ON THE MOON WITH APOLLO 17

A Guidebook to Taurus-Littrow

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

December 1972

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"On the Moon with Apollo 17" was prepared by Gene Simmons, MSC Chief Scientist, for use as a Guidebook to Taurus-Littrow, the landing area for the mission. Where possible, the original color or black and white images were substituted for the printed halftone images. The remaining images were carefully converted to continuous tone replicas. The original document was provided by Ed Fendell, Apollo Flight Controller.

This PDF version was produced by Bill Wood. The original pages were scanned with an Epson Expression 10000XL, using Silverfast AI Studio, to produce high quality 480 pixel per inch, 48-bit images, for further processing. Each page image was straightened and cleaned up in Photoshop CS3 prior to producing 300 pixel-per-inch EPS page images. Adobe Acrobat 9 Professional was used to prepare the final PDF edition. The document is made searchable by using Adobe ClearScan.

Bill Wood was a Unified S-Band Lead Engineer at the Goldstone Apollo MSFN station during the lunar missions. Ed Fendell was the Head, Apollo Communications Sections, Flight Control Operations Branch at JSC during most of the Apollo missions. Both are now retired in Barstow, California and Houston, Texas, USA.

ON THE MOON WITH APOLLO 17

A Guidebook to Taurus-Littrow

by

Gene Simmons

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

December 1972

Gene Simmons was Chief Scientist of the Manned Spacecraft Center in Houston for two years and is now Professor of Geophysics at the Massachusetts Institute of Technology. He has worked on the scientific aspects of the Apollo Program since 1965. He is the Principal Investigator of an Apollo 17 experiment to measure the surface electrical properties of the Moon.

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PREFACE

The Apollo Program, begun by NASA in 1960, was given impetus by President John F. Kennedy on May 25, 1961, when he dedicated this Nation to exploration of the Moon stating:

> Now is the time to take longer strides, time for a great new American enterprise, time for this Nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on Earth.

The 11 manned Apollo missions were each major steps in man's conquest of space. Apollo 17—scheduled for launch on December 6—marks the end of a series of scientific explorations in which man first walked on the Moon in his effort to learn more about the Universe in which he lives.

Throughout history, major scientific discoveries have been the result of work by one person—or a small group of people—and only later were shared with the general public. The newly discovered information was traditionally communicated by scientists in the form of technical papers or addresses made before scientific groups.

The Apollo missions drastically changed parts of this process. Millions of people throughout the world "participated" in some of the greatest scientific discoveries of our age. The speed and comprehensive reporting provided by modern communications—through television, radio, and print—gave people everywhere in the world "instant" knowledge concerning the experiences of our astronauts on the Moon. Science and scientists have been exposed to the public eye throughout the progress of the lunar experiments in a way never before seen. We have had an ever growing responsibility to explain more about our science. This booklet is intended to meet a part of that responsibility. In the preface to *On the Moon with Apollo 15*, I wrote:

> Never before in man's history has it been possible for more than a few people to witness major scientific discoveries. Yet with each Apollo mission to the Moon's surface, millions of people throughout the world can watch through television the activities of the astronauts. The understanding by the viewer of those activities and his sense of sharing in the scientific excitement of the mission are greatly increased when there is a general understanding of the scientific and engineering aspects. Yet for most of us, the usual discussions are clouded with jargon.

My purpose in writing this new guidebook is to give in simple terms information about the Apollo 17 mission to the Moon so that others can share with me the excitement of the scientific exploration of the Taurus-Littrow area of the Moon.

Many people helped me prepare this guidebook. Richard Baldwin, Gordon Tevedahl, John S. Kennoy, Jr., and George Esenwein collected background material. Rex Cline coordinated all art. Jerry Elmore, Norman Tiller, Ray

Bruneau, Barbara Matelski, and Boyd Mounce drew most of the original sketches. Andrew Patnesky and Mike Duke each provided several new photographs. Jeffrey Warner and Uel Clanton helped me select photographs of lunar rocks. The manuscript was improved greatly as a result of comments by: William Muehlberger, Edward Wolfe, Robert Parker, Jack Schmitt, George Abbey, Doug Ward, Jack Sevier, Herb Wang, Terry Todd, Sheila Murphy, Ruth and David Fitterman, George Esenwein, Floyd Roberson, Jim Head, Don Beattie, Peter Mason, John Pomeroy, William Vagt, Richard Naylor, and Rob Leppzer. Ludy Benjamin and the MSC Photographic Technology Division provided the excellent photographic prints, often working against very short deadlines. To all of these people, I express my thanks.

The accuracy and readability of the guidebook were improved by the comments and corrections made by the following persons upon the section dealing with their experiment: Mark Langseth, Joseph Webber, Otto Berg, Robert Kovach, William Muehlberger, David Strangway, Manik Talwani, Don Burnett, Fred Doyle, Robert Kaula, Roger Phillips (for ALSE), and William Sjogren. Their help is greatly appreciated.

And finally a special note of thanks to my wife Mary Jane who not only suggested improvements to the text, but persevered through the typing of several drafts.

Gene Simmons
Winchester, Massachusetts
October 1972

HOW TO USE THIS GUIDEBOOK

Excellent commentaries have been available over television for each previous Apollo mission. However, because of the increased complexity of the surface operations beginning with Apollo 15 and especially because of the greater amount of time devoted to science activities, I believe that a written guide would be welcomed by the interested viewer of Apollo 17. The material in this guidebook is intended to be used in conjunction with the other material shown over television.

The science activities of the astronauts on the surface are divided between "experiments" and "traverses." For the experiments, the astronauts setup equipment on the Moon that collects data and (generally) transmits the data back to Earth. These experiments are described briefly in the section "Lunar Surface Scientific Experiments and Hardware." The reader need not read about all the details of each experiment on first reading. Quite frankly, that section is somewhat long but rather complete, and I have chosen to keep it in the present form so that you may refer to the individual experiments as you wish. I do recommend *scanning* this section before the first Extra Vehicular Activity (EVA) in order to understand something about each of the experiments.

Most of the astronauts' time on the lunar surface will be spent on the traverses along which they describe the geologic features of the landing site, collect rocks, shoot pictures, drive core tubes, and so on. The section "Traverse Descriptions" is a guide to those activities. It tells in general terms the things the astronauts will do on each traverse. It should be used in the same way that a flexible itinerary for a vacation trip through New England would be used. Refer to it during the traverse. But do not try to read it in great detail before the traverse.

The section "Lunar Geology Experiment" should be read before the traverses begin. There you will find descriptions of the tools that are used, the various kinds of photographs taken, and so on. In the section "What We've Learned About the Moon," you will find a brief discussion of the new information about lunar science. I believe that perusal of that section will help you understand better the various experiments and surface procedures.

An important part of this guidebook is concerned with "orbital science." By orbital science, I mean those science activities done in space rather than on the lunar surface. The orbital experiments will probably not be covered extensively on television. But the data obtained on the last few missions are so exciting that I think you may wish to know what is being done on Apollo 17. A general discussion of the scientific work to be done is given in the section "Introduction to Orbital Science." And then in the section "Orbital Science Activities," you will find the experiments and their objectives described. You may not wish to read these sections through at one sitting. Rather, I have included them chiefly for your reference when needed.

