.

Analysis and return of gases from drilling operations. - It is recommended that the design of lunar drilling rigs should reflect the desirability of allowing for the introduction of any flow into a sensitive mass spectrometer, incorporating gas collection devices, and minimizing the generation of gas by the rig. Drilling operations will lead to the possibility of releasing gas from the fragmented and heated fresh rock that is exposed in the drilling process, and from volatiles that may be trapped in vesicles or capped by the overburden. Presumably, the deeper the drill hole, the greater the prospect of significant gas sources. The sensitive mass spectrometers expected to be available should have the capability to analyze gas densities far below what might reasonably be collected for return. Nevertheless, the possibility of a flow sufficiently large to be directly collected and subsequently returned to Earth for detailed precision analysis should not be ignored.

Apollo site selection. - It is recommended that the Apollo sites for ALSEP emplacement be located to give the most effective triangulation net consistent with other mission constraints. For the sites located within the allowed Apollo landing zone, this objective could be accomplished with two Apollo lunar surface experiments packages located near the same longitude, but with one as far north and the other as far south as feasible, and a third ALSEP spaced 30° to 45° in longitude from the other two. Several such nets can be constructed from the sites verified by the lunar orbiters, as for example Sites III P-12, II P-13, and II P-11 or III P-9. On the other hand, a site such as II P-2 or II P-6 cannot be incorporated with the remaining sites to form an effective three-ALSEP net.

CHAPTER 9

REPORT OF

PARTICLES AND FIELDS WORKING GROUP

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INTRODUCTION

In the preparation of this report, the Particles and Fields Working Group considered in detail the report made by the corresponding group at the Falmouth Conference in 1965.[1] This study is different from the Falmouth study in two ways: No consideration is given to (1) experiments which are covered more appropriately in other disciplines or (2) experiments which may be of high priority when long-term manned observations become possible on the lunar surface.

Some experiments proposed at the Falmouth Conference are obsolete because they have been accomplished by other means or because they are no longer applicable in terms of current knowledge. Particle and field experiments appropriate for the lunar scientific exploration program are considered in two categories:

1. Experiments with direct applicability to lunar science

2. Experiments concerned with particular studies which enable the timely scientific use of program opportunities and/or the Moon as a scientific base

These two categories of experiments were further subdivided into those best performed in lunar orbit and those best performed on the lunar surface to arrive at recommendations on magnetic-field, electric-field, plasma, low-energy charged-particle, and solar and galactic cosmic-ray experiments. Time limitations prevented detailed consideration of all particle and field measurements. An example is the promising technique for determining the solar-wind composition by exposure of titanium foils.

While particle and field experiments do not require the presence of an astronaut, circumstances can arise in which the skills of the astronaut can be utilized to deploy experiment packages at distances away from surface landing vehicles to reduce the effect of high magnetic, electric, and/or radioactive background from available vehicles.

The Particles and Fields Working Group notes with alarm the present lack of any program (in the unmanned space research effort) designed to investigate the lunar particle and field environment. The anchored interplanetary monitoring platform (AIMP) program, successfully concluded with the injection of AIMP-E into lunar orbit, has already yielded new and unexpected results which require a reexamination of the fundamental processes governing the solar-wind interaction with the Moon. Effective lunar research requires continued unmanned satellite experimentation in support of the Apollo Applications Program (AAP) investigations.

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[1] Results of the conference were published as NASA 1965 Summer Conference on Lunar Exploration and Science. NASA SP-88, 1965.

To pursue the AIMP-E results with followup investigations in the 1970 period, program opportunities must be made available now. To aid in obtaining such investigations within the shortest possible time scale, the Particles and Fields Working Group has included recommendations on the mode of experiment delivery to the lunar environment.

Recommendations concerning the Earth-orbital capabilities of the AAP were not strictly within the scope of the present study and thus were not generated. It was realized that a number of important particle and field experiments that might be suggested for lunar missions could more effectively utilize Earth-orbital-mission capabilities. Therefore, experiment proposals requiring the AAP Earth-orbital capabilities must be given scientific consideration in the AAP.

RECOMMENDATIONS

Orbital Missions

The following are the purposes of the orbital mission experiments:

1. To study the solar-wind interaction with the Moon and thereby obtain information on lunar parameters such as the magnetic field, gross conductivity, distribution of conductivity, interior temperature, et cetera

2. To study fundamental physics of plasma interactions

3. To obtain data on interplanetary, geomagnetosheath, and geomagnetic tail properties during those times when the Moon is in the appropriate regime

Experiments (ranked in order of priority) to observe the following phenomena are recommended for placement in lunar orbits as soon as possible:

a. Vector magnetic fields

b. Plasma

c. Vector electric fields

d. Low-energy charged particles ($\lesssim 1$ MeV)

Furthermore, the preceding portion of the lunar exploration program should be implemented through the following means:

1. Launch of two AIMP-type satellites into lunar orbit in the early 1970 period by thrust-augmented, improved Delta or similar launch vehicles and use of the basic experimental package previously described.

2. Launch of two similar type vehicles (Pioneer, AIMP) into precisely controlled orbits and with periselenes as low as is consistent with launch capabilities and long lifetime but at most 100 km, using the subsatellite transport capability of the Apollo

service module. The missions should occur as soon as possible and should overlap (in time) the two AIMP-type satellite launches. The missions should be continued at the rate of about one launch per year through 1975 if the scientific requirements so dictate.

Simultaneous observations from more than one orbital experiment and a network of surface stations are desirable.

The foregoing recommendations are based on the following facts:

1. Pioneer and AIMP are presently available platforms which satisfy the magnetic, electric, and radioactive cleanliness requirements of experiments in the area of particles and fields. No such hardware presently exists within the AAP.

2. The missions discussed previously can be implemented as soon as opportunities are available and certainly in the 1970 to 1971 period.

3. Total cost (launch vehicle and support, experiments, data analysis, et cetera) is estimated to be $7 to $10 million per mission for the Earth launched AIMP-type satellites and from $5 to $8 million per mission for the subsatellite mode of delivery. These payloads will provide a nominal 40 pounds of experiment and 25 to 100 bps of telemetry capability. Cost estimates for six Lunar Orbiter missions utilizing AAP hardware have ranged from $300 to $700 million and might provide 125 pounds of experiments and a telemetry bit rate of 8×10^4. The existing Lunar Orbiter requires significant modifications to meet required specifications (magnetic, electric, and stabilization) for particle and field experiments.

Surface Missions

It is recommended that a network of independent, simultaneously operating particle and field monitoring stations be emplaced on the lunar surface. The stations should include experiments to measure (in order of priority) the magnetic field, the electric field, the solar-wind plasma, and somewhat more energetic particles (10's of keV) such as might be accelerated in shock waves. As a minimum and immediate objective, the network should include two equatorial stations located at ±60° to the Earth-Moon line. It is important that station lifetime and emplacement be such that simultaneous operation is obtained.

A longer term objective is the simultaneous operation of four stations: three equatorial stations 120" apart and one high-latitude station. It is also essential to obtain observations simultaneously from ground stations and orbital missions.

Present unmanned soft landers do not meet the magnetic and electrical cleanliness requirements of particle and field experiments. Thus, manned missions for the purpose of package deployment from a central station are required.

The probability is small that a significant portion of the recommendation will be achieved in the present Apollo lunar surface experiments package (ALSEP) program. Therefore, the implementation of this recommendation should be a primary objective of the follow-on ALSEP program and the AAP. While the priorities are apt to change as more data become available, the rankings given above and in the orbital

mission recommendations are the current best estimates. Furthermore, orbital missions should have higher priority than surface missions as a first effort.

Solar and Galactic Energetic Particles

The Particles and Fields Working Group sees no strong requirement for solar or galactic cosmic-ray energetic-particle experiments on the sprface of the Moon or in orbit around the Moon. However, if payload space is available either for landing on the Moon or for orbit about the Moon, interesting and important experiments can be performed. While the importance of these experiments is recognized, it appears that the experiments on charged particles with rigidity less than a few BV can be carried out most economically and reasonably in highly elliptical Earth orbits or in low circular polar-Earth orbits. The experiments on charged particles with rigidity greater than a few BV can be performed in low-altitude, high-inclination Earth orbits utilizing the weight capability of the AAP.

