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MANNED LUNAR SCIENTIFIC OPERATIONS

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LUNAR SCIENTIFIC OPERATIONS

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This paper outlines the major objectives, methods, and expected results of manned lunar scientific operations possible with payloads transportable by launch vehicles developed for the Apollo project.

The chief scientific benefits expected from manned lunar exploration lie in the areas of comparative planetology and the study of the evolution of the solar system, and stem largely from the absence of an atmosphere and atmosphere-dependent geologic processes.

Manned lunar exploration should include three main phases:

1. Detailed orbital surveys, using photography, multispectral sensing, and geophysical methods.
2. Surface exploration traverses, during which geological, geochemical, and geophysical investigations would be made, and
3. Fixed-site, long duration studies of the moon, including geophysical monitoring and deep drilling.

After the lunar environment has been investigated by these methods, the moon might then serve as a uniquely valuable site for optical and radio astronomy, space physics, and biological studies.

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INTRODUCTION

Early manned lunar missions should center on scientific operations for two reasons. First, the scientific exploration of the moon has great inherent value; second, it will provide the necessary foundation of knowledge for later lunar and planetary missions. The purpose of this paper is to outline the major objectives, methods, and expected products of manned lunar scientific operations possible with launch vehicles and spacecraft, or modifications thereof, developed for the Apollo project.

The opinions expressed are those of the authors and do not represent official NASA policy. The projects described are not necessarily approved programs.

SCIENTIFIC BENEFITS OF MANNED LUNAR EXPLORATION

In addition to the more general benefits expected to accrue from manned lunar exploration, such as the stimulus to space technology and the focussing of the national space effort, we can expect significant scientific advances in a number of areas, some of the more important being the following:

Comparative Planetology

The scientific study of the moon is expected to produce fundamental discoveries in comparative planetology ("planetology" being defined as the study of planets and satellites by geological and geophysical means).

Because of the moon's great size, as compared with the earth, it can properly be considered the earth's sister planet. If, as seems probable, this sister planet has never had an appreciable atmosphere or hydrosphere, it furnishes us with a unique control in comparative planetology, because two major variables, air and water have had little or no effect on the moon's evolution. The importance of these

two factors in the development of the earth's crust is not commonly realized; however, most of the land forms and the vast bulk of rock (possibly including many igneous rocks) exposed on the earth are the products of atmosphere-dependent processes such as erosion and sedimentation. It should be emphasized that it is, in fact, difficult or impossible for geologists and geophysicists to separate completely the indirect or second and third generation effects of surficial processes from those of internal processes.

Two closely related problems, the origin of continents and the origin of granite, illustrate the potential application of comparative planetology to terrestrial geology. The continents are composed largely of granitic rock (using "granitic" in a broad sense), whose ultimate origin is not understood. The essence of the problem of the origin of granite, and hence of continents, is the importance of igneous processes. One school of thought holds that continents were, at least initially, formed by igneous differentiation in the primordial earth; opposed to this is the view that the continents are essentially sedimentary aggregates, modified by igneous and metamorphic processes[2]. Study of the geology of the moon should provide new insight into this problem. Because of the absence of sedimentary processes on the moon, the discovery of substantial quantities of granitic rock would provide support for an igneous origin for the earth's continents; the absence of lunar granites would support the opposing view.

Study of the moon will undoubtedly shed light on the role of major meteoritic impacts in the earth's origin and evolution. If the vast majority of lunar craters and maria prove to be the results of impact, as expected by many scientists, it will strongly suggest that impact was

important in at least the early evolution of the earth. If our studies were confined to the earth, solution of this problem would be extremely difficult, because ancient impact craters are frequently buried and obliterated by later sedimentation and erosion.

A last example of the moon's role as a comparison planet deals with the theories of the origin of metallogenic provinces (the clustering of ore deposits of the same metal over broad geographic areas) on earth. If such provinces result from compositional difference in planetesimals that formed the earth, the search for hidden ore deposits would be placed on a broader basis than at present. Wide-scale geochemical studies of the moon might lead to a resolution of this question, which is of direct economic importance.