Finally, you should know that a glossary, a list of acronyms and some tables are included in the rear of the guidebook. I expect the definitions and short discussions to be found in the glossary will help in understanding some of the terms and concepts now in common use in the scientific exploration of the Moon. Acronyms are short, usually pronounceable, abbreviations, such as NASA, LM, and ALSEP. In two tables, I list the people and companies that have built the scientific equipment. I think the extent of the participation in the scientific part of the Apollo Program may interest you. In another, I list the activities of the astronauts at each station along the traverses.

Introduction

The Apollo 17 mission to the Moon's surface is expected to be launched from Cape Kennedy on 6 December 1972 and to land a few days later in a beautiful valley nestled between two majestic mountains. The landing site is on the southeastern rim of the Sea of Serenity and is called Taurus-Littrow. A sketch of the front side of the Moon is shown in figure 1 and the location of the landing site is shown in relation to other sites. This landing site is extremely important from the viewpoint of lunar science because it contains information about the formation and history of the northeastern section of the Moon. It even has a very large landslide that will be sampled by the astronauts. The rocks collected at this site along with those already collected may provide the key with which to understand the early history of the Moon. They may also provide some new facts on the history of our solar system and of the Earth.

This final Apollo mission is the first one to carry a geologist for a first-hand study of the Moon. Jack Schmitt, the LM pilot, combines astronaut experience and ability with the scientific qualities and training of an excellent geologist. Gene Cernan, the Apollo 17 Commander, has an extensive background as a test pilot and an astronaut plus considerable training in geology and lunar science. Ron Evans, the CM pilot, also has an extensive background and, although he has studied geology and lunar science for many years, he has recently concentrated on the visual recognition and observation of geological features from great distances.

The actual surface on which the Lunar Module or LM * will land is everywhere pock-marked by craters of various sizes. The smallest craters known are less than 1/1000 inch across; the largest exceed 50 miles. Most craters are very old. Some may be several billion years old. But some were produced during the past few million years when objects from space struck the Moon. At velocities of 8 to 20 miles per second, these objects possess very high energy—even more than an equivalent mass of TNT! Such objects are still hitting the Moon. And the Earth, also. You can look into the sky at night and see "shooting stars," evidence that such impacts are still taking place on the Moon. Our atmosphere protects us. (These objects burn in the atmosphere because of the high temperatures caused by friction.) But what about the astronauts on the Moon where there's no protective atmosphere? Although the craters are still being produced, there is no danger to the astronauts because collisions with the Moon are very infrequent. For example, an object larger than birdseed would strike the landing site only once every few years. But because erosion is so slow on the Moon, the craters produced millions of years ago are still preserved and appear as seen in photographs throughout this guidebook. The mechanisms of erosion, the process by which rocks and soil are removed from a particular spot, are very different on the Earth and the Moon. Most terrestrial erosion is the result of running water. Most lunar erosion is the result of impacting objects and the resulting craters destroy previously existing ones.

Since the first manned lunar landing, Apollo 11, in July 1969, significant improvements in both equipment and procedures have increased dramatically the capabilities of Apollo 17 over those of the first four missions. Total duration of the mission has increased to a planned time of about 12½ days and a maximum of 16 days. Actual time for the LM to remain on the lunar surface has doubled; it is now planned to be 75 hours. The amount of time spent by the astronauts on the lunar surface outside the LM, which has become known as Extra-vehicular Activity or EVA, has

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*Abbreviations and acronyms are very useful in situations where time is limited, such as a mission to the Moon's surface. Common ones are noted in this book where first used. An extensive list is given at the end of the text.

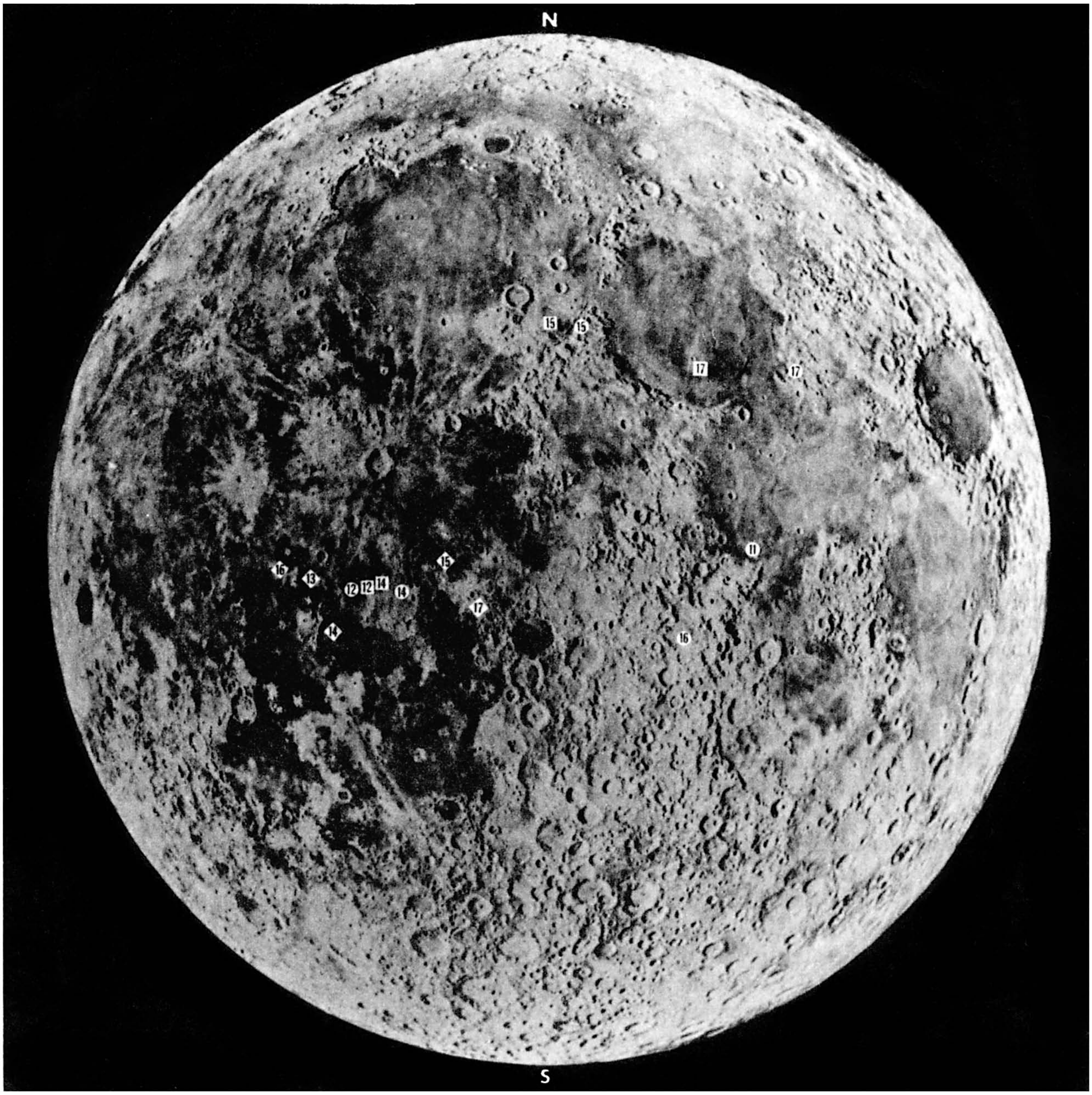

FIGURE 1.—Front side of the Moon. This side always faces the Earth. Shown here are locations of the previous Apollo landings (circles) and of the impacts on the Moon of spent S–IVB stages (diamonds) and LM ascent stages (squares). The numbers in the symbols are the mission numbers. Yes, the number 13 in one diamond *is* correct. Apollo 13, even though aborted, provided important scientific information! No, we did not forget the symbol for Apollo 16 LM ascent stage—it is still orbiting the Moon. The sound waves created in the Moon by the impacts travel through the Moon; they are used to study the interior of the Moon. NASA PHOTO S–72–50306.

more than doubled to a planned 21 hours. The EVA time will be spent in three periods of 7 hours' duration. The weight of the scientific equipment that will be used in lunar orbit has increased from 250 pounds to 1,050 pounds. The weight of the scientific equipment to be landed on the lunar surface has increased from 510 pounds to about 1,200 pounds. And finally, the astronauts will have with them for the third time a small, four-wheeled vehicle for travel over the Moon's surface. It is termed Rover and can carry two astronauts, equipment, and rocks.