Important energetic-particle experiments which require long operating and exposure times outside the magnetosphere and which are too heavy for small scientific satellites can utilize the AAP capability in lunar missions. In particular, the neutral and charge composition of solar particles and the very-high-charge component of galactic cosmic rays fall within this class.

Data Acquisition

It is strongly recommended that appropriate provision be made to insure continuous telemetry coverage of all scientific packages, both single and simultaneous operations, on and around the Moon. Provision must also be made to recover data continuously from the dark side of the Moon.

Project Scientist

The working group strongly recommends that a position of Project Scientist be established within the structure of the manned space flight program. The responsibilities of the Project Scientist will be to represent the scientific requirements and objectives of the experiment to the project manager and his staff and, conversely, to represent to the principal investigator project requirements which may affect his experiment. At least one Project Scientist should be associated with every Manned Spacecraft Center (MSC) project which includes scientific experiments; more than one Project Scientist might be desirable for a large project in which the number of scientific disciplines is large. Furthermore, the working group believes strongly that the Project Scientist should be a participating experimenter on at least one experiment in the project for which he is responsible. The position of the Project Scientist within the organizational structure should be at a level which insures adequate scientific input into the program.

Adequate scientific input means that the engineering systems developed in support of the MSC program will be suitable for the scientific experiments which are adopted for a particular mission. In addition, the systems developed should be suitable

for experiments which might be proposed for future missions. Thus, the Project Scientist plays an essential role in advanced mission planning. If his requests are ignored or lacking, it will be impossible to use effectively the engineering systems developed from past missions.

Principal Investigator

The following responses to questions concerning the role of the Principal Investigator are presented by the Particles and Fields Working Group:

1. The strong recommendation that present NASA policy concerning assignment and responsibilities of the Principal Investigator be retained in the AAP and post-Apollo programs.

2. The recommendation that the Principal Investigator have complete control of his data for a period of 1 year after its receipt in final form from NASA and that following this period, the data be made available to the scientific community.

Program Opportunities

The working group strongly recommends that any extension of the Apollo science program (for example, new Apollo hardware, follow-on ALSEP, or AAP), be implemented by open solicitation of experiments from the scientific community. Only in this way can the manned space flight program build the broad base of scientific support and participation necessary for an active and productive research program. In certain disciplines, the time scales involved may pose problems in implementing this recommendation. However, particle and field experiments are available which could be delivered on a relatively short time scale and thus allow the possibility of wider scientific participation in the Office of Manned Space Flight (OMSF) scientific program.

EXPERIMENTS AND SCIENTIFIC OBJECTIVES

Magnetic Field Measurements

The Moon is known from satellite measurements (Luna 2, Luna 10, and Explorer 35) to possess an extremely weak intrinsic magnetic field. The most recent results from Explorer 35, obtained while the Moon was imbedded within the magnetic tail of the Earth and thus shielded from the solar wind, suggest that the maximum magnetic moment is less than 4×10^{20} cgs units ($\sim 0.5 \times 10^{-5}$ of the magnetic moment of the Earth). Assuming a dipolar field, a surface magnetic field of less than 8γ ($1\gamma = 10^{-5}$ G) can be predicted. When the Moon is located within the geomagnetic tail, it is immersed within a very weak magnetic field, generally between 8γ to 15γ, depending upon magnetic and solar activity. An intrinsic lunar field is not expected to be formed since the Moon is probably lacking a fluid core within which a dynamo system of currents will evolve similar to the core of the Earth. The recent negative results of the planetary probes for Venus and Mars (Mariner II and Mariner IV, respectively) are consistent with this dynamo theory of planetary magnetic field origin.

The Moon is imbedded within the geomagnetic tail for 4 days near full Moon and within the geomagnetosheath for an additional 6 days. For the remainder of the 29.5-day synodic period, the Moon is immersed within the interplanetary medium. The interaction of the solar wind with the geomagnetic field leads to the development of a detached bow shock wave enclosing the magnetosphere. It has been suggested that the accretion of the interplanetary field by the electrically conducting material of the Moon leads to the formation of a magnetic tail and a lunar pseudomagnetosphere. However, from initial Explorer 35 results, it appears that in the case of the Moon such a configuration does not permanently exist.

From these recent experimental results, it is clear that the actual interaction between the plasma and the Moon is quite different from theoretical models which have gained rather general credence during the past few years.[2] Thus, it is evident that further experimental work (probably a considerable effort) is required to solve the problem. From the standpoint of lunar science, the solution will probably yield some definitive results concerning the composition and structure of the Moon.

Using a homogeneous Moon, the recent Explorer 35 results indicate that the electrical conductivity of the Moon on the average is less than 10^{-5} mhos/meter since the fields in the solar plasma appear to be convected through the Moon as fast as they are carried past the Moon by the solar wind. However, if the Moon were nonhomogeneous with an insulating layer covering a conducting interior, the situation becomes much more complex. If the solar wind is quasi-stationary on a time scale which is large with respect to the diffusion time of the interior $\left(\tau = \mu\sigma R^2\right)$, then essentially the entire Moon behaves as an insulator.

A study of the response of the Moon to interplanetary disturbances such as shock waves and sector boundaries may help to resolve the matter. Simultaneous observations of the undisturbed interplanetary medium and the flow field and electrical-magnetic fields near the stagnation point and behind the Moon are required.

Accurate vector magnetic-field measurements are required from 0γ to 100γ with a sensitivity of $\pm 0.1\gamma$. The samples should be taken at a minimum rate of one per second. Instruments capable of operating over time scales of months to several years exist and have been flight proven in the Explorer, interplanetary monitoring platform (IMP), eccentric geophysical observatory (EGO), Mariner, and Pioneer series of spacecraft. The weight, volume, and power requirements vary, depending on the specific detector system employed. Generally, triaxial systems for satellite instrumentation require from 5 to 15 pounds, 150 to 5000 cubic inches, and 0.8 to 5 watts. Similar figures should apply to lunar surface magnetometers.

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[2] See, for example, a report by the staff of Jet Propulsion Laboratory: Scientific Objectives and Requirements of a Lunar Orbiter to Investigate the Fields and Particles Environment of the Moon. JPL Advanced Lunar Studies Report No. 760-8, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, July 25, 1967.

The magnetic- and electric-field detectors should have a frequency response from dc to 20 kHz, a range which includes the proton cyclotron frequency (~ 0.2 Hz), the electron cyclotron frequency (~ 300 Hz), the proton plasma frequency (~ 500 Hz) and the electron plasma frequency (~ 10^4 Hz). These high-frequency fluctuations will saturate the telemetry of a present ALSEP system so that (1) a greater increased capacity is necessary for onboard data processing or (2) a suitable buffering and command capability are required to permit the field experiments to look at active periods in detail.

Solar Plasma Measurements

Plasma measurements in the vicinity of the Moon have three objectives: (1) to understand the interaction of the plasma with the Moon, (2) to obtain physical information about the Moon, and (3) to study the properties of the plasma as revealed by its interaction with the Moon, An "ideal plasma detector" suitable for such measurements does not exist. The principal difficulties are the lack of time resolution in the energy spectrum and in the angular distribution and the inherent problem of rapid directional scans in two orthogonal planes. Instruments currently available determine the angular (in one plane only) and energy distributions of the plasma flux in 10 to 20 seconds. While higher resolution is desired, significant and important measurements of the physical parameters which characterize the solar plasma can be obtained with these instruments. Thus, although a vigorous attempt should be made to improve the present instruments and the present satellite data-handling systems, these systems should be used as they now exist to investigate plasma flow near the Moon. Present instruments weigh about 5 pounds and require about 5 watts.

For the orbital missions, a spin-stabilized satellite with the spin axis perpendicular to the ecliptic plane will solve some of the problems associated with measuring the direction of flow and the angular distribution of the flux. The spin period should be as short as possible, preferably less than 1 second, and the use of several plasma sensors to increase the time resolution should be considered.

For the lunar surface station, a multiple array of detectors with an active pointing system referenced to the Sun during the lunar day should be considered. The telemetry bandwidth for such a system could be an order of magnitude higher than for the orbital system, and a detector of correspondingly better time resolution can be built. Work on the detector and on the pointing control should start at once.