The Lunar Geologic Record

It seems certain that a comprehensive program of lunar exploration will produce knowledge of fundamental importance about the early history of the earth and the solar system. It should be stressed, furthermore, that this knowledge can come only from investigations of solid bodies such as the moon and planets. Spaceborne investigations, which measure chiefly particles, fields, and radiation, tell us essentially what is happening in the solar system now; but the detailed examination of the solid bodies of the solar system will reveal its history, because solids remember, in a sense, what has happened to them. Of these solid bodies, the moon is the most promising for such studies for reasons which will be made clear in the following sections.

Although the moon is thought to have the same age as the earth, some 4.5 billion years, the commonly held belief that all of the moon's exposed surface is this old is probably not correct, and recent observations of changes

near and in the crater Aristarchus show that the moon is by no means geologically dead. However, the absence of earth-like weathering, erosion, and sedimentation make it virtually certain that we shall find a much better record of the moon's early history than we have of the earth's early history. Since direct evidence of the first billion years or so of the earth's development is unknown, a detailed examination of the moon would be of immense scientific value, telling us much, by analogy, about the earth's early history which can be learned no other way. This period of the earth's evolution is of great interest, because it was then that the earth's oceans, atmosphere, and continents began to form.

Even more important is the possibility that we may eventually find a reasonably complete record of the origin and development of the solar system, by study of the moon's history and of its accumulated meteoritic debris. A related possibility would be the deduction of the temperatures at which the moon, and by analogy, the planets, were formed. This would of course require a comprehensive program of geological mapping and geophysical measurements. However, the interpretation of thermal data produced on the moon would be somewhat simplified by the absence of the complications caused on the earth by sedimentation, long-term climatic changes, and unknown phase changes brought about in the interior by high pressures that cannot now be reproduced in the laboratory.

From the above discussion, it is apparent that the moon is a virtual Rosetta stone that, if properly read, may permit us to learn how the solar system, the earth, and the continents on which we live were formed.

EVOLUTION OF LUNAR EXPLORATION

Before discussing specific scientific operations, it is necessary to review the organization of lunar exploration as a whole, and to suggest some general principles for planning manned lunar missions.

The initial phase of lunar exploration, examination and mapping of the moon by earth-based instruments, has been underway since the invention of the telescope. Recent developments, such as the geological mapping being conducted by the U.S. Geological Survey, show that the potential of earth-based observations has by no means been exhausted and that new data are still forthcoming.

The second phase, that of investigation of the moon by unmanned spacecraft, is also well underway. Future unmanned lunar probes can be expected to provide valuable engineering and scientific data about the moon.

The third phase will begin, hopefully, by the end of this decade with the first manned landings. Because of limited stay time and payload capabilities, scientific exploration will be restricted in scope during the early Apollo missions. Manned operations after these initial landings could conceivably permit a greatly increased scientific program. It is felt that a program of lunar exploration should include the following main phases:

A. Orbital Surveys

B. Surface Traverses

C. Fixed-site Investigations

- Moon-oriented (geophysical monitoring, deep drilling, etc.)
- Moon-based (astronomy, biological studies, etc.)

The interrelation of these various phases is illustrated in Figure 1.

