measurements are required and these must be made in such a way that the total solar energy and infrared emission for each image element can be determined. If images of the reflected solar energy and thermal emission are made with different camera systems, having different observing angles so the radiative energy budget of the surface elements is lost, a large part of this type of data's usefulness to the micrometeorological picture is also lost. The diurnal and seasonal observations require an orbiter.

Some fairly straightforward observations of important meteorological parameters that can be made early in the Martian exploration program may be of considerable importance to exobiology. Further, as the technical capability of the program improves, a series of more sophisticated observations can be made that will yield fundamental understanding of planetary atmospheric motions *per se*.

3. THE MOON

SCIENTIFIC QUESTIONS IN LUNAR EXPLORATION

Major questions in the exploration of the Moon fall chiefly in three categories of basic problems: 1) structure and processes of the lunar interior, 2) the composition and structure of the surface of the Moon and the processes modifying the surface, and 3) the history or evolutionary sequence of events by which the Moon has arrived at its present configuration. These are principal categories of significant questions that can be asked of every object in the solar system of planetary or sub-planetary dimensions. In the case of the Moon special interest resides in the effects impressed on the lunar surface by such general processes operating in the solar system as the impact of solid bodies and of charged solar particles and in the physical record of such effects, especially for the early part of the history of the solar system. The possibility that ancient rocks and deposits on the Moon's surface may contain a unique record of events related to the formation or accretion of the terrestrial planets gives the scientific exploration of the Moon unusual potential significance. There is also the minor possibility of finding prebiotic material, either buried or in sheltered locations.

The major questions are as follows:

Structure and processes of the lunar interior

(1) Is the internal structure of the Moon radially symmetrical like the Earth, and if so, is it differentiated? Specifically, does it have a core and does it have a crust?

(2) What is the geometric shape of the Moon? How does the shape depart from fluid equilibrium? Is there a fundamental difference in morphology and history between the sub-Earth and averted faces of the Moon?

(3) What is the present internal energy regime of the Moon? Specifically, what is the present heat flow at the lunar surface and what are the sources of this heat? Is the Moon seismically active

and is there active volcanism? Does the Moon have an internally produced magnetic field?

Composition, structure, and processes of the lunar surface

(1) What is the average composition of the rocks at the surface of the Moon and how does the composition vary from place to place? Are volcanic rocks present on the surface of the Moon?
(2) What are the principle processes responsible for the present relief of the lunar surface?
(3) What is the present tectonic pattern on the Moon and distribution of tectonic activity?
(4) What are the dominant processes of erosion, transport, and deposition of material on the lunar surface?
(5) What volatile substances are present on or near the surface of the Moon or in a transitory lunar atmosphere?
(6) Is there evidence for organic or proto-organic materials on or near the lunar surface? Are living organisms present beneath the surface?

History of the Moon

(1) What is the age of the Moon? What is the range of age of the stratigraphic units on the lunar surface and what is the age of the oldest exposed material? Is a primordial surface exposed?
(2) What is the history of dynamical interaction between the Earth and the Moon?
(3) What is the thermal history of the Moon? What has been the distribution of tectonic and possible volcanic activity in time?
(4) What has been the flux of solid objects striking the lunar surface in the past and how has it varied with time?
(5) What has been the flux of cosmic radiation and high-energy solar radiation over the history of the Moon?
(6) What past magnetic fields may be recorded in the rocks at the Moon's surface?

GEOLOGICAL EXPLORATION OF THE MOON

Major Objectives of Geological Exploration

A major objective of the geological exploration of the Moon is the development of perspective in viewing our own planet and the solar system in which it resides. We are engaged not only in the exploration of space but also in the exploration of time. Key to this perspective in time is the recognition of the stratigraphic sequence, the order in which deposits of the past were laid down. On Earth this task is firmly grounded with the landmarks in the sequence tied to isotopically determined ages of rocks. The difficulty with the terrestrial record, however, is that active mountain building, erosion, and sedimentation have destroyed any recognizable remnant of the primordial Earth. At present we know almost nothing concrete about the first billion years of the Earth's history.

The Moon is of especial interest in working out the history of the solar system for two reasons. First, the surface of the Moon may be one of the few places where a very early stratigraphic record is preserved and decipherable. Secondly, because of its proximity to the Earth, it will be possible to determine the geology of the Moon in far greater detail, for a given level of effort, than that of the next nearest terrestrial planet. The events recorded on the Moon are likely to be more closely correlated to events on the Earth than the events in the record of any of the other planets. Consequently, the history of the Moon may have the most relevance to terrestrial history.