Electric Field Measurements

Electric fields near the Moon are associated with many interesting phenomena such as lunar surface processes and the interaction of the magnetized solar-wind plasma, the geomagnetosheath, and the geomagnetotail with the Moon. The electric fields should be measured for the following reasons:

1. The electric fields are fundamental to an understanding of the interaction of the solar wind with the Moon, the state of the plasma, and the acceleration processes occurring in the plasma.

2. Electric-field measurements with the proper sensitivity and frequency response have recently been demonstrated to be within the technology of present detector design.

For a plasma in which the conductivity is infinite

$$\bar{v}_{bulk} = \frac{\bar{E} \times \bar{B}}{B^2} \tag{1}$$

and

$$\bar{E} \cdot \bar{B} = 0 \tag{2}$$

Under these conditions, any two of the three quantities $\left(\bar{E}, \bar{B}, \text{ and } \bar{v}_{bulk}\right)$, can be measured and the third quantity deduced from equation (1). Whether all three parameters or two of the three parameters are measured becomes a question of convenience.

The previously stated assumption may not generally be satisfied in a collisionless, warm, magnetized plasma. As an example, a plasma instability could lead to the generation of electrostatic waves that greatly decrease the dc conductivity of the plasma. There may thus be dc electric fields along $\bar{B}$, ac electric-field oscillations not accompanied by magnetic oscillations, and a greatly inhibited bulk plasma flow in the $\bar{E} \times \bar{B}$ direction. In such a case; there is no simple relationship between the magnetic field, the electric field, and the plasma velocity; and all three quantities must be measured to understand the behavior of the plasma.

In the interplanetary medium away from the Moon, a major component of the dc electric field measured in a coordinate system at rest with respect to the Moon is the ~1-mV/m field given by equation (1). Other interesting electric fields may be present in the interplanetary medium because of nonapplicability of the infinite conductivity assumption behind equation (1).

When the interplanetary plasma encounters the Moon, a shock front may occasionally develop. Electrostatic oscillations at frequencies near the proton and electron plasma frequencies and with amplitudes as large as 1 V/m may arise in the shock. Behind the shock front there might be a thermalized plasma containing electrostatic waves and dc electric fields parallel to $\bar{B}$.

When a shock front is not formed by the solar-wind interaction with the Moon, fields such as those discussed above would not be present. During such times, the electric-field measurements would help to delineate among the possible lunar models that explain the rapid convection of magnetic-field lines through the Moon.

On the sunlit side of the Moon, the surface electric-field strength depends on the plasma-particle fluxes and the photoelectric emission from the surface. Because the

photoelectric emission is uncertain by at least an order of magnitude and the particle fluxes depend on plasma conditions, the electric-field strength may assume a wide range of positive or negative values as large as 10's of V/m. The field strength should vary over small areas of the surface depending on whether sunlight hits the given area, the composition of the surface material, et cetera. These electric fields may have important consequences in the determination of surface conditions such as dust migration, and they do perturb surface measurements of low-energy plasmas.

In addition to the electric fields directly associated with lunar phenomena, a detector on or near the Moon will measure electric fields in the magnetosheath and tail of the Earth at times near full Moon. Electrostatic as well as electromagnetic waves of frequencies from less than 1 to greater than 10^4 cps might be present. A dc electric field of about 1 mV/m should also be present. Measurement of its direction and magnitude would provide important data related to auroral and tail physics.

Among possible detectors of electric fields are the following:

1. A field mill that consists of a rotating grounded plate, whose motion alternately exposes and shields a second plate from the field. The alternating current on the second plate is a measure of the external electric field.

2. An electron beam whose trajectory is affected by the external electric field.

3. An electric dipole antenna consisting of a pair of conductors separated by a distance d. The potential difference between conductors is measured, and this difference (divided by d) is the strength of the electric-field component along the direction of separation.

The sensitivities of the field mill and the electron-beam detector are sufficient only for lunar surface electric-field measurements. Either might be appropriate for measurements of surface fields on the dark side of the Moon where there may be little or no plasma and where, as a consequence, the dipole antenna would not operate properly. For other cases, the dipole antenna is preferred since its sensitivity can be well below 1 mV/m, and it can measure vector electric fields over the frequency range of interest. Only the dipole-antenna electric-field detector will be discussed further.

The separation distance d between the conductors should be great enough that the true potential difference will be large compared to background voltages. The major background comes from contact potential differences between the two conductors which can be kept below 10 millivolts. Hence, antenna lengths of 10 to 100 meters are desired to measure electric fields less than 1 mV/m. If the antenna is rotating, a constant electric field produces an ac output at the detector which oscillates at the rotation rate while contact potential differences are, to the first order, constant. Hence, an even further separation of the two signal sources is possible.

For the plasma to provide enough current to the antenna without short circuiting the external voltage, the surface areas of each arm should be on the order of 1 square meter. The surface area can be decreased by biasing each antenna arm with a current whose magnitude depends on interplanetary conditions. Such biasing may also be

required for measuring frequencies greater than the ion plasma frequency or to improve operation at lower frequencies if the antenna dimensions are smaller than a Debye length.

A typical weight, exclusive of booms, might be 5 pounds; and power consumption, 3 watts. The package should contain two dipole antennas, one oriented along the satellite spin axis and the other in the perpendicular plane. A major limitation of the experiment would be the telemetry availability. Useful data could be obtained with bit rates as low as 30 bps, but much higher bit rates are desirable.

Low-Energy Particle Measurements

The low-energy particle detector supplements the plasma observations by measuring proton and electron intensities up to ~ 1 MeV. Although preliminary results from Explorer 35 indicate the absence of a lunar bow shock, the possibility still remains that such a shock could form under interplanetary conditions significantly different from those existing at the time of the Explorer 35 observations. With the formation of a lunar bow shock, it is expected that a fraction of the solar-wind plasma would be accelerated to energies greater than 10 keV. Thus, it is important to include a detector capable of sampling in this energy range and thus be prepared for the possibility of lunar shock formation.

While the inclusion of the low-energy particle detector is dictated primarily by the objective of studying the solar-wind-Moon interaction, the detector will also directly study particles in the interplanetary medium, in the magnetosheath, and in the geomagnetic tail.

Electrostatic analyzers used in conjunction with channel multipliers can conveniently span the energy range of a fraction of a keV to ~ 40 keV. Solid-state detectors can easily span the range from ~ 35 keV upwards. A low-energy detector package with these elements would weigh less than 10 pounds and use less than 3 watts. An electrically clean and spinning (to obtain angular distributions) spacecraft is required.

Solar Energetic Particles

The study of solar-energetic particles is of scientific interest primarily for two reasons. First, the Sun provides the best opportunity to study stellar phenomena in detail. The processes by which charged particles are accelerated to very high energies in localized regions and in short time intervals are of fundamental importance. Of equal importance are the processes that continuously accelerate and produce lower energy particles. Second, the injection of energetic particles into the interplanetary medium provides the opportunity to study the mechanism of charged-particle diffusion and energy transfer in a moving medium of low-density plasma and weak magnetic fields.

A significant advance in our knowledge of solar-energetic particles has come from small scientific satellites. In the future, much more detailed observations will be required. Of particular importance are simultaneous charged-particle, magnetic-field, plasma, detailed-particle composition, and neutron measurements.

The small, eccentric-orbiting scientific satellite program can best meet all requirements for solar-particle studies with the exception of neutron and composition measurements. Small detectors cannot make these measurements since the flux of heavy particles is low and very large geometric factors and weights are required.

Track-recording detectors such as plastics and emulsions appear to be appropriate for solar composition studies because of their relative simplicity, reliability, and lower operational requirements. These devices require recovery. Larger and more complex electronic experiments that telemeter data could also be used. Neutron experiments with large area and geometric factors using proton recoils are desirable,

Galactic Cosmic Rays

Cosmic rays carry important information about properties of the universe. The charge-energy distribution and isotopic composition give information about the nature of the cosmic-ray sources, the mechanisms of acceleration, the age of the cosmic rays, and the containment regions. Some of the interesting problems are particle interactions with the black-body radiation, the existence of anti-matter in our galaxy, and the observation of heavy nuclei with $Z > 80$ in the study of mechanisms for stellar energy productions such as supernovae.