A summary of major events for the entire Apollo 17 mission is shown in Table 1.

During the journey to the Moon and before the landing, one of the spent stages of the rocket that was used to lift the spacecraft from the Earth, and designated S–IVB, will be crashed into the Moon. The sound waves generated by the S–IVB impact travel *through* the Moon and will be detected by sensitive receivers (seismometers) now operating at the Apollo 12, 14, 15, and 16 sites. (This experiment is discussed more fully later in this guidebook.)

Shortly after placing their spacecraft in orbit about the Moon, the astronauts separate it into two parts. One part, the combined Command and Service Modules (CSM), remains in lunar orbit while the other part, the Lunar Module (LM), descends to the surface.

One astronaut remains in the CSM and performs many scientific experiments. These orbital experiments will obtain data over a large part of both front and back sides of the Moon because the path of the point directly beneath the spacecraft, termed ground track, is different for each revolution of the spacecraft. See figure 2. Notice that the orbit of the CSM is not parallel to the equator. If the Moon did not rotate about its axis, the ground track would change very little on each successive revolution of the CSM. However, the Moon does rotate slowly about its axis. It completes one full revolution every 28 Earth-days and therefore the ground track is different for each CSM revolution.

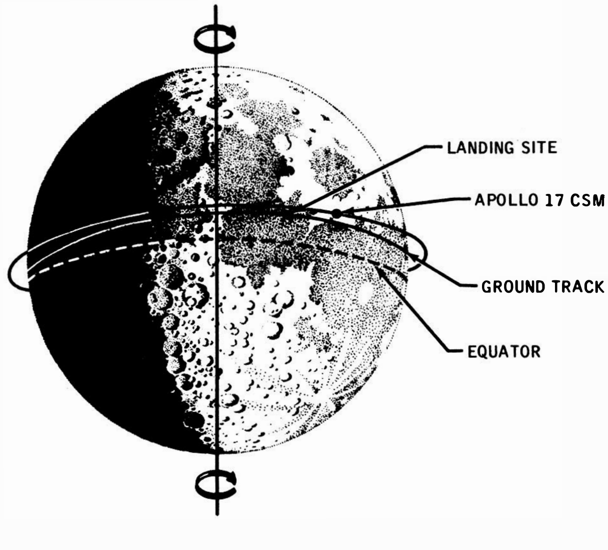

Figure 2.—Orbit and ground track of Apollo 17. Because the Moon rotates, the ground track is different for each revolution of the CSM.

Some of these orbital experiments are entirely new and exciting. One will measure the chemical composition of the Moon's tenuous atmosphere. One will look for "hot spots" on the Moon. And a third experiment will actually look inside the Moon to depths of a few hundred meters. Other experiments that are similar to those flown on previous missions will be flown again to obtain data in different regions of the Moon. One experiment will measure the variations of gravity around the Moon. A laser altimeter will be used to obtain precise elevations of features that lie on the Moon's surface beneath the orbiting CSM. An extensive set of photographs will be obtained of the Moon's surface and of several astronomical objects. The pilot will observe and photograph many features on the Moon never before available to astronauts.

The other two astronauts descend to the surface of the Moon in the LM, illustrated in figure 3. The LM has two parts, a descent stage and an ascent stage. The descent stage contains a rocket engine, fuel necessary to land both stages, a four-wheeled battery-powered vehicle to be used on the Moon, water and oxygen, and scientific equipment to be left on the Moon when the astronauts return to Earth. The other part, the ascent stage, contains the following items: (1) equipment for communications with the Earth and with the CSM, (2) navigational equipment, (3) a computer, (4) food, oxygen, and other life-support supplies, and (5) another rocket engine and fuel needed to leave the Moon and rendezvous with the CSM. All three astronauts return to Earth in the Command Module.

When the astronauts leave the LM, a process appropriately termed egress and shown in figure 4, they must wear a suit that protects them from the Moon's high vacuum. This suit is illustrated

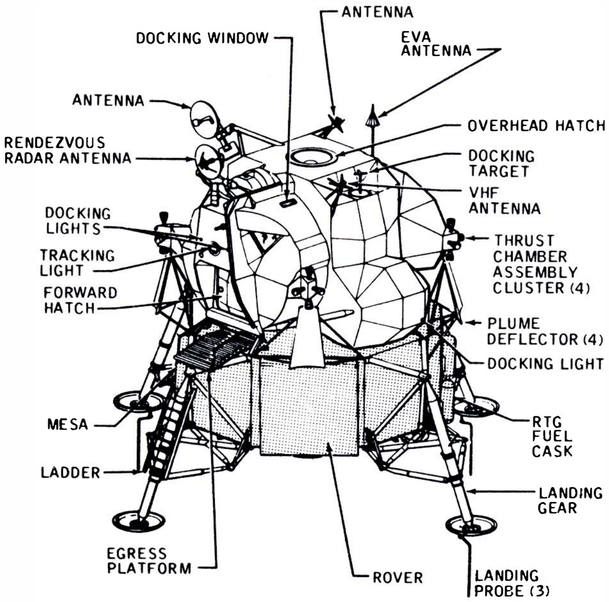

FIGURE 3.—The Lunar Module (LM). The shaded portion, the descent stage, remains on the Moon when the astronauts leave in the ascent stage to rendezvous with the CM and return to Earth. Scientific equipment is stored in the MESA.