The question of the origin of the Moon illuminates the relevance of lunar history to questions about the Earth. If the Moon was captured by the Earth, violent disturbances of both would have occurred during capture. The age of features on the Moon produced by these disturbances would provide the key to recognizing the effect of the disturbance on the Earth. If the Moon was formed by capture or coalescence of multiple satellites, there may have been a disturbance from a concomitant rain of fragmental debris on the Earth. If the Moon was formed by fission from the Earth, on the other hand, the present composition of the Moon provides direct evidence on the degree of differentiation of the Earth at the time of separation. Under this mechanism the possible presence of organic material on the Moon would provide clues to early evolutionary stages of life on the Earth. Finally, if the Moon was formed by independant condensation from a proto-Earth nebular mass, the present composition of the Moon should furnish important clues to the chemical differentiation mechanisms operating during formation of the Earth-Moon system.

Telescopic observation forms the basis of attempts to elucidate the stratographic history of the Moon. At present the sequence of deposits is known to a first order in the equatorial regions. For some of the lunar geologic units, the general mode of origin can be inferred. It is because the geological processes that change the surface of the Moon probably operate much more slowly than those on the Earth that part of the lunar stratigraphic sequence gives promise of providing a record of the early history of the solar system that we can never find on Earth.

The historical record preserved in the lunar strata bears upon several processes of the solar system. In contrasting the older with the younger deposits, we can ask what has been the distribution in time and in mass of solid bodies impacting the Moon. The history of cosmic radiation and changes in its intensity or character should be recorded in the nuclear changes in the upper part of stratigraphic units. Some of these units probably have been exposed through much of geologic time, others have been exposed for a brief fraction of lunar history. The problem of origin of planetary bodies would be greatly aided by examination of a primordial or very ancient surface of one of the bodies of the solar system, by studying its chemical and isotopic composition, or even by looking for the strength of early magnetic fields in the solar system through paleomagnetic measurements on early volcanic rocks.

Many basic problems of the Earth can be approached by comparison of the Earth with the Moon. We still do not understand the chemical evolution of the Earth's crust as complicated through reworking by surface waters. The Moon stands as an example uncomplicated in this way, possibly having evidence of protocontinents. It may be the best place to see what an early crust looks like. The processes of mountain building on Earth are only partially understood, in part because tectonically active areas are covered by oceans or thick sedimentary deposits. In the lunar environment, tectonic deformation of the surface of a planet can be examined without the camouflaging effect of erosion, sedimentation, or oceans. Similarly, volcanic products that on the Earth are contaminated by passing through the chemically reworked surface sediments, should, on the Moon, be free from such effects.

Geological Complexity of the Moon

In the light of present knowledge, the Moon is a heterogeneous body. Differences in color, albedo, polarizing, and thermal properties that are correlated with topographical differences form the basis for recognition and mapping of geologic units. Although most of the large craters on the Moon are probably of impact origin, some of the geological units exhibit topographic features closely resembling certain volcanic forms on Earth. The surfaces of the maria, for example, have clearly defined features that closely resemble terrestrial lava flows. Fields of small domes with summit craters, some of which are nearly identical in form to terrestrial volcanoes, occur irregularly over the lunar surface. These features are diverse in both kind and relative age, suggesting the Moon may have had a long and complex magmatic history.

Unlike the Earth, the Moon bears no evidence of folded mountain chains, but has a well-defined pattern of linear features that probably correspond to fractures and faults. This contrast in tectonic features should help to elucidate the mechanisms of formation of terrestrial mountain ranges when the internal structure and processes of the Moon are better understood.

Geological Exploration

The known diversity of layers of material with different physical characteristics and the observed complexity of structure of the lunar surface requires an extensive program of exploration if the broad relations of the stratigraphy and structure are to be solved. The stratigraphy and structure are solved primarily by the technique of regional geological mapping, supplemented by geophysical (principally seismic) exploration to obtain subsurface structure and by local drilling.

