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LUNAR GEOLOGICAL FIELD INVESTIGATIONS

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ABSTRACT

The Moon offers an opportunity to test hypotheses based on terrestrial observations that bear on the geologic history of the Earth. The Apollo Lunar Geology Experiment should provide sufficient information to determine the general nature of the processes that filled the mare basins and that modify their surfaces.

The basic systems capability for more extended exploration of the Moon has been built through the development of the Apollo system, and it is recommended that this system be fully utilized for extended lunar exploration.

INTRODUCTION

The major goal of geologic exploration of our nearest planetary neighbor should be to compare fundamental geologic processes that are, or have been, active on the Moon with processes that operate on Earth. Models have been proposed for such things as diastrophism, volcanism, and magmatic differentiation, based largely on the observation of the results of processes that operate under terrestrial gravitational, pressure, temperature, and atmospheric conditions. These models, which are critical to an understanding of the evolutionary development of Earth, should be tested by examination of geologic features that have been produced under the different environmental regime of the Moon.

The Moon may offer a unique opportunity to study a planetary surface that is nearly primordial in terms of geologic evolution. Because of the lack of a lunar atmosphere, the external processes which modify the lunar surface must predominantly comprise meteorite bombardment, solar radiation, and diurnal temperature changes. Available data suggest that these processes alter the lunar surface at a rate that is lower by orders of magnitude than the rates at which weathering, erosion, and material transport modify the Earth's surface. Thus many of the first-order features on the Moon's surface such as the mare basins and highlands, and many of the major structures, may be representative of features formed in the early stages of planetary development, features which have long since been destroyed or altered beyond recognition on Earth.

APOLLO LUNAR GEOLOGY EXPERIMENT

The Apollo missions will provide the first opportunity to return samples of lunar material to Earth for analysis; even more important, they will provide the first opportunity to apply man's mobility, dexterity, vision, and reasoning capabilities to the task of obtaining information (including samples) which will provide a basis for understanding lunar geologic processes.

Geologic Objectives

The general objectives of the Apollo Lunar Geology Experiment are to determine the composition and origin of mare materials, determine what major surface processes have operated and are operating on the mare surface to produce the observed landforms, and from this information, determine what is the general evolutionary history of the lunar maria. The Apollo missions will provide general, in some cases inconclusive, answers to these questions. However, answers can be obtained for questions such as: are the rocks volcanic, and of what type(s), and do they vary sufficiently to indicate some kind of differentiation; what are the modes of origin of the smaller craters, and is the mode of origin size-dependent; what are the spatial relations of different rock types, do stratigraphic sequences exist, and, if so, what were the mechanisms for formation of the sequences.

Age-dating of returned samples will put a "youngest" limit on the age of the Moon, and mineralogic studies will show whether most of the mineral phases are the same as terrestrial silicates, and if rare or new minerals are in abundance. Documentation of sample locations, with descriptions and photographs that relate them to their environment, will enhance interpretations as to the origin and history of the samples.

Although the first two or three Apollo landings will provide geologic data from an extremely small percentage of the area included in the lunar maria, much of the information probably can be extrapolated with a relatively high degree of confidence to large portions of the maria because of the similarity of much of the mare surfaces shown by Orbiter photography. Detailed interpretation of certain features less common than the more typical small craters, fine-grained regolith, and blocky materials, may have to await the time when missions of longer duration and more mobility are possible.

Experiment Description

Because of limitations that space suits impose on the astronauts' mobility and dexterity, special tools must be used for the Apollo geology experiment. The astronaut will not be able to kneel and therefore will be furnished with a long-handled scoop for sampling particulate materials and a pair of tongs for picking up rock fragments. Three drive or core tubes will be supplied with which to sample, and preserve the stratigraphy, of the uppermost foot or so of the mare regolith.

Field descriptions will be transmitted to Earth by radio and will be supplemented by photographs from the Apollo film camera. Sample locations and orientations will be documented mostly by photographic methods. Precise orientation of the camera axis, for photometric and photogrammetric reduction of the pictures, will be obtained by placing a gimbaled gnomon, which seeks local vertical, in the field of view of the camera.

These tools, and a few accessory tools such as a hammer for driving the core tubes and chipping large rocks, a hand lens, sample bags, and a staff for support of the camera, will be transported by the astronaut in a three-legged tool carrier, because the suit affords no practical means of attaching the tools to a belt or pack in the conventional manner of the field geologist.

POST-APOLLO EXPLORATION

All of the scientific data from the first two or three Apollo flights will be of great interest and importance But the system for the first lunar landing was designed primarily for getting a man on the Moon before 1970, secondarily as a technological step toward the development of the eventual capability of exploring the Moon and planets, and last as a system, which in unmodified form, would be used for collecting scientific data from the lunar surface.

The present Apollo system does not provide for sufficient lunar stay-time to perform an in-depth study of the lunar surface in the immediate vicinity of the landed spacecraft, nor the surface mobility for even reconnaissance of an area beyond a few hundred meters of the landed spacecraft, nor an instrument payload allowance that would provide for precise measurement of more than a few parameters of scientific interest.

After a few landings in smooth mare areas along the equatorial belt with the present Apollo system, the geological data would become more and more repetitive, and new information would come largely from the happenstance of landing near a feature of a type not yet examined, and of special significance. Thus it would seem a waste to continue lunar launches of the early Apollo type without some sort of upgrading of the system.