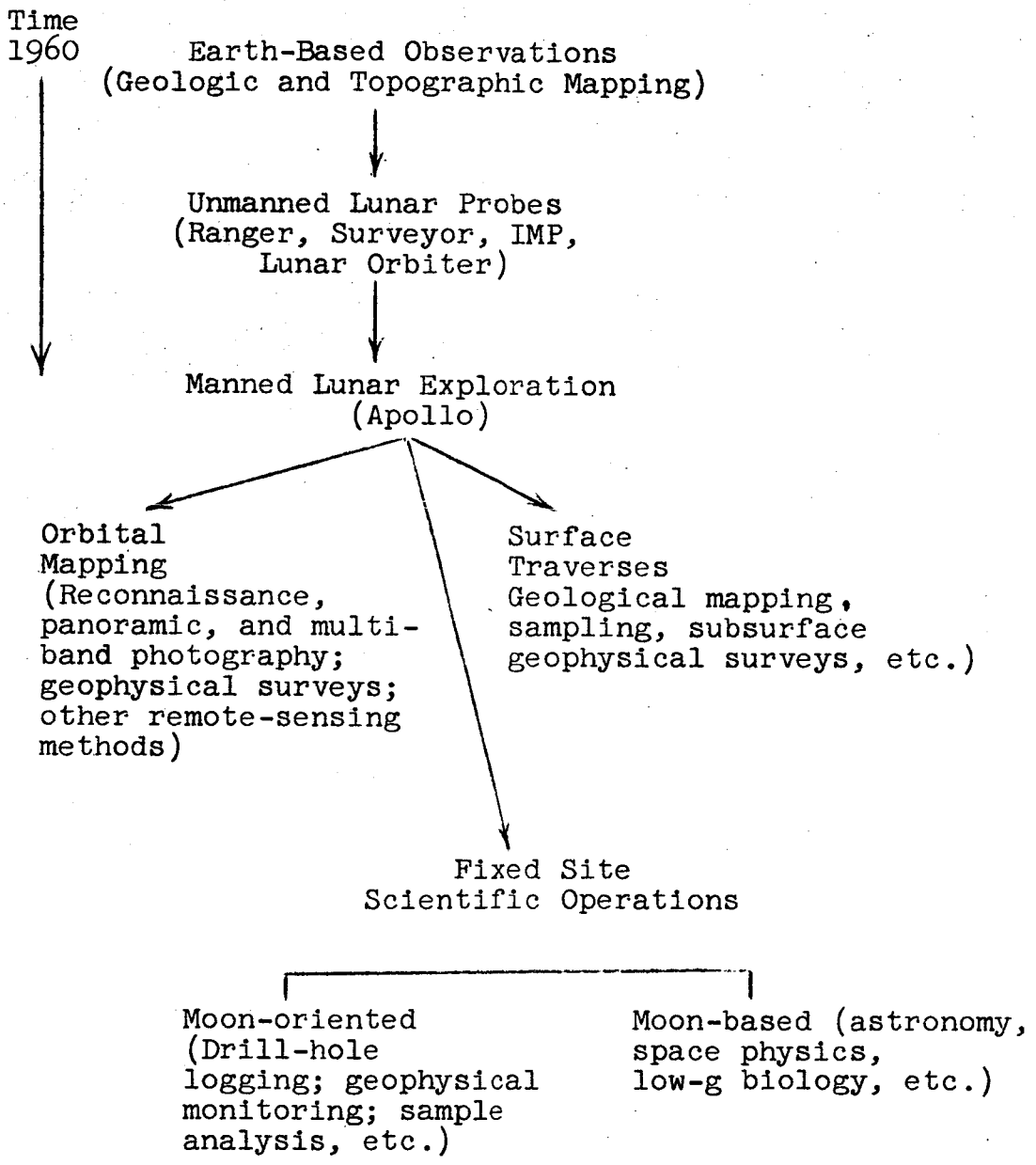

Figure 1 The Evolution of Lunar Exploration

Since the scientific investigations of highest priority are in the fields of geology and geophysics, it appears that there is definite value in extending manned lunar exploration by the use of modified Apollo equipment. Experience has shown that geophysical and geological mapping investigations of large areas are continuing tasks; like the painting of the Golden Gate Bridge, they are never really finished, because new concepts, questions, and methods evolve during the program. The occasionally-expressed view that the major questions about the moon could be settled by a few landings and the return of a few samples ignore the experience of several centuries of terrestrial geology and geophysics.

It also seems certain that adequate exploration of the moon will require long-distance surface traverses, rather than a few landings with restricted radius of operations. Terrestrial experience demonstrates that the ability to examine large areas in detail is fundamental to the solution of difficult geological problems, and the size and number of lunar features indicates that this will also be true on the moon. This does not imply that the entire moon will be mapped on the surface. Most of the mapping will have to be done by photography and other remote-sensing methods from orbiting vehicles because of the moon's large surface area. The surface program should consist essentially of field-checking maps made from data obtained from space, and supplementing these data by detailed studies and by subsurface investigations.

After the nature of the lunar environment and the extent of lunar resources have been determined, the moon can be used as a platform for many other investigations. These are described in brief in the last section of this paper.

SYSTEMATIC ORBITAL MAPPING

One of the major objectives of the exploration of the moon's surface will be topographic and geologic maps. Much mapping on the earth, chiefly photography, is done from aircraft by various remote-sensing methods. These methods can, in principle, be adapted for use in the systematic mapping of the moon.

The low speeds and altitudes characteristic of aircraft cannot, however, be matched by vehicles flying over the moon without high fuel expenditure, since flight must be entirely reaction-sustained. Remote-sensing techniques must therefore be adapted for use aboard orbiting spacecraft. Altitudes on the order of 8 to 80 miles and speeds of approximately 1 mile per second will be required of lunar satellites. Under these conditions, it may be difficult or impossible to duplicate the resolution of some types of terrestrial airborne surveys. Nevertheless, several techniques appear promising for systematic orbital mapping, including the following.