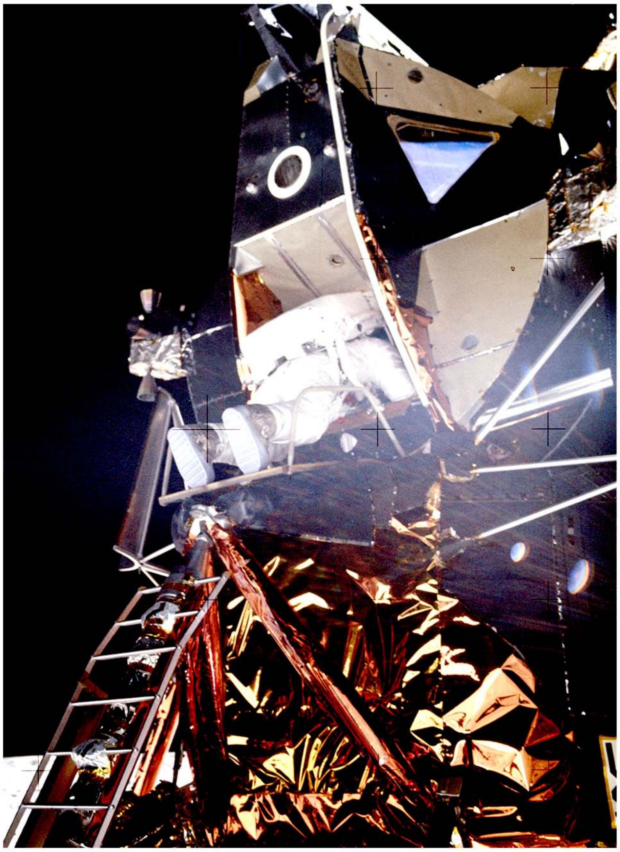

FIGURE 4.—Egress. Apollo 11 Astronaut Aldrin is shown egressing from the LM. Note the ladder that leads down one leg from the platform. NASA PHOTO S–71–31090.

in figure 5. Although it was designed to allow freedom of movement, it still restricts considerably the motion of the astronauts. An example may be useful. Think how difficult it is to run, chop wood, or work outdoors on an extremely cold day in winter when you wear many layers of clothes. The astronauts' suits are even more restrictive. The Portable Life Support System (PLSS) contains the oxygen needed by the astronaut and radios for communication. It also maintains the temperature inside the suit at a comfortable level for the astronaut.

The rest of this guidebook is a discussion of the astronauts' equipment and of their activities on the lunar surface and in orbit.

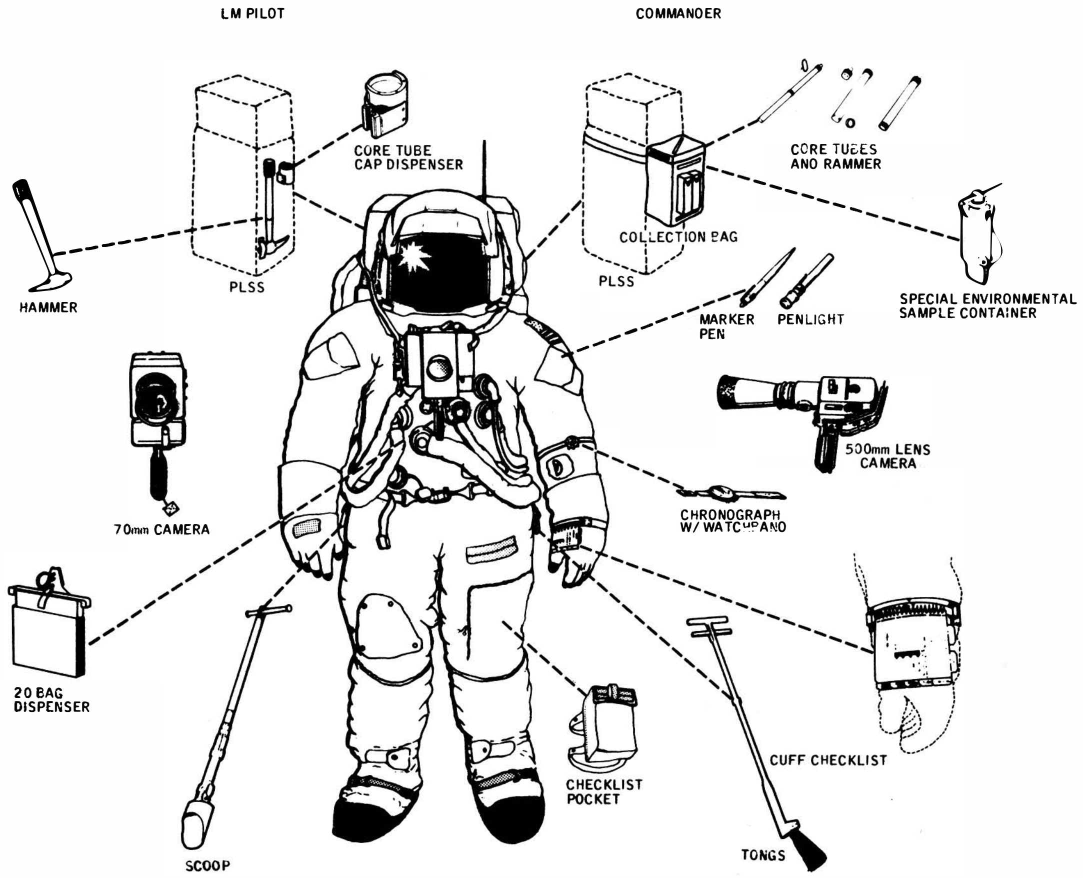

FIGURE 5.—Astronaut suit and equipment. The suit prevents exposure of the astronaut to the Moon's vacuum. It incorporates many improvements over the suits used on early Apollo flights. Sketched also are several items of equipment. NASA PHOTO S–71–29731.

Landing Site Description

The Apollo 17 landing area, termed Taurus-Littrow, lies in the northeastern sector of the Moon (latitude 20°09′50″ N., longitude 30°44′58″ E.). For this landing, we have selected a valley nestled between two very large mountains. The general location is shown in figure 1. See figure 6 for a beautiful view of the site, sketched by artist Jerry Elmore, and figure 7 for the sketch of the region surrounding Taurus-Littrow. In drawing figure 6, we have combined the precision that is available from modern-day computers with the insights that can come only from an artist. Thus the features are very accurately drawn but they are displayed in a way that the human eye will see them. Then in figure 8, I have included a pair of stereo photographs arranged so that you can see the landing site in full three dimensional form. A few minutes spent on learning how to focus your eyes to see these photographs in true three dimensional vision will be extremely rewarding to you.

Since prehistoric times, man has known that the Moon, as seen with the unaided eye, has both light areas and dark areas. The dark areas look smooth, the light areas more rugged. The dark areas are called maria (plural of mare) from the mistaken belief, now centuries old, that they were once seas. (*Mare* is the Latin word for *sea.*) We visited such areas on Apollo 11, 12, and 14. Then on Apollo 15, we landed just at the edge of a dark area and during the exploration that fol-

FIGURE 6.—Taurus-Littrow, Landing Site of Apollo 17. We are looking towards the southeast from a vantage point directly above the mountains on the north side of the valley. The planned touchdown point for the LM, near the cluster of craters, is marked with an X. The general geography of the region is shown in figure 7. *Artwork by Jerry Elmore.* NASA PHOTO S–72–49761.