The measurements of cosmic rays with rigidities below a few BV should be made on eccentric or high-inclination orbiting satellites in order to get outside the magnetosphere, Small scientific spacecraft such as the IMP and the EGO are adequate. The measurements of the more energetic particles require heavier and larger detectors to obtain statistically meaningful data in a reasonable time because of the rapidly decreasing flux with increasing energy. The payload weights for measurements greater than 100 BeV/nucleon are measured in tons for most techniques. These experiments can more easily be carried out in the AAP Earth orbiting program and will not be considered further here.

Exceptions to the above are charge and composition measurements. In the search for very high Z cosmic rays, it is necessary to obtain long exposure times outside the magnetosphere. Consideration should be given to carrying this experiment on lunar missions.

CHAPTER 10

REPORT OF

ASTRONOMY WORKING GROUP

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INTRODUCTION AND SUMMARY

As astronomers, the Astronomy Working Group examined the potential use of the Moon as a base for astronomical observations. The 1965 Falmouth Conference[1] concluded, "the Moon may well offer an attractive and possibly unique base for astronomical observations . . . ." The 1967 working group expresses a sustained interest in lunar astronomy and has set out to define a series of measurements to obtain data that are fundamental to the establishment of a lunar astronomical base. The goal has been to list measurements and instruments for making these measurements in as much detail as possible without regard to overlap with measurements made by scientists in other disciplines. Close cooperation between astronomers and other scientists is essential in the final planning.

It is necessary to emphasize that most of the environmental information should be obtained as soon as possible so that decisions vital to long-range planning in space astronomy can be made with the facts in hand. A lack of discussion about specific scientific experiments should not be interpreted as a lack of interest in using the Moon as a base for astronomy. To design specific experiments efficiently, astronomers must have the information about the lunar environment which is requested in this report.

Four basic areas of astronomy were considered: radio, X-ray and pray, nonsolar optical, and solar optical astronomy. The following discussions of the required data and methods for obtaining them are summarized by listing the conclusions without detailed justification.

Radio astronomy, X-ray astronomy, and pray astronomy require observations that probably can be made better on the lunar surface than in any other place. Nonsolar optical astronomers can decide the question of Earth-orbital versus lunar-based observations only after obtaining the information requested in this report and comparing it with information derived from orbital experience. Solar optical astronomy will require observations from the lunar surface only if approved orbital studies fail to yield the desired results.

A single site may be suitable for all of the astronomical observations. The X-ray and pray occultation experiments require a crater with a 50-kilometer radius, the rim of which stands 1 kilometer or more above a fairly flat crater floor. Radio astronomy requires an area of about 30 by 60 kilometers which is free of cliffs, mountains, canyons, et cetera. A simple criterion is that an astronaut could walk throughout

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'Results of the conference were published as NASA 1965 Summer Conference on Lunar Exploration and Science. NASA SP-88, 1965.

the area. A site near the lunar equator is preferred. Nonsolar optical astronomers prefer a site near the limb. A preliminary selection may be possible from currently available, detailed lunar photographs.

The following environmental characteristics of the lunar surface should be determined at the selected site. The measurement of these characteristics has approximately the priority of order listed.

1. Micrometeorite environment

2. Radiofrequency noise levels

3. Surface impedance and conductivity

4. Density and extent of the lunar ionosphere (if it exists)

5. X-ray and γ-ray intensities, including the zenith-angle distribution of the intensities

6. Soil mechanics such as bearing strength and stability, depth profiles of temperature, seismic activity, and ionizing radiation

7. Thermal effects on astronomical instrumentation

8. Contaminants such as dust, spacecraft outgassing, spacecraft radiofrequency interference, and astronaut seismic noises

9. Deterioration of precision optical surfaces

10. Evaporation rates for optical coatings

X-RAY AND γ-RAY ASTRONOMY

For X-ray and γ-ray astronomy, the Moon offers long-range advantages over Earth orbiting experiments. It is an extremely stable platform with a slow rotation rate which can be determined with high precision. A distant horizon can provide an excellent occulting edge for the determination of position and angular size of sources over a wide range of wavelengths to an accuracy probably unattainable with Earth orbiting instruments. Very long exposure times in combination with large area detectors can be used to achieve great sensitivity. Complex, large area experiments demanding relatively frequent servicing over long periods of time can be best performed on the Moon.

The site for these observations should be the central region of a crater such as Grimaldi, with a diameter of approximately 100 kilometers and a rim greater than 1 kilometer above the crater floor. The central floor of the crater should provide an unobstructed view of the rim in all directions. To obtain as complete a view of the sky as possible, the crater should be located near the lunar equator.

To fully evaluate the advantages of a lunar base, it is necessary to measure a number of fundamental properties of the lunar environment.

Environment Measurements

Micrometeorites, primary and secondary. - Measurements of micrometeorites must be carried out on the lunar surface. The measurements can be accomplished by measuring the number of holes produced in a series of beryllium and plastic sheets of graded thicknesses, for example, 100-cm^2 beryllium sheets with thicknesses of 0.25, 0.5, 1.0, 2.0, 5.0, and 20.0 mils. The sheets should be exposed for about 1 year and then analyzed. The experiment weighs 1 pound and occupies about 0.1 ft^3.

Thermal properties. - To evaluate the thermal balance properties of instruments near the lunar surface, the temperature, as a function of time, of a small object of known emissivity located several feet above the lunar surface should be measured throughout a lunar day and night. Temperature measurements should also be carried out on the lunar surface and at several points below the surface down to about 5 feet.

Mechanical properties of the soil. - A measurement of the static bearing strength at the proposed site will be necessary for designing the mounting structure for any proposed instrument. The lunar surface must be stable to differential vertical and horizontal displacements of the order of 1 cm/km over a distance of about 50 kilometers for periods of several days. This should be checked with a small theodolite.

Topography. - A 360° photograph of the horizon measurable to an accuracy of about 1 arc second as seen from the site and a topographical map of the crater and rim to about 10-meter accuracy will be necessary for final site evaluation.

Background Radiation Measurements

Whether X-ray and p r a y astronomy can be accomplished on the Moon depends on the intrinsic and cosmic-ray-induced background. Measurements of this background can be made with several relatively modest, highly tested, and reliable instruments. The astronaut would be required to place the experiment at a distance of about 30 meters from the lunar module (LM), initiate its operations, and visit it at about 10-hour intervals to change the detector orientation. The measurements should continue for about 3 days. The following specific detectors are suggested.

X-rays in the energy band of 1 to 100 keV. - X-rays in the energy band of 1 to 100 keV require two different detectors to cover the energy range. A gas-filled proportional counter of about 100 cm^2 can measure the background in the range of 1 to 20 keV. A second detector, consisting of a sodium iodide crystal and photomultiplier, will cover the range of 20 to 100 keV. The detector system (except for the entrance window) must be surrounded by an anticoinci'dence shield.

The counters will occupy about 0.5 ft^3 and require about 100 milliwatts, possibly supplied by a battery in the package. A hard line to the LM can carry the data for transmission to Earth. The data rate is about 100 bps.

The detectors should be provided with 15°- by 60°-field-of-view collimators to permit measurement of the intensity distribution of the background as a function of the angle above and below the horizon. About three or four elevation settings would be adequate during a 3-day period. Each resetting would require about 10 minutes of astronaut time.

<u>y-ray observations (0.1 to 10 MeV)</u>. - An omnidirectional detector for the energy region of 0.1 to 10 MeV would consist of a 3- by 3-inch scintillation crystal of thallium-activated cesium iodide CsI (Tl), surrounded by an anticoincidence shield of plastic scintillator 1-inch thick; both scintillators would be viewed by a single 5-inch photomultiplier tube. Each event is stored in a 128-channel pulse-height analyzer, and the analyzer is periodically read out in a digital code. The counting rates of each scintillator are also coded with an integration time of about 1 second. The detector and associated circuitry weigh about 8 pounds, occupy about 0.1 ft^3, and use about 0.5 watt which could be supplied by a battery. The experiment could be connected by a signal cable to the LM and the data then telemetered to Earth. A data rate of 100 bps would be needed. This experiment could be performed without rotation from the zenith to the nadir.

<u>y-ray observations (energies greater than 50 MeV)</u>. - A directional detector for the energy region greater than 50 MeV would consist of a scintillation crystal in coincidence with a Cerenkov counter to detect the electron-position pair produced by a y-ray photon converting in the crystal.