Geological mapping of the Moon can proceed most efficiently by systematic surveying with remote sensing instruments from lunar orbiting spacecraft, followed by local detailed studies on the lunar surface. Studies on the surface are needed at key localities where the contacts and structural relations between different mappable units are best exposed and at localities where features of special interest occur. The first step in the systematic surveying should be the preparation of topographic maps by photogrammetric methods from photographs taken from lunar orbit with cameras designed for mapping. Control for the mapping can be obtained from accurate determination of the orbit, the orientation of the spacecraft, and radar altimetry from the spacecraft to the lunar surface. Topographic maps at scales of 1:1,000,000, 1:250,000,000, and, locally, 1:100,000 will provide the base maps needed for most of the geological investigations. The distribution of different geological materials is also mapped from the photographs on the basis of differences in topography, albedo, and reflectivity and emissivity over a wide range of the electromagnetic spectrum. In addition to the photographs taken with the mapping cameras, the gamma radiation and thermal emission of surface and reflection or scattering characteristics from the ultraviolet to radar wavelengths should be measured from orbit.

Direct examination of the lunar surface should be carried out by landings at different localities and by extended traverses over the surface. This examination is needed to determine the detailed strucural relations between geologic units mapped from orbit, to obtain physical data that can only be acquired from instruments in contact with the surface, and to obtain samples for mineralogical, chemical, isotopic, and other analyses after return to Earth. Thoroughly trained observational scientists will be needed to carry out the more advanced stages of this work on the lunar surface.

Investigations on the lunar surface are needed on at least three different scales. The smallest features, ranging in size from near microscopic to hundreds of meters, the fine structure of the lunar surface, can be studied by men on foot during early Apollo landings. Very detailed investigations of features at this scale and the processes by which they are produced may require a small lunar base to sustain men over much longer periods of time than is available during the early Apollo landings. To study features ranging in size from one to many kilometers requires a vehicle to carry men over these distances from the landed spacecraft. This is the scale on which most of the contact relations of regional geologic units and mesoscale structures, such as relatively large craters, faults, folds, and possible igneous intrusions and volcanoes must be examined. Finally, surface traverses of ten to hundreds of kilometers in length are required to examine features of crustal and subplanetary dimensions, such as the basin and surrounding mountain ring of Mare Imbrium and other circular maria. These traverses are needed to obtain deep seismic reflection and refraction profiles correlated with surface gravity measurements and geology. Such traverses provide extensive opportunities to sample and study areal variations in the regional geologic units.

GEOPHYSICAL OBSERVATIONS ON THE MOON

Introduction

As explained in the section on geological exploration, the Moon is the second relatively large member of the solar system available to us for detailed study. In addition to satisfying an intrinsic interest in the constitution and history of the Moon itself, study of the Moon provides valuable insight into fundamental questions concerning the morphology of the Earth and the solar system. Study of the figure of the Moon, the distribution of matter within it, the heat flow from the interior, and the magnetic field increases our knowledge of the composition and history of the Earth-Moon system. Study of the present tectonic activity as evidenced by seismic activity, volcanism, measurable deformation (faulting), and anomalies in the gravity field, increases our understanding of similar processes on Earth. In the opening paragraph of this section is a list of fundamental questions for which we hope to obtain answers through exploration of the Moon. The following suggested geophysical observations, combined with geological and geochemical observations, are required for such exploration.

Geophysical Observations from an Orbiter

Magnetic field. Provided that earlier measurements of the magnetic field indicate an internally produced field of sufficient magnitude, this field should be mapped from an orbiter. Such a map will provide a reference for ground-based magnetic profiles obtained on traverses; for measurements of residual magnetization of lunar samples; and for studies of the origin of the main internal field. It is possible that the field induced by the solar wind will predominate. Observation of the time-dependence of this field will provide information on electrical conductivity at depth within the Moon.

Microwave temperature. Measurements of the radiation temperature, at wavelengths near 10 cm, can be used to map the steady-state near-surface temperature. This temperature will be strongly dependent upon surface thermal properties. By using more than one wavelength it may be possible to separate surface effects and outline regions of anomalously high heat flow.

Geodetic measurements. Observations of the motion of an orbiting spacecraft or special geodetic satellite, combined with measurements of the lunar librations, are needed to obtain accurate values for the principal moments of the Moon. Since the mass and the moment of inertia are fundamentally important constraints on the internal constitution of the Moon, such measurements are extremely important. The higher harmonics of the gravitational field, obtained from observations of an orbiter, contain information on the departure of the Moon from fluid equilibrium and place constraints on the symmetry of the density distribution within the Moon. When combined with radar distance measurements between the orbiter and the lunar surface, the observed gravitational field provides datum for topographic mapping and for studying the possible degree of isostatic balance between regions of high and low elevation.