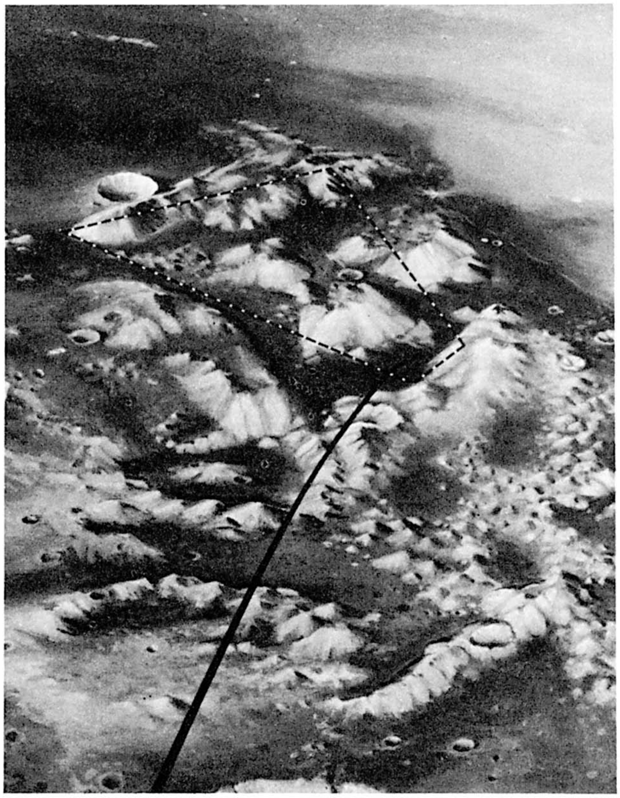

FIGURE 7.—The Region around Taurus-Littrow. The dashed area is the outline of figure 6. The heavy black line is the path of the descending LM. NASA PHOTO S-72-50304

lowed climbed part way up the initial slopes of the Apennine Mountains, a light area. And finally on Apollo 16, we landed in a large highlands region.

The light areas are termed highlands, a name carried over from the days when it was believed that they stood higher than the lunar seas. That indeed they stand higher than the maria is now well established by measurements made on previous Apollo flights. On Apollo 17, we will visit a region that is believed to be ancient highlands. The rocks there are surely very old.

A topographic map of the landing site is shown in figure 9. This map shows in detail the elevation of each point on the landing site. It represents in somewhat more mathematical form the basic data used to construct figure 6. Notice that the floor of the valley is quite flat and slopes gently towards the east. Also, note an elevation of the top of the mountain on either side and compare it with an elevation from the floor of the valley. And then compare this difference in height with these Earth features that you may know:

Empire State Building, New York—380m.
Eiffel Tower, Paris—300m.
Matterhorn, Switzerland—4,475m elevation.
Mount Rainier, Washington—4,400m elevation.
Grand Canyon, Arizona—1,700m depth.
Highest elevation east of Mississippi River—2,000m.

(To convert these heights, which are given in meters, to the more familiar unit of feet, multiply by 3.) Such mental comparisons coupled with the three-dimensional image that you can obtain from figure 8, will give you a clear idea of the size of the features at Taurus-Littrow.

In addition to the topographic map, one can obtain other information about the landing site from the photographs. Even from the reproductions in this booklet you can see that the Moon's material *looks* different in different places. And of course, the high quality photographs from which these reproductions were made show even more differences. I am certain that you can see that the Moon's material in the large mountains is different in appearance from the material in the smaller hills and that both of these materials appear to be different from the material in the valley. And finally, notice that the material exposed in the sides of the craters in the valley floor has a different appearance from the material on the valley floor. Lunar geologists, with considerable experience in interpreting such aerial photographs of features on the Earth where they can easily check their photographic interpretation, have studied intensely the photographs of the landing area. They have drawn a geologic map of the area; it is reproduced in figure 10.

In the rest of this section, I will discuss the several geologic features present at the landing site: rock units, craters, mountains, and those breaks in the rocks that are termed faults. All of them are clearly visible in figures 6 through 10.

DESCRIPTION OF ROCK UNITS

Several different kinds of rocks can be seen in the various photographs of the Apollo 17 landing site. The aerial distribution of the various units is shown in the geologic map (figure 10). At the present time, before actually visiting the area to see the various rock units, we cannot be certain of the exact kinds of rock that compose these various units. So we prefer NOT to give the rocks of the units that compose the North Massif a particular rock name, like breccia or basalt. Rather, we prefer

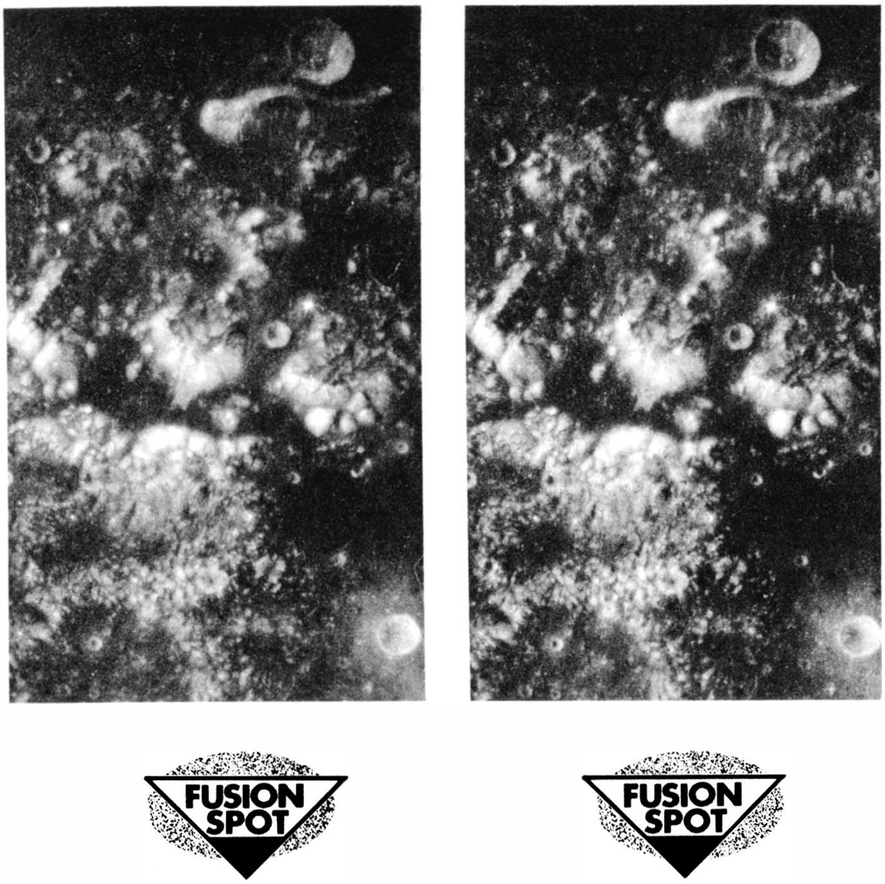

FIGURE 8.—Stereo Photographs of the Apollo 17 landing site. These photographs were selected by Leon J. Kosofsky and arranged by Earl E. Krause. Most people can train their eyes to focus on these photographs in such a way that they will see them in full three-dimensional vision. To help you train your eyes, Krause has written the following description:

Here's how free vision works: Each eye is trained to look straight ahead at its respective image. The eye muscles learn a new trick—to focus at reading distance while the lines of sight are parallel as if looking at something distant. Both are normal functions now used in a new orientation. At first, some beginners' eyes may sense strain but since this is eliminated by practicing moderately at repeated intervals it is not to be feared (eye surgeons say the best thing for the eyes is to use them).

Prominent spots, targets, or see-through holes located above, below and actually in the images are aids which help the eyes "lock on" to their respective images and hold the fix of parallel lines of sight. The fusion spots below each photograph can be used to help focus your eyes.

Keep the pictures in good light and level. A slight wobbling of the head or the pictures helps find the most comfortable level which allows extended periods of free vision viewing. If eyestrain is felt while practicing, discontinue in favor of short sessions at later times.