Photography

High resolution space photography (the orbital analogue of aerial photography) is believed to have great potential value for geologic and topographic mapping[3]. There appear to be three major types of space photography which can be performed from lunar orbit:

a. Small-scale reconnaissance photography with relatively small cameras (e.g., 70mm format) using only one or two film types.

b. Large-scale photography with long focal length panoramic cameras, corresponding in scale and application to

conventional aerial photographs.

c. Multispectral photography carried out with an array of relatively small cameras, each of which would produce pictures in a small region of the spectrum.

Other Techniques

Because the application of remote-sensing techniques even to aircraft is still in an elementary stage, we can only list some possible lunar uses (Table 1). For more detailed descriptions of these methods as used on the earth, the reader is referred to Shellman[4].

Table 1

POTENTIAL ORBITAL MAPPING TECHNIQUES

Technique	Possible Application
Infrared sensing[5]	Compositional mapping, detection of thermal anomalies, location of subsurface ice
Radar	Topographic mapping, measurement of dust thickness
Passive microwave radiometry[6,7]	Mapping subsurface structure
Magnetometers	Mapping broad features of lunar magnetic field, monitoring interplanetary field
Gravity gradient measurement	Detecting gravity anomalies for deduction of subsurface structure

Table 1 (Cont'd)

POTENTIAL ORBITAL MAPPING TECHNIQUES

Technique	Possible Application
Electromagnetic pulse methods[8]	Measurement of dielectric constant, polarizability, and conductivity of terrain
Gamma radiation detectors[9]	Mapping of distribution of nuclear species, distinguishing rock types

SURFACE TRAVERSE INVESTIGATIONS

It is possible, despite our present ignorance of the detailed nature and origin of lunar topographic features, to identify a great number of distinctive features, such as rills, domes, and scarps. These features occur at many places on the earthward hemisphere, and, through study, will be the key to better understanding of the moon.

The use of a surface vehicle in the early stages of exploration appears at this time to be essential, since exploration should consist, to a large extent, of checking maps made from orbit and establishing some basis for interpreting the maps over large areas. The philosophy behind the requirement for extensive surface mobility is that several type sections or type areas should be established at an early stage in our exploration of the moon. The type areas would serve as controls from which we could expand our surface knowledge using any of the foreseeable follow-on surface exploration programs in connection with orbital mapping.

The basic method of manned surface exploration after the first few Apollo landings should thus be long distance traverses across the surface in pressurized vehicles. Continuous, periodic, and special interest observations and measurements would be made during the traverses. Ranges of

up to 300 miles might be required to utilize effectively the longer stay times possible and to visit a sufficient number of sites to conduct a reconnaissance type of exploration.

For economy of effort, each surface traverse must be pre-planned to extract as much information as possible from the traverse route, even if some of it cannot be immediately interpreted. For example, reduction of gravity measurements depends on close vertical control along the route. However, even without such control, gravity measurements should be made so that they can eventually be interpreted when vertical control does become available.

If we assume the capability for moderately long-range surface travel, and the ability to support teams of two or more men for extended periods, we may ask what scientific investigations or operations would be of most value. Scientific investigations on the surface should be largely confined to those which provide the maximum amount of knowledge about the moon itself, and which take best advantage of the fact that they can be conducted by man. It appears that the most valuable investigations fall into three major categories: geology, geochemistry, and geophysics. Geology and geochemistry are so closely interwoven that they shall be treated as one field here. Under these categories, surface traverse investigations will be discussed in the following section. It will be noticed that this organization is somewhat arbitrary; for example, the drill hole logging methods include some measurements of primarily geophysical interest.

Geology and Geochemistry

Geological Survey: The detailed study (with sampling) of rock exposures is the keystone of field geology and, to a large degree, of exploration geophysics. A geological survey would have as its broad purpose the determination of the lunar stress field, the relative and absolute ages of structures and rock types, and the origin and significance of surface features such as mountains, maria, and craters.