Geophysical Observations from a Lander

Measurement of lunar motions. Measurement of lunar librations can be improved by radar observations from Earth of three widely separated (about 1000 km) corner reflectors. These measurements are needed for determination of the moment of inertia. In addition, such observations would help unravel the dynamical history of the Earth-Moon system.

A fixed and comparatively small optical telescope emplaced on the Moon allows measurement of the length of the lunar day and its slight variations. The absence of an atmosphere makes this measurement simpler and more precise than it is for the Earth. In the absence of the fluctuations of atmosphere and oceans the greater precision will be significant in relation to other dynamical effects. Tides raised on the Moon by the Earth and the Sun come into this category, as well as the librations. Any internal fluid motion would be expected to show an effect.

The instrument required is a telescope with a photoelectric detector behind a slit, aligned approximately along a lunar meridian. Telemetry with millisecond timing, as stellar images sweep across the slit, is all that is required.

Passive seismology. Assuming there are natural moonquakes with a temporal distribution of events and magnitudes roughly similar to that of Earth, passive seismology provides the most direct source of detailed information on the deep interior of the Moon. Implantation of at least three small remotely operating seismic observatories at widely separated (about 1000 km) locations is recommended. Such instruments should be capable of recording all frequencies between several cycles per second and tidal frequencies in three components of motion. With such a net most larger events could be located (latitude, longitude, depth, time) and active zones delineated. Once active regions are identified, additional (perhaps simple) instruments should be installed so that these sources can be used most efficiently to study different tectonic provinces; short-period instruments can be used to study smaller events within active areas, longer-period instruments can serve to study pure maria or highland paths from larger, distant events. All such instruments should be designed to operate as long as possible.

In the absence of natural moonquakes, impacts of large meteorites, large explosions, or impacting Lunar Excursion Modules (LEM) may provide sufficient energy for large-scale studies. If meteorite impacts can be differentiated from moonquakes, by focal depth or other criteria, the seismograph net can be used to monitor the distribution of larger meteorites in the vicinity of the Moon.

Active seismology. Seismic refraction and reflection techniques should be used to extend geological observations to depths beneath the surface. Refraction measurements using chemical explosives are probably most efficient for general reconnaissance since they give both average velocity and thickness of a layered structure. Under certain conditions, local reflection surveys might be useful in the study of small-scale variations. At least two scales of refraction surveys are recommended: short profiles, 1 to 10 km, using explosive charges of a few pounds or less, to determine shallow structure down to a few hundred meters; and long profiles, 10 to 100 km, using explosive charges up to several hundred pounds, to investigate the structure of the entire crust (if any) and upper mantle. An expended LEM, crashed into the lunar surface, should provide sufficient energy for the long profiles. For this purpose the location and time of crash should be known to 1 km and 0.1 sec or better.

Heat flow. Heat flow from the interior of the Moon provides essential information on the distribution of radioactive elements and the thermal history, including volcanism. It is probably necessary to use a hole 1 to 10 meters deep in order to obtain the heat flow. A considerable amount of work on theory and observational techniques is needed in this important area. Care should be taken to assure that such measurements are taken both at typical and at interesting places.

Gravity-magnetic. Essentially continuous measurement of the gravitational and magnetic fields should be obtained along all traverses for correlation with the geological and seismic data. Such observation can be highly automated. Gravity should be measured to about ± 1 milligal and elevation to 3 or 4 meters, if possible. However, even cruder data would be useful for regional studies. It will probably be necessary to operate a magnetometer at a base station during magnetic traverses in order to remove the effects of temporal variations in the field.

Magneto-telluric. Information about the internal distribution of electrical conductivity may be obtained by combining the base station magnetic variations with variations in the horizontal electrical field.

GEOCHEMISTRY OF THE MOON

Introduction

Studies of the lunar surface in the visible, infrared, ultraviolet, and microwave portions of the electromagnetic spectrum show that there is much diversity in its reflective properties. Correlations between topographic features and color differences suggest that the Moon is chemically and mineralogically heterogeneous on the scale of present telescopic observations. Some of the topographic forms are suggestive of volcanic flows. There is, however, little agreement among observers about the mechanism that may be responsible for chemical differentiation.