The counter telescope would also be surrounded by an anticoincidence shield of plastic scintillator. The high-energy y-ray detector used in the Explorer XI satellite would satisfy the above criteria. The detector could be rotated 180° from the zenith to the nadir in six steps to measure the angular distribution of the background radiation. The experiment weighs 28 pounds, occupies a volume of about 2 ft^3, and requires 100 milliwatts, which could be supplied by a battery. The experiment could be connected to the LM by a signal cable and the data relayed to Earth at a rate of 10 bps.

Priorities

The micrometeorite measurements and X-ray background in the 1- to 100-keV band are the most urgent measurements needed. A high micrometeorite puncture rate would render observations in the 1 to 10 keV range impossible. At energies above 10 keV, considerably thicker windows can be used, and micrometeorites are not likely to be a problem. The background measurement in the 0.1 to 10 MeV range is probably the next most important measurement. The soil and thermal properties, the detailed photography and topography of the crater, and the measurement of the y-ray background for y-rays over 50 MeV rank next in importance.

RADIO ASTRONOMY

The Moon has great potential value as a site for long-wavelength radio-astronomical observations. The very large dimensions of arrays (tens of kilometers) required to obtain the needed resolution for the study of planetary, galactic, and extra-galactic sources would be more easily obtainable on the Moon than in orbit around the Earth because of the extremely difficult problem of stowing, deploying, and stabilizing adequately large structures in orbit. An array on the lunar surface should have an effective beam width of 1 degree squared, side lobes of 20 dB maximum, and a declination motion over a 60° range controlled from the Earth. Three preliminary experiments are proposed to determine the lunar environmental factors of importance in the design of large arrays to be located on the lunar surface. Any of the experiments will also yield some measurements of the flux density of solar, Jovian, and terrestrial emissions, although the hip-pocket experiment cannot distinguish between terrestrial and celestial background flux. It is noted that the Moon has another possible application to radio astronomy; some long baseline radio interferometers in the frequency range 400 to 3000 MHz have baselines measured in thousands of kilometers. Such instruments could have baselines up to 400 thousand kilometers if one telescope were located on the lunar surface and one on the Earth, with a corresponding increase in the angular resolution obtainable.

A Noise Survey Conducted From an Early Lunar Orbiter — Experiment I

The experiment will determine the ambient cosmic noise background as well as the noise contributions from the Sun, Jupiter, and Earth. It could also disclose unexpected emission from the Moon. The use of the Moon for occultation provides a tool for determining separately the contribution from the various sources. The orbiter experiment will determine the noise levels on the far side of the Moon.

The range of observed frequencies should extend from 100 kHz to 10 MHz. The choice of frequencies and the number of channels can be made with the particular spacecraft in mind to avoid mutual interference. Three frequencies of observation is a minimum need. However, it is a simple matter to extend the coverage down to include the frequencies of interest to the plasma physicist, that is, to dc. These observations would also give a measure of the properties of the lunar ionosphere at the satellite altitude.

The equipment would consist of a deployable dipole antenna system, measuring 120 feet from tip to tip. Each of the two antennas required weighs 0.5 pound and occupies about 4 in^3. Antenna systems such as the stem or tee systems have been used extensively in satellite programs. Existing radiometers are suitable for this application. They typically weigh 1 to 2 pounds and are about 5 by 7 by 2 inches.

An orbit close to the equator with a nominal altitude of the order of 100 kilometers will suit the needs of the experiment, but the altitude is not critical. A duration of 3 days or longer is desirable. Also desirable but not critical is to have the Sun, Earth, and Jupiter in the same hemisphere. Occasional use of a wideband channel (1 kbps) is desirable for the examination of the statistical properties of the signals

and for the identification of interference. A 1-kbps channel is needed for telemetry for each frequency of observation. It may be possible to observe the occultation of discrete cosmic sources and of the Sun, Jupiter, and Earth from a lunar orbiter. Such observations yield the flux densities, angular sizes, and one coordinate of the angular positions of the sources. An astronaut is needed to carry out specific observations lasting about 1 hour. Such observations would be conducted about four times during a 3-day mission.

A Radiometer in the Pocket of the Astronaut — Experiment II

The experiment represents the very simplest type of survey experiment. Although it lacks many of the advantages of the orbiter experiment, notably the far-side survey and the potential resolution obtained by occultation, a limited yet valuable survey can be carried out by a hip-pocket experiment placed on the lunar surface by the astronaut. This experiment consists of an antenna, a multifrequency radiometer covering the range from 50 kHz to 15 MHz, and an impedance meter. Limited information on the properties of the lunar material will be obtained from the impedance data. Variations in the properties of the lunar ionosphere or local photoemission cloud can be determined from the impedance measurements. The multifrequency radiometer will yield the ambient background noise level and the dynamic spectral characteristics of sporadic sources of emissions.

Although this experiment is not as complete as Experiment III, it goes a long way toward the determination of the basic environmental factors, with an extremely small expenditure of payload. The radiometer, calibration noise source, impedance bridge, and antenna system have already been space tested. A typical weight is less than 5 pounds, and the experiment occupies about 200 in^3.

The astronaut would be required to drop the experiment at a short distance (about 100 feet) from the possible radiofrequency interference sources aboard the lunar landing vehicles, High-data-rate (1000 bps) information would be recorded on tape for a few hours and distributed over the observing period. These data can be returned by the standard telemetry system. During the remaining time, the experiment can collect data at a low data rate (about 35 bps). It would be desirable to connect this experiment to an electronic support system so that data could be obtained and telemetered back to Earth for a long period after the astronaut leaves the site. For example, the Apollo lunar surface experiments package system could supply the necessary electronic support.

Long-term operation of the experiment would allow important environmental data and worthwhile scientific data concerning the long-wavelength dynamic spectra of solar, Jovian, and terrestrial radio bursts to be obtained. It is estimated that the astronaut will take 1 hour to set up the experiment and conduct certain measurements at the high data rate.

Simple Interferometer on the Lunar Surface — Experiment III

The experiment is designed to determine the electrical characteristics and radio noise environment at the lunar surface to permit evaluation of the site for a future large kilometer-wavelength radio telescope. Specifically, the environmental factors to be determined are as follows:

1. The complex impedance of the antenna in the vicinity of the lunar surface as a function of frequency and as a function of the height of a standard dipole antenna above the lunar surface must be determined.

2. The electron density of the lunar ionosphere, the electron-density distribution with height and time, and the density and characteristics of the photoelectric cloud (if it exists) at the lunar surface must be determined.

3. The integrated radio noise background intensities must be determined.

4. The position, motion, and intensity and dynamic spectra of strong sources of solar system noise such as the Sun, Jupiter, and Earth must be determined.

The measurements of the complex impedance of a standard antenna will require the extension of the antenna on a stand which can be placed at various heights above the lunar surface up to heights of 6 feet. A self-deployed stem antenna mounted on an insulated stem device will serve this purpose. The antenna complex impedance is determined by standard techniques. For example, flight-qualified (orbital) impedance probes already are available. The impedance measurements will be made at each height over a frequency range of 50 kHz to 10 MHz. The number of frequencies in this range and the exact range may be modified as knowledge of the lunar material improves.

A typical impedance bridge weighs 2 pounds for a 10-frequency instrument and occupies a 2- by 7- by 9-inch volume. Power required for the short measuring cycle (a few seconds per measurement) is about 1 watt. The weight and size of the antenna element is considered later, since the antenna element is also used as part of the system for noise measurements.

The measurements of the local ionosphere and/or photoemission cloud can be accomplished by the various types of traps or Langmuir probes used in orbital experiments for detecting electrons or ions. The measurements can and will be complemented by determining the local electron density from the radiofrequency-impedance measurements discussed previously.

The most vital part of the environmental measurements is the determination of the ambient noise level and the observations of the position, intensity, and motion of sporadic radio signals, which the establishment of an extremely simple two-element interferometer will allow. The interferometer will, under suitable observing conditions, measure the noise contributions from Earth, the Sun, and Jupiter independently. Such observations are worthwhile scientifically, and they are essential in the design of a large array since an assessment must be made as to how badly the sources will interfere with the observing program of a large array.