Because time will be the most valuable commodity during lunar exploration, it is imperative that techniques not normally used in terrestrial exploration, or perhaps entirely new techniques, be available to the lunar geologist. The terrestrial practice of returning again and again to the same region to conduct special purpose surveys will not be practical on the moon. It would appear that more extensive use of photography, coupled with the use of tape recorders, may allow the geologist to cut down his overall time at the outcrop.

Route surveying, or the accurate mapping of traverse routes, is extremely important for proper planning and interpretation of geological measurements. It is unlikely that the scientists will be able to locate the route or critical geological sites with sufficient precision from photographs or topographic maps alone. Therefore, automatic or semi-automatic techniques for rapid, accurate, and reliable lunar route surveying are necessary.

The ability to drill holes in the lunar surface is a prerequisite for many investigations. The depth required for early drilling cannot be specified with any precision, but depths of up to 100 feet will probably be necessary for sampling, emplacement of geophysical instruments, and

possibly for emplacing explosives for active seismic surveying. Continuous coring would preserve the maximum amount of information from the drill hole, but samples consisting of short cores and cuttings would also be extremely valuable.

The subsurface structure and composition of the maria and highlands cannot now be predicted, and it is quite possible that there will be little variation encountered in a 100 foot hole. However, to get the maximum scientific value from the operation, a logging program should be prepared that is capable of measuring all the foreseen properties of interest.

This program will obtain in situ measurements of variations in rock properties as a function of depth. They should be useful in structure mapping and as an aid in interpreting the results of geophysical investigations, such as seismic records. The major anticipated types of drill hole measurements include the following:

1. Electric properties
2. Radioactivity
3. Thermal properties
4. Sonic velocity
5. Magnetic field.

Analysis of the Lunar Atmosphere: The present concensus is that the lunar atmosphere is so thin (below 10^{-13}atm) as to be negligible for most purposes. However, the observation of possible gas emission from Alphonsus and Aristarchus shows that degassing may be continuing. The nature of these emissions would be of great scientific and engineering interest.

The most practical technique for atmospheric analysis appears to be the use of lightweight mass spectrometers developed for satellite experiments. Such instruments can

analyze charged and uncharged gases with a wide range of molecular weights. Portable gas chromatographs might also be useful in identifying gases such as acetylene.

The outgassing of the surface vehicle and the space suits may present a difficult problem. If the normal lunar atmosphere is as tenuous as expected, instruments placed near the vehicle would be swamped by the gas coming from it. This problem may be overcome by placing the analytical instruments in a remote spot for later untended readout.

Areal Radiation Survey: The lunar surface can be expected to be somewhat radioactive because of exposure to primary cosmic rays and solar corpuscular radiation that have produced such isotopes as Al^{26} and Be^{10}. In spite of this induced radioactivity, it should be possible to discriminate between rock units of grossly differing composition, such as peridotite and granite, on the basis of their U, K^{40}, and Th contents. Such discrimination might be useful in mapping the rocks along the traverse routes if their surface characteristics are obscured by the products of sputtering or radiation darkening. Radiation measurements might also be helpful in detecting accumulations of radon, which in turn might lead to discovery of faults or mineralized zones.

A gamma ray spectrometer carried on or near the surface vehicle should permit construction of a continuous radioactivity profile along the surface route. Adaptations of spectrometers designed for unmanned probes such as Ranger and Surveyor could discriminate between the activity due to K^{40}, U, and Th.

Continual Surface Measurements for Orbital Surveys:

As previously mentioned, the great surface area of the moon will make it necessary to do most of the systematic geologic and topographic mapping by the orbital analogues of aerial surveys, using photography and other remote-sensing methods. To aid the interpretation of the data gathered by these techniques, it will be useful to make continuous surface measurements of the same properties along the surface traverse routes.

The most useful properties to be measured would be the total spectral distribution of electromagnetic radiation from the ultraviolet to the intermediate infrared (around 15 microns) and the microrelief.

Geophysics

Heat Flow Measurements: If the moon's evolution has followed the same general path as that of the earth, it may have been dominated by the lunar heat balance. The most important single datum necessary for study of the moon's thermal history will be accurate determinations of the amount of non-solar heat coming from the interior.