In general, chemical differences produced on the lunar surface may be ascribed 1) to material or energy arriving from space and 2) to processes driven by energy released from the Moon's interior.

The extent to which either of these two kinds of processes predominate in determining both the chemistry and morphology of the lunar surface will be at least partially answered through studies of samples collected during the first manned lunar landings. Samples returned from these missions should also allow some characterization of the chemical nature of lunar differentiation processes. Establishing the relative importance of particular processes on the lunar surface is, clearly, of first-order importance. From a scientific point of view, however, this knowledge is only a part of a larger picture, i.e., the origin and history of the Moon. It is doubtful that answers to basic questions on the Moon's history, gross composition, and over-all degree of chemical differentiation can come from samples collected in two or three relatively small areas on the Moon, particularly if the chemical variations are large. Investigations of significant portions of the Moon's surface are probably necessary to obtain answers to these fundamental questions. An integral part of these investigations will be a more detailed study of the geochemical processes on, and properties of, the lunar surface, both to characterize the materials and to determine their place on an absolute time scale. It cannot be overemphasized that such studies must be coordinated with a larger program for investigating the structural stratigraphic and geomorphic features of the lunar surface, i.e., a geologic mapping program.

Specific Geochemical Problems on the Lunar Surface

1. Radioactive Isotopes and an Absolute Time Scale

The isotopes of uranium, Th^{230}, K^{40}, and Rb^{87}, and their stable daughter products are the basis of the most powerful methods for the determination of time on the 5-billion-year scale of the solar system. The study of these nuclides in lunar materials will be very important for estimating the time of formation of the Moon and the times during which melting and differentiation of silicate materials took place. If internally driven chemical differentiation processes are discovered, isotopic dating methods will tell us when and for how long in the Moon's history such processes were active.

It would be of great interest if we were to find portions of the lunar surface dating back to the times when the chemical differentiation recorded in meteorites took place.

2. Bulk Composition of the Moon

In order to understand the origin of the Moon, in particular, to see its relation to the Earth, the Sun, and other planets, it will be necessary to deduce the over-all composition of the Moon. If the surface of the Moon is chemically heterogeneous, only extensive sampling of the lunar surface will permit us to infer its over-all composition.

It is quite possible that a significant amount of material on the present lunar surface is foreign to the Moon in terms of its characteristic composition. The existence and identification of such foreign materials (probably similar to some meteorites) will also depend on detailed chemical and isotopic studies.

3. Lunar Magmatism

Should magmatic processes occur on the Moon on a large scale, an understanding of the chemistry and mineralogy of magmatically produced materials will be essential for understanding its geological history. It will be important to determine whether such processes have concentrated radioactive elements and volatile elements near the surface as they have on the Earth.

4. Lunar Degassing

The evolution of the Earth's atmosphere and oceans is a fundamental part of terrestrial history. These features are the consequences of chemical potential gradients that tend to drive volatile components like CO_2, H_2O, Cl_2, and H_2S from hot high-pressure interior regions to cool low-pressure surfaces. The mechanism by which these gases are transported in the Earth is not entirely understood, but it is probably associated with volcanism. It has been suggested that even in the absence of volcanic processes there will be transfer of volatiles from the interior to the surface of the Moon. Detailed studies of the gases absorbed in subsurface layers and of the transient lunar atmosphere will be necessary to delimit the nature of lunar degassing processes.

5. Cosmic Ray and Solar Wind History

In the absence of a lunar atmosphere the surface materials are constantly bombarded by energetic cosmic rays and the solar wind. The nuclear reactions resulting from cosmic-ray bombardment have been studied extensively in various meteorites. These studies suggest many important applications to the lunar surface, e.g., rates of turnover and cosmic-ray flux may both be determined. The krypton and xenon content of surface material may also be an indication of the solar wind flux averaged over the exposure time of the surface materials. Older materials that have been buried and shielded from cosmic-ray and solar wind bombardment may furnish a way by which the magnitude of these quantities in the past may be investigated. Such studies can be made only after the geological history of a particular region is fairly well understood.

The problems outlined above represent the major questions that appear interesting with our present knowledge of the lunar surface. The discovery of processes that are not now anticipated may easily lengthen the list of chemical problems on the lunar surface that will challenge our ingenuity and intellect.