The two elements of the interferometer, electrically short antennas deployed and mounted as described previously, will be separated 'about 1 kilometer in the east-west direction. The best height of the elements above the lunar surface can be determined from the impedance measurements. It is possible that the antennas can simply be laid on the lunar surface.

The major tasks required of the astronauts for the establishment of the interferometer are (1) surveying an east-west baseline to an accuracy of about 50 feet, (2) carrying and unreeling the feeder system (about 4 pounds) to the end points, and (3) setup of the individual antenna elements. The radiometer system for this swept-frequency interferometer has for the most part been developed. The frequency range of the interferometer will be approximately 500 kHz to 15 MHz. The high-frequency end of the interferometer observations is made to overlap with Earth-based interferometer measurements. One element of the system will be used for integrated noise and dynamic spectra measurements of 50 MHz to 15 MHz.

In summary, one element of the interferometer will be used for impedance and local plasma measurements; the other element of the interferometer will be used for average noise and dynamic spectra observations; and the two elements together will be used as a swept- or stepped-frequency, two-element interferometer for solar-system noise source observations. The estimated weight of the system is 20 pounds with a power during normal operation of 2 watts. The size of the stowed instrument is between 2 and 3 ft^3 and includes antennas, an impedance probe, and cables.

Two astronaut hours are needed to lay out the transmission lines and set up the antennas. Two more hours are needed for other measurements. The remainder of the data, recorded at low rates (50 bps) can be telemetered to Earth automatically.

Site Requirements

The major instrument, planned for later use, requires a large area of 30 by 60 kilometers and free of cliffs, mountains, canyons, et cetera. The simplest criterion of acceptability is that an astronaut could walk throughout the area. Equatorial latitudes are preferable. If the Earth proves an unexpectedly strong source of interfering signals, a site on the back side of the Moon would be preferred.

Experiments II and III could be performed anywhere that an Apollo spacecraft is likely to land, but equatorial latitudes are preferable.

Priorities

The design of the large kilometer-wavelength radio telescope will require a detailed knowledge of the lunar environment. Therefore, Experiment III must be considered as highest on the priority list, since it will provide the necessary environmental measurements.

Experiments I and II are considered of equal priority as far as a noise survey is concerned, for although Experiment II gives impedance data as well, Experiment I

provides noise measurements on the far side of the Moon and the possible separation of noise sources. In general, if Experiment III cannot be carried out early in the program, it appears essential that either Experiments I or II should be substituted. Experiment II is extremely simple to conduct and has a high success probability. The potential scientific value of the Lunar Orbiter (Experiment I) as a noise survey platform and as a platform from which to perform lunar occultations of discrete sources deserves careful consideration. Although the substitution of experiments deviates from the mainstream of the proposed program, NASA is urged to consider the value of such a project independently.

NONSOLAR OPTICAL ASTRONOMY

The ultimate goal of nonsolar optical space astronomy is a large precision telescope in the 100-inch class. The Moon is a possible site for such an instrument, especially if the potentially serious problems of scattered light, accurate guidance, and thermal control cannot be solved in Earth orbit. Thus, the central task of the early lunar astronomy program must be the evaluation of the Moon as a site for a large telescope with consideration given to environmental factors (that is, can large telescopes be operated on the Moon) and to scientific factors (that is, should large telescopes be operated on the Moon). The lunar investigation begins with small site-testing packages and gradually incorporates more scientific packages to examine operational and astronomical engineering problems and to demonstrate the extent to which the Moon offers unique advantages for optical astronomy.

Potentially, the Moon may offer both scientific and environmental advantages over orbital systems, Among the most apparent reasons for lunar operations are the following:

1. The lunar night on or near the lunar far side offers the ultimate in minimizing background light and noise for faint-signal discrimination. In orbit, the primary light sources of the Sun, Earth, and Moon combine with complex time-dependent view patterns scattering from structures and contaminants and with local radiation noise to degrade the ultimate signal-to-noise ratio obtainable.

2. The lunar horizon occults the Sun and thus permits near-solar access for measurements of the inner planets, comets, zodiacal light, and outer coronal features. Orbital systems become highly constrained within about 45° of the sunline.

3. The Moon provides a platform with a known time coordinate system which allows highly predictable and rapidly programable orientation control, programable drive, and single-star guidance control.

Other factors which could offer advantages for specific problems include the following:

1. Access to virtually every point in the sky (in the dark) every lunar month for relatively long, uninterrupted periods

2. Availability of local radiation shielding so that film can be protected for long periods against cosmic rays

3. Minimal velocity-dependent effects such as differential aberration and Doppler shift during an observation

4. Low local magnetic fields

5. Flexibility of the manned interface

6. Long-term growth, self support, and operational flexibility

7. Location outside the geocorona of the Earth which will reduce the Lyman-a background brightness

Lunar Experiments

In the period covered by this study, the emphasis in lunar astronomical experience will be on environmental evaluation with simple compact packages. The following listing of early experiments is considered to be fairly exhaustive, although additional unknowns may arise. A more detailed discussion of the relevant experiments is given in later sections.

Environmental studies. - The environmental studies include measurements of the following:

1. Thermal mapping (spatial and temporal) and thermal properties of materials

2. Dust and scattering contaminants and optical degradation

3. Microparticle environment

4. Natural and locally-induced seismicity and vibration

5. Soil mechanics relating to erection of large stable structures

6. Local radiation environment and radiation depth profile

7. Surface luminescence, night, earthlit, and sunlit illumination levels

8. Lunar motions

Scientific studies. - The scientific studies include determination of the following:

1. Sky brightness on a coarse scale (approximately 1° resolution)

2. Near-solar sky brightness on a moderate scale

If the earliest lunar experiments demonstrate the possibility of effective operation on the Moon, more sophisticated experiments with astronomical instruments can begin the accumulation of operational and technological data.

Site Considerations

Unlike geological exploration of the Moon, astronomy requires the selection of a single specific site. Selection of the astronomical site with site-testing instrumentation emplaced there requires considerable planning because as lunar development proceeds and if lunar astronomy becomes fully and demonstrably desirable, the same site will be revisited and utilized. Possibly, the site evaluation emplacements will not be revisited, but later instrumentation will be designed to suit the site. Also, a progressive knowledge of the site as a base must be accumulated.

The astronomical site should be near but slightly south of the equatorial plane to provide favorable access to the Magellanic clouds which lie close to the south lunar rotational pole. If the southern latitude is too great, an appreciable segment of the sky will be lost in the north circumpolar cap. A desirable latitude range appears to be $-5°$ to $\pm 3°$.

The site for the very large telescope should be on the far side of the Moon, continuously beyond the visible range of the Earth, to achieve the best dark conditions through the elimination of earthlight. There is no optical requirement that the site be more than slightly beyond the maximum libration limb, and a site which libration occasionally brings into view of the Earth is acceptable. Since the ultimate desirability of far-side operations may present an initial operational restriction, early exploration may be desirable for a second near-side limb site with a longitude from the central meridian of $75° \pm 10°$.

The two near-side limb sites lie near Grimaldi and Langrenus. Both areas have moderately broken terrain. The terrain at the final site should be fairly flat without great local roughness or an irregular horizon. The southern horizon, particularly, should be unobstructed. A slight elevation favoring southern exposure and perhaps somewhat above the lowest levels of the possible secondary ejecta haze should be considered. The highest site altitude which can be achieved without recourse to very rugged terrain may be advantageous.

Thermal hotspots are known to occur on the Moon. The spots may be either advantageous or disadvantageous astronomically, depending upon their exact character. If the spots do not have local structural or seismic drawbacks, the moderation which they offer of the lunar nighttime ground-radiation temperature appears desirable. Therefore, an understanding of the nature of thermal hotspots is of possible significance to astronomy, although a detailed investigation of such zones for astronomy alone is not of high priority.

In the early phases, optical astronomy will place only minor requirements on astronaut surface mobility. Instrument packages for optical astronomy need never be placed beyond 1 kilometer from a landing site and can usually be closer. The initial tasks for men on the Moon should not involve more than one man at any time. The tasks definable at this time include (1) deploying experiment packages from the LM to the

lunar surface, (2) orienting instruments, (3) activating experiment packages, (4) providing man-induced perturbations (such as raising dust or walking near seismic recorders), and (5) drilling at the site and making soil mechanics measurements. The initial mission duration need not exceed 1 day for each experiment unless the drilling requires more time. However, some packages must be left to operate automatically for at least a month. A requirement for one or more 15- to 20-foot drill holes would be the pacing item in manned requirements on an early mission.