The general technique for measuring the heat flux will probably be similar in principle to that currently used for measuring the earth's heat flux in drill holes or on the sea floor. The major uncertainty in applying these techniques to the moon is the lack of knowledge of the conductivity and structure of the shallow part of the lunar crust. If the low conductivity and density implied by astronomical measurements extend to depths of a few meters, it may be possible to use an adaptation of the present marine thermal probes, which are simply driven 3 or 4 meters into the surface. However, if the observed

thermal properties are the result of a thin dust layer underlain by solid rock, it may be necessary to drill holes for emplacement of the thermal probe. Terrestrial experience demonstrates that heat produced by drilling upsets the thermal profile, which may take weeks or months to approach equilibrium. Which of these possible subsurface models more nearly approximates lunar conditions should be determined by early Apollo investigations.

Active Seismic Surveys: Active seismic surveying should be possible at an early stage in surface exploration. In general, seismic information would be applied in its usual manner to interpret subsurface structure. Both refraction and reflection techniques should be applicable.

Landing and traversing in the maria seems most probable at this time. Knowledge of the structure and configuration of the underlying surface will be desired. In addition, it will be useful to make seismic profiles across stratigraphic contacts and structural features such as wrinkle ridges and domes.

Non-conventional terrestrial techniques may be necessary to generate the seismic impulses. Above ground or surface "shooting" or the falling weight technique may be alternatives to emplacement of explosive charges in drill-holes.

Gravity Measurements: Gravity measurements during early manned exploration should be an important exploration technique when related to surface mapping and other investigations. Accurate measurements of the moon's body tides and its surface gravity value will probably be made at one or more fixed sites before surface traverses are under-

taken. Thereafter, measurements made during the traverses would indicate local or broad anomalies that could be investigated in more detail if desirable.

It seems possible that semi-automatic surveying and navigation systems can be developed for a lunar surface vehicle that would permit determining surface elevations to an accuracy of 1 in 3-5000, relative to the landing site. Given this degree of accuracy in the route survey, a rather high order gravity survey could be conducted. In addition to a gravity meter (modified for lunar use), a gradiometer might be valuable, because it is not as dependent on accurate elevation data.

Magnetic Field Measurements: The magnetic field measured on the surface of the moon will probably be the resultant of interaction between the lunar and interplanetary fields. Measurements at 50 km above the moon by Lunik II and studies of surface luminescence by Kozyrev[9] indicate that the lunar surface field will be weak. However, Neugebauer[10] has pointed out that the solar wind may flatten the moon's field so that even if it were as strong as 1000 gammas, it would be undetectable at a 50 km altitude.

The purpose of the magnetic survey would be to obtain precise information on the areal variation of the moon's near-surface field. The technique will probably be a composite of those used in terrestrial aerial and ground magnetic surveys and in satellite magnetic measurements.

Magnetic data should be helpful in deducing subsurface structure and composition. Presumably the vertical component will be the most informative quantity measured, but the horizontal component and the first and

second derivatives may also be of interest.

Surface Electrical Measurements: Surface electrical measurements might provide additional information on subsurface structure and perhaps assist in development of a low frequency point-to-point communication system. The major possibilities appear to include measurement of:

a. moon-wide telluric currents
b. spontaneous potential
c. artificial electrical potential fields
d. resistivity
e. induced magnetic fields.

SURFACE FIXED-SITE STUDIES

In addition to the scientific investigations described for surface traverses, it will be necessary to make concurrent studies at one or more fixed sites. The fixed-site studies fall into two major categories: Geology/Geochemistry and Geophysics/Space Physics. The latter category is a composite because it will be difficult, in some instances, to separate lunar and interplanetary phenomena; an example might be magnetic field measurements.

Geology/Geochemistry

Deep Drilling and Logging: Deeper drilling than would be possible with a lightweight, vehicle-mounted drill will eventually be required. Drill holes with depths of several thousand feet might permit more representative sampling of the lunar crust, and the measurement at depth of the variation in physical properties of the rocks by means of logging devices similar to those described for the surface traverses. Deep drilling equipment which meets the requirements of the Apollo system does not presently exist, but will be the subject of future study.

Analytical Studies: The high cost per man hour of lunar surface time during early Apollo missions will probably preclude any intensive rock or mineral analysis on the moon; it will be much more efficient to return the samples for study on earth. However, longer mission stay times with surface traverses will probably result in the collection of such large number of samples that they cannot all be returned. Therefore, it may be useful to screen these by chemical and mineralogical analysis. This capability might also permit the resolution of geologic problems on the spot.