Conduct of Chemical Investigations

With the sample return capabilities that are planned in both the early Apollo and post-Apollo missions, it is clear that enough material can be obtained on a scale to represent quite well those that may have been mapped or investigated during a mission. If sample consumption is optimized, all the obvious chemical and mineralogic analyses can be done on samples of several hundred grams. Hence, there is relatively little need for performing analyses on the Moon, particularly if they compete for time that could be used for observing and examining surface features. A number of cooperating analytical facilities would be required on Earth, including several laboratories equipped for modern mineralogical analyses, geochronometry, and chemical analyses for major and minor elements. The Earth-based geochemical program should be well coordinated with all other aspects of the lunar exploration program.

The success of the geochemical program is very much dependent on the skill with which materials are collected and returned to Earth. The observational skill of the scientist-astronaut on the lunar surface will be the most important factor in obtaining significant materials from the lunar surface. It seems clear that geological field experience would most closely approximate the type of situation that may be encountered on the lunar surface. Training and selection of geologist-astronauts thus would be an important part of the preparation for an extensive program of lunar exploration.

Other preparations may include the development of special tools to aid in sample collection on the surface, e.g., boring devices, sample containers, etc., and devices for rapidly differentiating visually similar materials, e.g., gamma-ray survey instruments, microscopes for examining thin and polished sections.

Studies of the lunar atmosphere and degassing products will almost certainly require some type of extremely sensitive gas analyzer on the lunar surface. Because of the difficulty of returning samples that fully preserve the lunar conditions, such an instrument should be capable of measuring a wide range of atomic masses or molecular weights (mass 12 to mass 200) and be capable of measuring extremely low partial pressures at least down to 10^{-14} atmospheres. In preparation for detailed analyses of lunar gases a simple device measuring total gas pressure may be useful on earlier missions.

Lunar orbiters present an excellent opportunity to map the chemical differentiation of the lunar surface, by surveying the gamma-ray activity of the surface: such a survey should clearly identify regions where potassium, uranium, and thorium are concentrated relative to other areas. By analogy with the terrestrial situation, such a survey should clearly distinguish differentiated regions from nondifferentiated regions.

It is not now clear whether the possibility of back-contamination of the Earth by pathogenic organisms from the lunar surface will be a serious problem in the long-range exploration of the lunar surface. If the question is not answered by early Apollo missions, the precautions that may be required by this hazard should be integrated into the analytical program in a way that will result in a minimum of degradation of the materials and methods used to analyze the lunar materials.

PHYSICAL PROCESSES ON THE LUNAR SURFACE

Geological investigation of the Moon and understanding of the surface features and their time scale will require, first of all, some understanding of various externally induced processes that may operate there. Erosion, surface transportation, impact, evaporation, and recondensation will need to be understood in addition to the externally induced changes in the appearance and physical structure of the surface material.

Erosion and Transportation

There is evidence that erosion and surface transportation of material has occurred on the Moon and it will be of great importance to understand the nature of that process. It may be simply due to the accumulated effect of meteorites, including micrometeorites, which would tend to redistribute material and cause creep. It may be that impact, evaporation, and subsequent recondensation are major factors. It may also be that other effects, such as electrostatic forces, play a part in the erosion and transportation mechanism. The detailed appearance of the surface may, of course, give an indication to help resolve these questions. Physical measurements and some simple observations carried out on the Moon may, however, be needed for better understanding.

The rate of micrometeorite bombardment and of secondary bombardment on the surface should be measured. From this, the direct rate of surface transportation and the time to produce a given degradation of a crater could be estimated. The shapes and size distribution of very small craters in the range of centimeters to millimeters will be helpful here, and if such craters can be seen, good photography should bring back the information.

The precise manner of deposition of the material will determine the way in which it reflects and polarizes light. Since returned samples are unlikely to have preserved the optical surface characteristics, it will be necessary to measure, in place, the angular scattering law and the polarization law at optical wavelengths. Variations from place to place in these optical properties, and especially between fresh craters and other surfaces, should be observed. Since these properties are well known for the Moon as a whole, a study in one locality will also serve to establish whether the particular site is a representative one.

If electrostatic effects are significant in the transportation of small particles, perhaps after they have been loosened by micrometeorites, such particles would probably accumulate to form distinctive structures of small scale that could not be ascribed simply to meteoritic action. Any such shapes should, of course, be carefully photographed for subsequent study. They might appear as small-scale waviness of the surface or any other near-periodic irregularities. They might also involve preferential attachments of small particles to points or edges of other material.