On the other hand, an enormous potential for lunar and planetary exploration has been developed through the entire Apollo system. The Saturn rockets are capable of transporting payloads of several tons which can be soft-landed on the Moon. This system can be used to provide for extended unmanned missions, or to support extended manned missions, in which most of the payload can be in the form of scientific instruments to be left on the lunar surface, in place of the vehicle required to return a manned spacecraft to Earth.

In addition, the launch facility at Cape Kennedy, the Mission Control Center at Houston, and the world-wide Deep Space Flight Network, provide a tremendous capability for guiding and tracking the spacecraft, and for telemetering scientific and engineering data to centers such as the Manned Spacecraft Center, Goddard

Spaceflight Center, and Jet Propulsion Laboratory, for analysis. Thus it would be a waste of this potential to terminate the lunar program, or to neglect development of the full potential of the system.

Lunar Features Suggested for Extended Exploration

Several features on the near side of the Moon which have been studied extensively through telescopes, and more recently have been studied by use of Lunar Orbiter photographs, would lend themselves to the study of processes which are fundamental to the formation of lunar surface features, and would undoubtedly yield information on the nature of the Moon's interior structure and processes. Reference below to terms such as "impact" and "volcanic" are not meant to imply proven facts, but only to describe the most widely accepted hypotheses to date. A major goal of lunar exploration should be to test these hypotheses and to alter or refine them if necessary.

Major impact features

Many of the lunar craters appear to have formed by impact of meteorites. These craters range in size from a few centimeters in diameter, as shown in Surveyor pictures, to tens of kilometers (Copernicus and Tycho) and possibly even hundreds of kilometers (Imbrium basin).

Copernicus, a classical example of an impact crater, has been extensively studied and described (Shoemaker, 1962; Schmitt, Trask, and Shoemaker, 1966). Study of the central peaks, structures in the crater floor and walls, and the ejecta blanket and a search for high-pressure polymorphs should confirm or refute the hypothesis that this is an impact crater and add to our knowledge of hypervelocity impact mechanisms. The crater walls should expose parts of the lunar stratigraphy in this region, but much of the stratigraphy may be obscured by mass-wasting processes.

The large size and rugged topography of this feature may preclude its complete exploration in the near future, and the topography and geology are such that use of both surface rovers and flyers would be required.

A smaller impact crater may therefore have to be selected, for practical reasons.

Volcanic features

Numerous volcano-like features appear to be present on the lunar surface. One of the most notable assemblages of such features is the Marius Hills, described by McCauley (McCauley, 1965; Karlstrom, McCauley, and Swann, 1968). Volcanic cones and extrusive or shallow intrusive bodies appear to occur there. Several potential landing sites are present from which this general hypothesis might be tested during a two- or three-day mission employing either a surface rover or small flyer; however, superfluous magmatic differentiation and structural problems could best be studied by a slightly longer mission utilizing both a rover and flyer (Karlstrom, McCauley, and Swann, 1968).

Large lunar ridge structures, also of possible volcanic origin, may be analogous to terrestrial features such as the Mid-Atlantic Ridge (McCauley, 1967; Karlstrom, McCauley, and Swann, 1968), and a combination of geophysical and geological exploration techniques should reveal much valuable information concerning the development of these features on both Earth and Moon. It would be quite significant to determine that these features can form in environments as different as those that exist on the Earth and Moon.

Basin development

The Orientale basin has been interpreted as a young mare basin that formed as the result of a major impact. It consists of a central depression with wide, concentric terraces to the rim. The floor, portions of the terraces, and craters in the area of the rim have been flooded with a dark, possibly volcanic, material (Hartmann and Kuiper, 1962; Ulrich and Saunders, 1968). This feature might well represent a type of major, primordial structure that may have once existed on both the Moon and Earth and has since been modified on the Moon, and destroyed on Earth, by geologic processes.

A feature of this size and complexity obviously requires an advanced system for extensive exploration (Eggleton, 1967, Ulrich and Saunders, 1968). Long-range surface traverses for continuous exploration of critical areas and large flying vehicles with which to negotiate major topographic obstacles will be required for effective exploration of a feature of this type.

However complicated and expensive, this type of system may eventually be required for gaining a fuller understanding of the origin and evolution of the terrestrial planets.

Other features

Exploration of several other types of features may be essential to the understanding of lunar processes and may shed light on the development of the terrestrial planets. Notable examples are sinuous and linear rilles, mare-highland borders, and the lunar poles. Areas studied in detail by manned missions should be tied together where possible by unmanned rover traverses. An intensive study of Lunar Orbiter photographs, and supplementary orbital missions with high-resolution sensing systems, will provide an inexpensive means of extrapolating data from the relatively small areas studied through manned and unmanned missions.

SUMMARY

Processes that modify terrestrial geologic features have probably destroyed most, if not all, of the record of the Earth's early history. The moon offers the possibility of testing hypotheses concerning geologic processes that form terrestrial and lunar features, and of studying the primordial development of a terrestrial planet.

The system developed for the first few lunar landings can be upgraded and utilized effectively for further scientific study and exploration of the Moon. It would be uneconomical, in terms of scientific return and technological advancement, either to continue the early-Apollo type of mission or to terminate lunar exploration, after the first two or three lunar landings. The

present Apollo system should be upgraded so that it can provide longer missions with surface and flying vehicle mobility, and a larger complement of scientific instruments.

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