One way readers may teach themselves this useful visual trick is to start by staring fixedly at a point far across the room or out the window. This makes left and right lines of sight practically parallel. Hold the stereo picture level in good light just under your gaze. Then raise the pair of images slowly up into the unblinking stare. Don't try to refocus immediately but note the daydreamy double vision appears to give three or four images in a row. Concentrate on the center image(s) to make them "swim together", disregarding the side ones. It's easier with contrasty masses in the picture or with fusion spots located close above or below. Still without blinking, sharper focus. POP, Stereo!

In addition to the fusion spots another helpful aid is a divider in the form of a long envelope, cardboard, or even the flat hand held vertically straight out from the nose to block the view of the distracting wrong image from each eye. Keep the picture in good light and level. A slight wobbling of the head or the pictures usually seems to encourage the images to merge properly and help find the most comfortable level which allows extended viewing periods.

Various pocket stereoscopes may be helpful to the few who find free vision difficult. (Hubbard Scientific Co., P.O. Box 105, Northbrook, Ill. 60062, offer their folding stereoscope No. 575 at $2.25 ppd.)

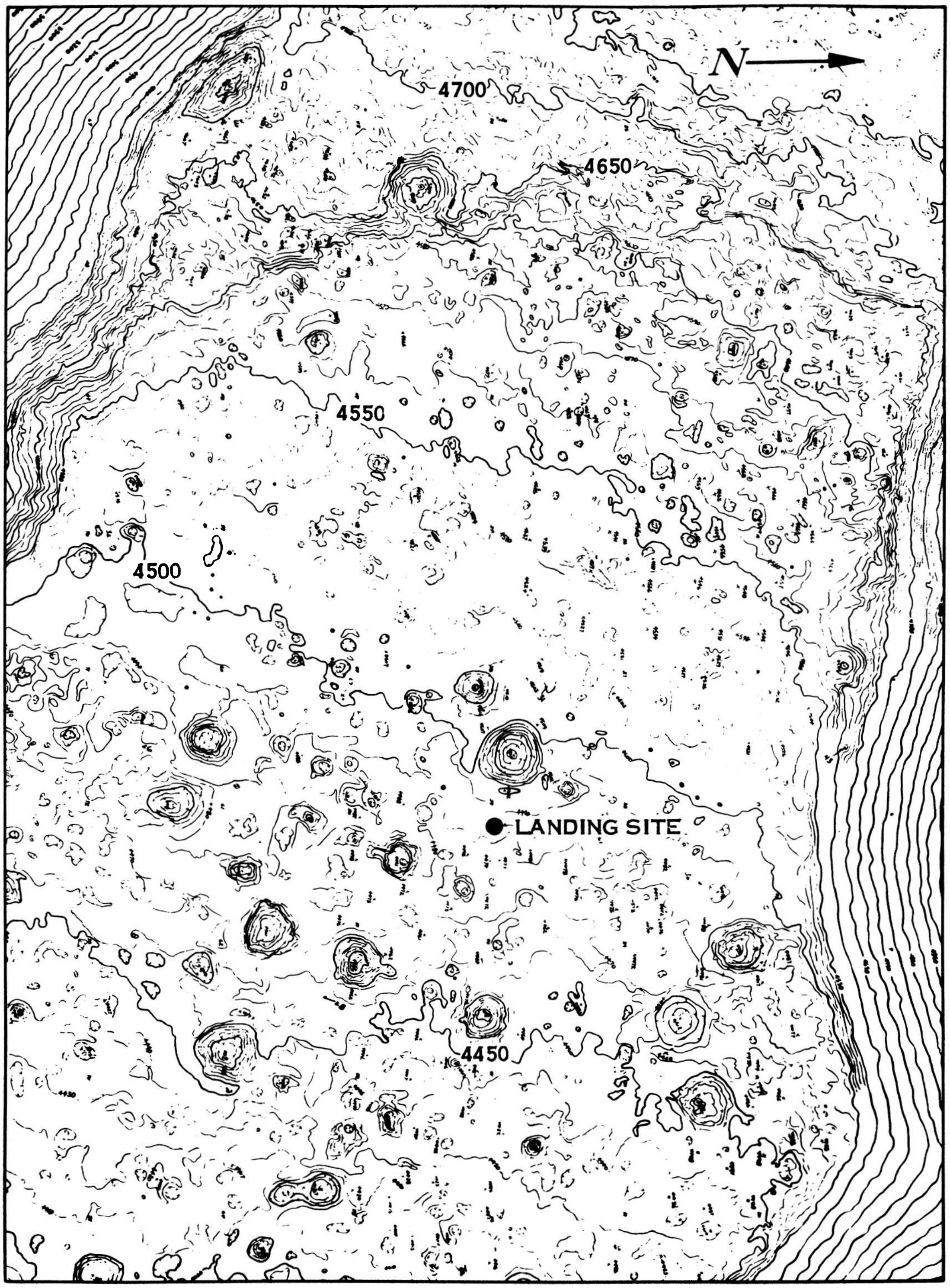

Figure 9.—Topographic map of the Taurus-Littrow region. This map shows the elevations of the surface of the Moon in the vicinity of the Apollo 17 landing site. The lines, called contours, connect points of equal elevation. Thus the line that is labeled 4550 indicates that the elevation of all points on the Moon's surface corresponding to that line lies at a relative height of 4550 meters. On topographic maps of the Earth, we measure elevations relative to mean sea level. For the Moon we measure elevations relative to a sphere of radius 1,738,000 meters. The difference in elevation between adjacent lines on the valley floors is 10 meters (about 30 feet) ; on the steep sides, it is 50 meters. NASA PHOTO S–72–50327.

now to simply map from the aerial photographs the material that underlies the North Massif as a single rock unit and call it "MASSIF MATERIAL." The distinctive nature of the massifs suggests that they probably consist of lunar breccia.* It is possible that the MASSIF MATERIAL may not have a uniform source; some may have been thrown out of the various large maria. (Serenitatis, Nectaris, Crisium, and Imbrium, as well as others). We believe though that most of the material probably came from the Serenitatis Basin.

The Sculptured Hills are underlain by material that may be different from the material beneath the massifs. From the photographs, *you* can see that it looks different. Its different appearance is largely the result of its different topographic expression. Note that the MASSIF MATERIAL forms high, steep, and relatively blocky mountains whereas the SCULPTURED HILLS unit forms several closely spaced and rounded hills. From many photographs of the Moon (not shown in this guidebook), we know that similar features are widespread in the highlands between Serenitatis and Crisium. So we are quite anxious to learn the exact nature of this material.

The LOW HILLS material occurs in rather discontinuous patches around the MASSIF and SCULPTURED HILLS materials. We believe that the LOW HILLS are most likely the tops of large blocks of either MASSIF or SCULPTURED HILLS materials that have dropped into the valley and are now mostly covered by the SUBFLOOR material. These features may be somewhat like icebergs in the Earth's seas in that only small portions protrude above the surface. Only from our study of the various samples that will be brought to Earth from the Apollo 17 site will we know with certainty whether the LOW HILLS material is the same kind of material as either the SCULPTURED HILLS or the MASSIF materials.