For understanding such electrostatic processes, measurement of the daytime electric field above the surface on a scale of millimeters is essential. The photoelectric effect is expected to produce an electric field above the surface in the first few centimeters and of the order of a few volts. Observation of a low-energy electron beam at various heights close to the surface would be one way of studying such electric fields. Perhaps measurements of electrostatic force are another possibility.

The possibility of chemical differentiation being produced or maintained during erosion processes should be studied.

A simple observation of how a handful of dust picked up from the surface and allowed to fall back to it will distribute itself is also most important. If the particles do not generally appear to fall on straight ballistic orbits back to the ground, their motion should be photographed and that should be done both in the sunlight and in a locally shaded region or the lunar night.

Thermal Properties

The thermal properties of the surface material are also critically dependent on its detailed fine structure and therefore not likely to be preserved in a sample returned to Earth. An understanding and the detailed interpretation of thermally oriented maps will require a study of the regional relations and correlations with other observable features. Again, this will also serve to establish the degree to which the landing site is representative of other areas. The thermal property best measured would be the rate of cooling, as observed at infrared wavelengths, in a region shielded from sunlight.

Proton Bombardment

The intensity of the solar wind proton bombardment and alpha particle bombardment of the Moon's surface is not necessarily the same as that which would be deduced from interplanetary measurements. It will, therefore, be necessary to make a direct determination of the bombardment rate on the Moon's surface. The study and precise photography of regions where the local topography prevents most or all of this proton bombardment from reaching the ground will be of particular value in defining the nature of the effects produced.

Gases and Volatiles

The percolation of gases and volatile substances through the lunar surface is a matter of great interest. First, such substances may contain important information concerning the interior of the Moon and its mode of derivation. Second, they may have affected and helped to shape the present surface. Some knowledge of these processes is necessary for understanding the geology.

The returned samples may contain condensates of some substances that have come from the Moon's interior and have frozen out at a temperature near that of the subsurface. Many other substances may have condensed at lower levels where the temperature is higher, and only traces of them may reach the surface and may not be discernible in an analysis of the sample; substances that do not condense, even at the subsurface temperature can, of course, not be found in the returned samples except possibly in very small amounts on surface nightime samples that have reached an extremely low temperature. Analysis of returned samples is thus not likely to yield the required information concerning such exhalation of gas. An investigation and instrumentation on the surface of the Moon will be needed to tackle the problem.

There are likely to be very great regional variations in the outflow of gases and possibly some of the known features are related to these processes. The dark-haloed craters have been mentioned in this connection. Since the rates of flow are likely to be very small and detection therefore difficult, one would be tempted to consider first locations that look particularly promising in this respect.

Instrumentation will have to be devised that is suitable for the detection of water vapor, carbon dioxide, nitrogen, argon, methane, ammonia, helium, and perhaps several other gases. Cryogenic capture and return will be suitable for some of these, ion pumping and capture or direct mass spectrography may also be appropriate. Optical spectrographic methods, such as observation of the temporary lunar atmosphere in grazing sunlight, may also be useful, especially in connection with the possibility of water vapor and resulting OH.

4. VENUS

UNCERTAINTIES AND SCIENTIFIC QUESTIONS

Our understanding of Venus is at present limited by the complete cloud deck that obscures the underlying surface.

While some physical measurements can be made, it is remarkable how little certain knowledge we have because of complexities and ambiguities in the interpretation of observations. Although it is our sister planet our knowledge is extraordinarily slight and paradoxes abound. A brief review will illustrate these statements.

Even the pole and rate of rotation of Venus are not certainly determined. The obliquity of the orbit is probably not great and radar observations suggest a 200-day retrograde rotation.

The cloud itself may well be of ice-crystals, as Strong's infrared measurements indicate, but the complete coverage then suggests an absence of downward motion of the atmosphere, which is, of course, impossible. The upper 10 to 30 km seems to be extremely finely dispersed and is in a state of violent and rapid motion.

The presence of a fine, scattering cloud makes the interpretation of certain measurements very difficult. Thermal emission (of which excellent maps can be made) may involve both scattering and absorption, and cannot be related to temperature with certainty. Spectral absorption lines of water vapor and carbon dioxide show the presence of these