Eventual astronomical operations on the Moon will require a capability for nighttime operations on the lunar surface. These should be of short duration (less than 1 hour), of short range (less than 1000 feet), and over terrain well known from daytime operations. For operations which might include the assembly of large complex instruments, a thorough knowledge of the capabilities of man in the lunar environment must be obtained.

The selection of primary and alternate sites for early exploration will require the collection and analyses of available data on the regions specified in this report in conjunction with restrictions on Apollo missions. Consideration should be given to the joint value of the site for geological and astronomical purposes and to the implications of longer term operations at the site.

Site Evaluation Experiments

The thermal properties of lunar soil and the thermal behavior of various materials and systems in the lunar environment must be determined. Sensing elements will be thermistors in simple bridge circuits that occupy a fraction of a cubic inch and draw only milliwatts. The following temperatures must be measured throughout a lunar month and, where possible, through several months to determine long-term degradation effects.

1. Temperature must be measured as a function of depth under the lunar surface, to about 1 foot with some deeper measures in drill holes; thermistor probes should be placed at the surface and at about 1, 2, 6, and 12 inches in depth.

2. Temperature must be measured on the top and bottom surfaces of test pads of selected materials such as aluminum with various paints, superinsulation, structural plastic with various paints, polished steel, and steel ground to various degrees of roughness, et cetera; use can be made of materials on the Moon for other experiments.

3. Temperature must be measured within 1- or 2-inch hemispherical enclosures or comparable instrument boxes of various materials exposed to total solar radiation. Gold plating, titanium oxide paint, and other thermal control coatings for which the emissivity is well known can be used. Secular changes in response will also be a measure of surface degradations.

4. Temperature must be measured on an aluminized fused-silica mirror about 3 inches in diameter and 0.5 inch thick exposed to cold sky at night and after dawn; the temperature should be monitored on the front, back, and edges as a function of time.

The microparticle environment must be measured to derive data on the direct impact damage from the primary and secondary fluxes, on dust accumulation, and on particle flux as a function of elevation angle, azimuth angle, and time. The electrical-charge properties of secondaries should be determined. These data will provide a direct assessment of optical damage and indicate what means might be employed to minimize degradation,

Measurements should employ penetration detectors and, possibly, acoustical detectors set at various angles. Optical surfaces should be monitored for scattering, transmission, and reflection in several geometries. A variety of optical materials and surface coatings should be employed, including some surfaces with electric-field shielding. While not essential, package recovery is desirable after a period of several months. The contamination of a test surface produced by a prescribed and typical adjacent manual operation and by the effects of LM ascent should be monitored with the parts of the experiment activated following LM departure. If feasible, a simple fixed photometer should be utilized to observe bright-star settings to detect any haze-layer light attenuation. The weight of such a photometer is estimated to be 2 pounds with a volume of 500 in^3 and a power consumption of 1 watt. One hour of astronaut time will be required to set up the photometer.

The local vibration of seismic pattern should be recorded, including both natural seismicity and vibrations induced by man during a prescribed task, with emphasis on frequencies below 5 cps and on amplitudes in excess of 0.5 micron. Motion at the surface and subsurface should be compared, if possible, to distinguish surface thermal creep-relief motion or differences in the unconsolidated layer and substratum response. Any creep relief in excess of $0.5\mu/\text{sec}$ must be detected. The LM ascent vibration should be measured.

The soil mechanics of the site must be monitored in a prescribed and recorded pattern including onsite measurements of bearing strength, compressibility, and other structural indices. Soil and rock samples must be preserved and returned. Drilling to several feet in an estimated 20-foot grid over a 100-ft^2 area and to 15 to 20 feet in one or more central locations is required to ascertain the depth of the unconsolidated layer and the variation of structural, chemical, and radioactive properties with depth and to provide a test hole within which thermal, radiation, and possibly seismic data can be obtained. Representative parts of the cores must be returned. The need for deeper drilling has not been determined, but deeper drilling might be required in a followup mission.

The pattern of particle radiation (proton and electron components as they affect optical systems, photographic films, and photoemissive detectors) must be monitored on the surface as a function of time to determine the typical quiet and solar-flare radiation doses, The cosmic-ray secondary shower dose and local radioactivity profiles with depth must be monitored to evaluate the feasibility of subsurface storage of film. Measurements to 15 to 20 feet appear necessary.

Illumination levels should be measured from various types of terrain and at various angles throughout the lunar cycle to provide definitive measures of the phase-dependent light levels of sunlit, earthlit, and dark terrain including possible

surface-luminescence effects resulting from radiation exposure. A luminescence photometer for use in the command and service module (CSM) in lunar orbit while over the dark lunar face or earthlit face would permit a general survey for luminescence, although this is of minimal priority for astronomy.

Existing or proposed geological or physical instrumentation may provide suitable measurements of many of the desired parameters, and joint utilization should be made whenever possible. It should not be assumed without thorough review, however, that existing instruments and currently planned measurements will automatically satisfy the astronomical program. The astronomical program must make use of the broad lunar geological study to compare the astronomical site with other parts of the Moon. Thus, the astronomical survey plan should be closely coordinated at all levels with the geology planning. Thermal, microparticle, seismic, soil mechanics, radiation, and lunar-motion instrumentation will exist for other programs and can be adapted in many cases, although microparticle measurement has not been emphasized in the present plans.

Optical Environment Test Package

The instrumentation required for the optical evaluation of the Moon is unique to astronomy. Thus, such instrumentation should receive high priority for development and flight. The optical environment test package should include most of the following: (The suggested techniques are illustrative only and will require considerable detailed refinement.)

1. Degradation of reflecting and transmitting optical surfaces by microparticle and radiation etching and radiation darkening can be most easily detected by retrieval of optical elements which have been left on the Moon for several months and preferably for at least a year. Automated techniques can be envisaged but they are probably less satisfactory. The test-instrumentation parameters are as follows:

Weight, lb	3
Size, in^3	500
Power (automated operation), W.	1
Astronaut's time, min	30

2. Degradation of optical surfaces by settling dust can be monitored by measuring the changing brightness of bright stars which transit the field of view of a small photometer. A standard calibration source must be measured alternately with the sky brightness. The test-instrumentation parameters are as follows:

Weight, lb	10
Size, ft^3	0.5
Power, W	2
Telemetry, bps	20
Astronaut's time, min	30

3. Additional information on dust and microparticle damage and on particle flux and direction can be obtained by monitoring the growth of light signals behind

aluminized glass plates and behind Mylar films of various thicknesses, or by retrieving the films and plates after several months. An electric-field screen in front of one or more detectors can determine the charge on the dust grains. The test-instrumentation parameters are as follows:

Weight, lb	3
Size, ft^3	500
Power, W	1
Telemetry, bps	10
Astronaut's time, min	30

4. Extinction effects in a horizontal haze layer can be monitored by tracking setting stars with a fixed-image dissector. Further, star pattern identification will provide good orientation data and show whether any positional shifts occur in the package. Sky brightness as a function of wavelength can be monitored with a small, automated meridian photometer. These can be combined with a small photometer. The test-instrumentation parameters are as follows:

Weight, lb	15
Size, ft^3	0.5
Power, W	2
Telemetry, bps	20
Astronaut's time, min	30

5. Thermistors should be mounted on and in these instruments to understand the thermal environment of the instrument.

6. A crude indication of the particle radiation intensity and spectrum will be useful.

Typical Scientific Experiments

Few astronomical experiments will be made during the Apollo period. The principal astronomical interest will be in monitoring the broad geological data for the Moon. The lunar motion derived from Earth-based observations of corner-cube reflectors will also be of interest.

A small handheld wide-field photometer could be used from the CSM in lunar orbit to test for the existence of lunar luminescence on the lunar dark face and to measure typical earthglow and sunlit light levels at various wavelengths. Such a device would yield data of geological and astronomical value, but the device is not of high astronomical priority. Such an instrument would weigh about 1.5 pounds, occupy 0.2 ft^3, and require a few watts. Recording could be manual or by tape recorder at a low bit rate (about 10 bps).