The DARK MANTLE material is presumably a loose fine-grained material like sand or gravel or soil. We see no blocks larger than 2 m (which is the minimum size that can be seen in our photographs). From earth-based radar data, we know that cobbles (stones roughly 25 cm diameter) and small boulders are scarce in this material. The DARK MANTLE occurs as a blanket a few meters to a few tens of meters thick on the surface of the valley and on the floors of nearby basins (which however are not seen in the figures of this guidebook). It is patchy on sloping surfaces and on steep walls of pre-existing craters. Although the DARK MANTLE is rather thin, it covers everything below it and the SUBFLOOR material can be seen only in craters and on a few crater rims. Our present best guess for the origin of the DARK MANTLE material is that it is a volcanic rock that was blown out of nearby volcanic vents and deposited over the whole area. However, we have not identified any such vents in the immediate area. (Possibly they are too small to resolve in our photographs or we are unable to distinguish

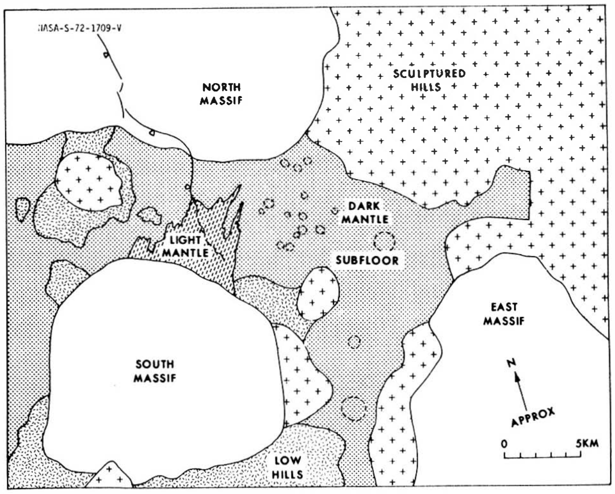

FIGURE 10.—Geologic map of Apollo 17 area. The different patterns are used to show the aerial distribution of different kinds of rock on the Moon. From a study of the relations of the various materials to each other, we *think* that the LIGHT MANTLE material is the youngest, the DARK MANTLE material intermediate in age, and the other materials are all older. We do not yet know the relative ages of the MASSIF material (which is shown with no pattern), the SCULPTURED HILLS material, or the LOW HILLS material. The lines that separate each material from the other on the map may actually be located in some cases by the astronauts on the Moon with an accuracy of a few meters by noting the change from one rock type to another. The line, with small triangular barbs, that extends from the upper left hand corner of the map into the LIGHT MANTLE material is the map representation of a steep cliff. The dashed circular outlines that can be seen in the DARK MANTLE pattern represent craters that existed in the material beneath the DARK MANTLE material *before* the DARK MANTLE material was deposited. SUBFLOOR material is exposed only in the walls and rims of craters. MAP COURTESY OF E. W. WOLFE, J. W. HEAD, V. L. FREEMAN, AND H. H. SCHMITT.

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*See the section on samples in this guidebook for an explanation of rock terms. There you will find photographs as well as descriptions.

them from impact craters.) If our guess as to the volcanic nature of the deposits is correct, then we know from our experience of studying such materials on Earth that they will contain considerable volcanic ash and volcanic glass.

The LIGHT MANTLE material—seen as a bright ray-like feature with linear ridges and finger-like projections out over the DARK MANTLE material—was probably deposited by an avalanche of rock debris from the steep slopes of the South Massif. We know that this deposit is thin because we can see the outlines of craters that exist below it. We can see also the cliff that extends southward from the North Massif and into the LIGHT MANTLE material. On even the best quality photographs of the landing site, we are unable to see any boulders that are larger than 2 m except near the south end of the slide and on the adjacent slope of South Massif. From radar data, we infer that more cobbles are present in the LIGHT MANTLE material. On the basis of a very few small scattered impact craters, the position of the LIGHT MANTLE material over the DARK MANTLE material, and the lack of mixing near the thin edges of the LIGHT MANTLE material, we believe the LIGHT MANTLE material to be the youngest of any present at the Taurus-Littrow site.

The floor of the Taurus-Littrow valley is covered everywhere with the LIGHT MANTLE and DARK MANTLE materials which we believe to be fairly thin, only a few tens of meters at most, and beneath them is a rock that is termed the SUBFLOOR UNIT. A remarkable feature produced by that unit is the smoothness of the floor of the entire valley. We believe that the SUBFLOOR UNIT may be basalt flows, sheets of breccia, or possibly material eroded from the nearby mountains. Samples of the material are probably present in the material ejected from some of the craters. We are anxious to collect samples of this unit.

SURFACE FEATURES

Several major surface features of special interest occur at the Apollo 17 site. These include a thin regolith; several faults; a long, steep, east-facing cliff (geologically, scarp) and several craters. All of these features are readily apparent in the photographs of the region. They are especially clear in the stereo photographs. The description of the geologic features of the landing site is perhaps easier to visualize with the aid of a block diagram. Shown in figure 11 is a large chunk of the Moon as it would appear if lifted out of the Moon so that we could view it.

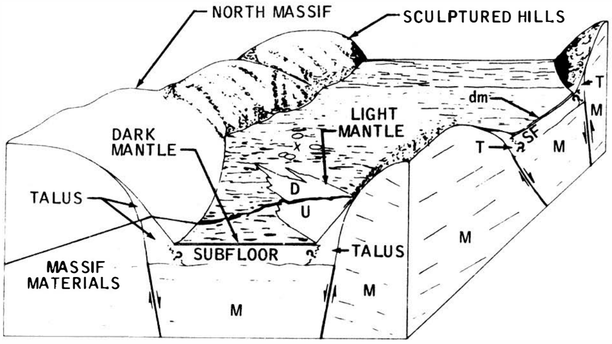


Figure 11.—Schematic view of Taurus-Littrow. Visualize, if you will, a large section of the Moon's material sawed out, lifted by a gigantic crane, and placed on a huge tabletop for us to view. From our photographic observations, previous study of lunar rocks, and our experiences in studying geology on the Earth, we believe that such a block of the Taurus-Littrow site would appear as we have sketched it in this drawing. The vertical scale has been exaggerated by a factor of about 2½ times the horizontal scale.

Regolith. An unusually thin regolith, the outer layer of soil and loose rock that has been churned up by meteorites, is expected at the Apollo 17 landing site. We see no evidence of mixing of the LIGHT MANTLE material, the DARK MANTLE material, or the units below them. Indeed, the study of small craters shown in Apollo 15 orbital photographs of the Taurus-Littrow area suggest that the thickness of the regolith may be much less than 1 m and probably only 3–30 cm. At other landing sites, we have found greater thicknesses, ranging from 3 to 14 m. For example, the regolith at the Apollo 14 site was about 8 m thick.

Scarp. A very prominent, apparently young, east-facing scarp, or cliff, crosses the floor of the valley about 5 km west of the landing point. It continues into the North Massif (figure 10) and probably extends much farther. In the valley, heights as great as 80 m occur along the scarp. On orbital photographs, the scarp appears to be covered by a veneer of the LIGHT MANTLE material. From our experience on Earth with such features, we believe that the scarp is the surface expression of a geologic fault that extends to considerable depth in the Moon. Rocks that have been

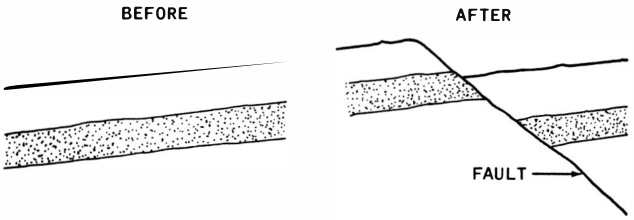


FIGURE 12.—Fault. The geological term fault is used for any surface on which movement has occurred. Although layered rocks are shown in this illustration, faults also occur in rocks that have no layering. The rock may move in any direction; in this example the rocks on the right hand side of the fault have moved downward with respect to those on the left hand side.

uplifted by the fault may be exposed in the face of the scarp. Samples collected from the base of the scarp may possibly include samples of these rocks derived from the entire 80 m. Obviously, high resolution photographs of the scarp face taken by the Apollo 17 astronauts from the surface of the Moon would be very useful later for "restoring" the samples to their correct original position on the face of the scarp.