Geophysics/Space Physics

Stationary Seismographs: A three-component seismograph or a series of seismographs with various frequency ranges will be necessary to record with high resolution the moon's natural seismic activity. Such instruments might also record elastic waves produced by metoritic impact. This information will be extremely valuable in determining the deep structure of the moon.

Theodolite Observations: Precise location determination will be made by theodolite observations. These will also make possible the accurate determination of the direction of the moon's axis of rotation and the amplitude of the physical librations.

Meteoroid Flux: Detailed knowledge of the long-term directional flux and energy of both primary meteoroids and their ejecta will be necessary. To measure these quantities, large-area meteoroid detectors could be deployed at several sites for long-duration monitoring.

Radiation Measurements: Long-term monitoring of incident electromagnetic and corpuscular radiation could be

accomplished with adaptations of space probe and satellite instrumentation. This would be important not only for the obvious scientific and engineering purposes, but also to provide a measurement of the temporal variations in background radiation, thus supplementing the traverse radiation measurements described elsewhere.

Magnetic Field Fluctuations: Continual monitoring of the lunar magnetic field at the surface might be necessary to record the lunar equivalent of terrestrial diurnal variations. Knowledge of such variations, if they exist, will be necessary if areal magnetic surveys are to be properly interpreted.

THE SCIENTIFIC USES OF THE MOON

The preceding sections of this paper have been centered on scientific investigations of the moon itself; however, there are many ways in which the moon may be valuable as a space platform. Before discussing the, let us review some of the unique characteristics of the moon as a vantage point for scientific research.

The most obvious of these is of course the extremely low average density of the lunar atmosphere, currently estimated at about one-trillionth of the density of the earth's sea level pressure. In addition to its inherent usefulness, this near-vacuum provides an unlimited spectral window for observations from the moon, and should permit primary cosmic and solar radiation to reach the surface with very little atmospheric interaction.

Another valuable characteristic is the moon's weak or non-existent magnetic field. Coupled with the fact that the moon is effectively beyond the earth's magnetosphere, this may open new vistas of investigation in space physics impossible from the earth or even from an earth-orbiting

space station.

Finally, it should be pointed out that, despite its biologically hostile environment, the moon is probably in many ways a more convenient place to live than space. The lunar gravity field, though weak, should prevent many of the physiological difficulties presently foreseen for long periods of weightlessness. More important may be the fact that a lunar laboratory would not be plagued with escaped liquids, dust, and loose objects floating free - problems already encountered during the Mercury orbital flights.

It appears that these characteristics may make the moon useful as a site for scientific research in the following disciplines.

Astronomy

Much valuable astronomical research will be done with unmanned orbiting satellites such as the OAO, which use the unlimited spectral window provided by space. However, a lunar observatory might have certain advantages over such investigations. Guidance systems could be much simpler because the moon would provide a stable base. Long exposures (up to two weeks) would be possible without the frequent interruptions encountered in earth-orbiting vehicles. Finally, the fact that the moon should be easier to live on would permit human participation during long periods of instrument operation.

Radio astronomy should also be feasible from the moon; an advantage additional to those already mentioned for optical astronomy would be the relative freedom from interference encountered near the earth.

Space and Solar Physics

The unique lunar environment should permit the moon to

be used as a laboratory for a number of physical investigations. For example, the ultra-high lunar vacuum, which cannot yet be simulated in large terrestrial vacuum chambers, might facilitate experimental studies of surface chemistry, free radicals, and cold plasmas. The weak or non-existent lunar magnetic field, coupled with the absence of an atmosphere, would permit detailed studies of primary cosmic rays and multispectral solar monitoring. Finally, the moon's remoteness might be utilized to study the propagation of gravitational waves, in conjunction with earth-based measurements.

Biological Research

A lunar laboratory might permit elaborate long term studies of the effects of reduced gravity on the physiology of man, animals and plants, thus tending to fill the gap between zero-gravity and the environment of earth. Research might also be possible on the genetic effect of primary cosmic rays.

SUMMARY

The moon's unique relation to the earth makes its study an immensely valuable key to many questions about the origin and evolution of the earth, and of the solar system in general. Furthermore, the lunar environment should permit the moon to serve as a space platform for many scientific investigations.

The full realization of the potential value of the moon will require carefully planned but imaginative manned scientific exploration centering on geology and geophysics, conducted both on the surface and from orbiting vehicles. Such exploration can be carried out with launch vehicles now under development for the Apollo project.

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