Priorities

The primary astronomical environmental test package should be emplaced on the Moon in the early post-Apollo period. The 'early scientific experiments are of limited priority, but desirable ones appear to include the following: (1) wide-field photometry of the general sky brightness on a coarse scale (1° resolution) which has both environmental and scientific value and can be accomplished with a simple meridian telescope and (2) mapping the sky brightness near the Sun after sunset (or before sunrise) to approximately 1-arc-minute resolution, Each experiment requires approximately 1 ft^3 and weighs 5 to 10 pounds. Some parts of the experiments can be combined easily with the optical evaluation package.

If the lunar environment proves optimal for astronomy during the early program, it will be highly desirable to land scientific packages on the Moon in the later Apollo Applications Program (AAP) period. The packages should be designed to begin the effective utilization of the scientific advantages of the Moon and, particularly, to begin the accumulation of operational experience. The following are typical experiments which would utilize the advantages of a lunar site:

1. Twelve-inch high-resolution imagery of near-solar objects such as Mercury, at 100-kilometer resolution

2. Differential photometric survey of a large sample of stars for intrinsic stability, surface phenomena, and Jovian-type planetary transits across stellar disks (The slowly rotating lunar reference frame simplifies the instrument operation.)

These experiments range from the 100- to 1000-pound class and are typical of the type of lunar experiments which can command scientific priority and provide operational experience on the Moon.

Priority Summaries

Measurements of highest priority which have basic impact on astronomical planning include the following:

1. Optical environment test package'
2. Seismicity
3. Microparticle mapping
4. Basic soil mechanics

Important but of lesser priority are the following measurements:

1. Radiation environment
2. Deep drilling and variation of structural parameters with depth

Also of interest are the following measurements:

1. Lunar luminescence

2. Lunar motions

Scientific experiments for the early period include two experiments of relatively low scientific priority.

1. Luminescence photometry from the CSM in orbit

2. Sky-brightness photometry with coarse and fine resolution

Some parts of these experiments can be incorporated into the general optical evaluation packages.

SOLAR ASTRONOMY

Present plans for solar astronomy in space are based on spacecraft in Earth orbit, but two problems may arise which would limit the usefulness of orbiting spacecraft for solar astronomy. First, it may not be possible to guide the spacecraft with the required accuracy of 0.01 to 0.1 arc second; and second, scattering due to the spacecraft environment may impair the effectiveness of a coronagraph.

In this case, despite the higher cost of a lunar mission, it will be necessary to consider a Moon-based solar telescope. Since the lunar environment may also present difficulties for solar astronomy, the investigation should be commenced between 1971 and 1973.

To accomplish such a course of action, several experiments are suggested to be carried out in the following order of priority:

1. A small convex (to avoid the danger of a focused beam) precision-ground optical mirror about 4 inches in diameter should be exposed to possible dust, micrometeoroids and other particles, thermal changes, and evaporation effects for several days and then be returned to Earth. Careful premission and postmission inspection would reveal lunar deterioration of the mirror surface. The experiment will require about 30 minutes of one astronaut's time on the lunar surface and weigh about 3 pounds, including a vacuum-tight carrying case.

2. A small, externally occulted ultraviolet coronagraph, similar to the ones currently being flown by the Naval Research Laboratory in rockets, should be used on the lunar surface to investigate in more detail the lunar atmosphere environment and particularly problems of dust which might produce undesirable scattering. Time requirements for one astronaut are about 3 hours for initial setup and 30 minutes a day for alinement checks and for changing film. The volume of the experimental hardware is 1.5 ft^3, the weight about 75 pounds, and requires about 10 watts of power,

Other data about the lunar environment which will be needed prior to installation of a large solar telescope include the following:

1. Bearing strength, stability, and seismic disturbances of the surface (similar to, but probably less severe than, those needed by stellar astronomers)

2. Knowledge of the extent of radiation damage to film (fogging) and to electronic components

Other than the need to acquire the Sun for long time periods (which might exclude craters of a site with nearby obscuring mountains) no serious site location problems are anticipated. These experiments could, therefore, accompany other site-dependent experiments.

Some early experiments of scientific value to solar astronomers would include the following:

1. A telescope of 8- to 12-inch aperture equipped to obtain time-lapse pictures in white light and simultaneous filtergrams in Hα, Ca^+(K), or some other convenient wavelength

2. A similar telescope equipped with a universal spectrograph for the wavelength region 300 to 3000 Å

3. A similar telescope equipped with a Lyman-α spectroheliograph, such as planned for the Apollo Telescope Mount.

APPENDIXES

APPENDIX A

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APPENDIX B

Photography by Astronauts on the Lunar Surface

The following group met on August 2, 1967, to discuss lunar photography: Thomas Gold, Eugene Shoemaker, Wilmot Hess, Harold Mazursky, Capt. William T. O'Bryant, J. Schmitt, Harold Gartrell, M. H. Hait, and Fred Pearce. The subjects discussed were landing-site photographic survey, closeup photography, handheld conventional range photography, and training.

Landing-site photographic survey. - It was generally agreed that panoramic photographs from a high vantage point, such as on top of the lunar module (LM), would be of great value from a scientific investigative standpoint and would serve to document the position of the LM. The photographs should be stereo, and the stereo baseline possibly should be vertical and adequately long, approximately 1 or 2 meters. There are complications in taking photographs from the top of the LM. The spacecraft hatch at the top is blocked by gear at this time, and there is a concern for the safety of the astronaut in clearing the gear and opening the hatch. Other means of obtaining a high vantage point, such as an erectable mast or pole, should be investigated.

Closeup photography. - Dr. Gold described a special handheld microphotographic instrument suggested by Dr. Purcell, Dr. Land and himself. It is a 35-millimeter camera with matched stereo lenses of f/20 to f/40 aperture to work perhaps between unity magnification and at one-third scale. The field of view would be 24-millimeters square at unity magnification. Illumination would be from a strobe unit incorporated into a housing surrounding the field of view. The interior of the housing would be a reflector. The focus, aperture, and shutter speed would be fixed. The shutter is merely a gate in which the flash duration actually determines the exposure. The device would be mounted on a stick to facilitate use. The only control would be a shutter release on the stick. Film transport can be either electric or from a manually operated lever on the handle to save battery weight and complication. A resolution of 40 microns was suggested as readily obtainable from the tiny, relatively simple lenses. The weight was estimated at 2 pounds.

There is a case for using color film for such a closeup instrument. Among those present, the support for developing such a camera was unanimous.

Handheld conventional range photography. - Dr. Gold suggested a simple device for making stereo pairs with a Hasselblad camera. A ski-pole monopod is fitted with a two-position bubble level which indicates the camera position on each side as the assembly is tilted. Dr. Schmitt pointed out that two vertically detented positions on the staff had been considered for the same purpose. The ski-pole tilting method appears to be less demanding on the astronaut and would give more natural horizontal-base stereo.

Dr. Gold is concerned that a handheld exposure meter is too awkward. Since the only variables are Sun angle and azimuth of the sight line to the Sun angle, he suggested that a very simple sundial divided into a few sectors and mounted on the camera would suffice to give the correct exposure dependence on azimuth. The dependence on Sun elevation angle can, of course, be provided for beforehand. The remaining variability which is due to local properties of the lunar ground is well within the normal brightness range on a photograph.

Training. - Dr. Gold suggests that all potential astronauts for the Apollo lunar landing missions be especially trained in photography, generally, and in particular, in the use of the Hasselblad camera for the early Apollo missions. The astronauts should be given Hasselblad cameras with viewfinders similar to those to be used on the Moon. They should be encouraged to take many pictures of their everyday activities and surroundings. These pictures should be extensively criticized by an expert who would give each participant constructive advice. Such a program will help instill an instinct for good documentary pictures on the lunar missions. In conjunction with this program, a large lunar photometric model should be constructed inside a building such as an old hangar. A collimated solar simulator would be mounted so as to offer a variable time-of-day light source. The training program would schedule exercises and routine photographs in this simulator.

In training and in the design of future camera equipment particular attention must be given to the problem of correctly framing each picture. The viewfinder must readily accommodate to the faceplate of the pressure suit.

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