Faults. A fault is the geological term for the surface along which a break has occurred in rocks. See figure 12. The rocks that were at one time continuous across the fault have been broken and physically moved into positions where they are no longer continuous. We believe that the prominent scarp at Taurus-Littrow is the surface expression of one fault. We believe that several other faults are also present. It is rather likely that the sides of the valley are bounded by faults.

Faults are very common on Earth where they are studied intensively. In mountainous regions, we may find ore bodies with gold or silver associated with faults. In nonmountainous regions where petroleum occurs, we sometimes find oil and gas associated with faults. And finally, let me note that the movement along faults is always associated with earthquakes. Every Californian has heard of the San Andreas Fault and its various branches and knows that most of the destructive earthquakes in California are produced by the movement of rocks along that particular fault system!

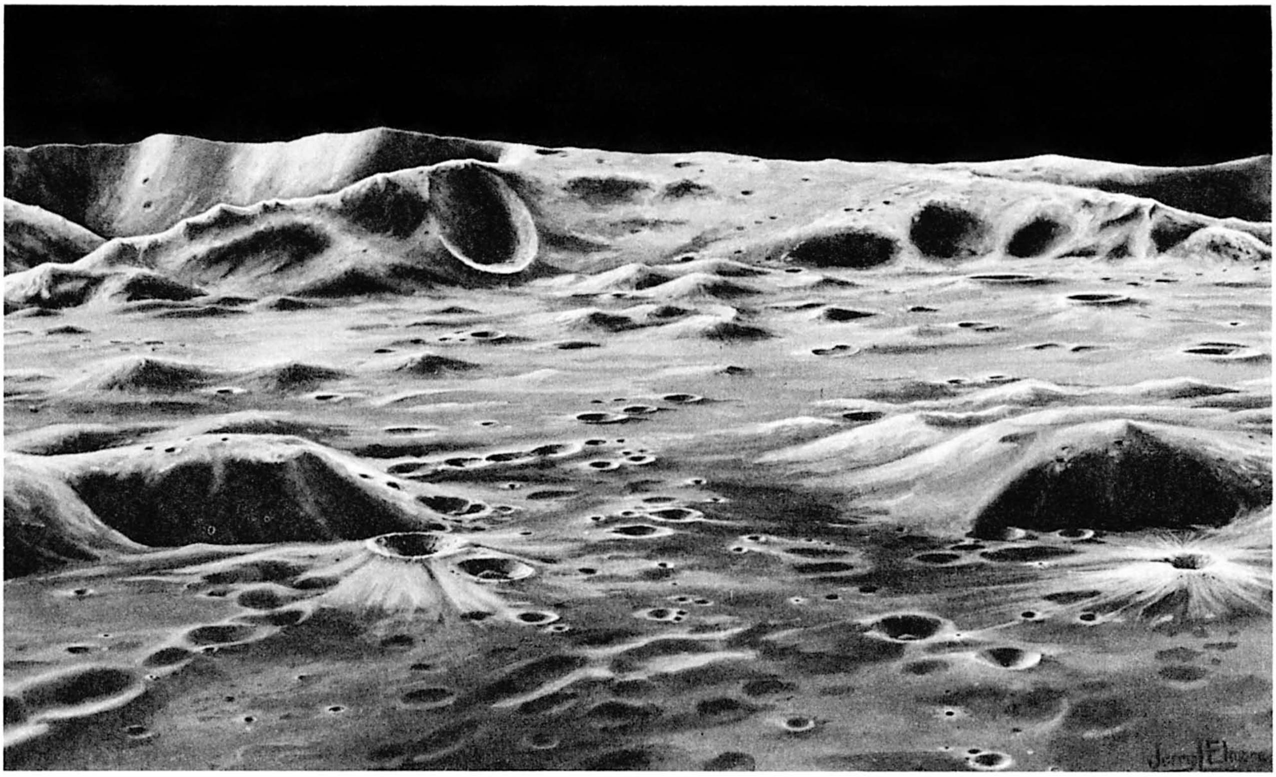


FIGURE 13.—The descartes region, landing site of Apollo 16. We are looking due east and downward at an angle of about 10°. The bright rayed crater in the lower right hand corner is South Ray. The one slightly to the left of center and in the foreground is North Ray Crater. The LM landed roughly midway between these two craters. *Artwork by Jerry Elmore.* NASA PHOTO A–71–60976.

Craters. Craters are rare on Earth. They are present everywhere on the Moon. Even the most casual TV watcher of the previous lunar landings has now seen many craters, but what he may not know is how much can be learned about the Moon from craters. The "freshness" of a crater is a measure of its relative age. See figure 13, Jerry Elmore's drawing of the Apollo 16 landing site, the Descartes Region. Notice how sharp the crater North Ray appears. (North Ray is the bright rayed crater in the left foreground.) Compare it with the much smoother one about one-half mile west. This comparison suggests that North Ray is the younger of the two craters. It is easy to generalize this comparison to a regular gradation of sharpness which can then be used to obtain the relative ages of many craters.

Our understanding of the details of crater formation has been greatly improved by the study of impact craters on Earth. One such crater that is generally well-known is Meteor Crater, near Flagstaff, Arizona. Other impact craters, less well-known to the public but intensely studied by geologists, exist in Tennessee, Canada, Australia, Germany, and elsewhere. An oblique photograph of Meteor Crater is shown in figure 14.

But not all features on the Moon's surface were formed by impacting objects. Some were formed by volcanism. It is never easy on the basis of photographs or telescopic observations to distinguish between an impact and a volcanic origin for a particular feature. In fact Galileo, the first man to look at the Moon through a telescope, about 350 years ago, suggested that *all* the craters on the

FIGURE 14.—Meteor crater. This crater, about a half mile across, 600 feet deep, and located near Flagstaff, Ariz., was caused by the impact of a large meteorite with the Earth in prehistoric times. Thousands of pieces of the meteorite have been found in the surrounding area. This feature has been studied extensively by members of the U.S. Geological Survey and has shed light on the details of crater formation. Note the raised rim, a characteristic of many lunar craters. The crater, readily accessible by automobile, is well worth the small time required to visit if one is nearby. PHOTO COURTESY OF U.S. GEOLOGICAL SURVEY.

Moon were due to volcanoes. His hypothesis stood unchallenged for two centuries until someone suggested the impact hypothesis. As so often happens in science, long, and sometimes bitter, arguments over which hypothesis was correct raged for about 100 years. Today, we believe that *most* lunar features have resulted from impacts but *some* have been caused by volcanic processes.

The craters provide samples that came originally from below the Moon's surface and are now sitting on the surface of the Moon. The interpretation of those samples allows us to infer changes of the rocks with depth. Basically, we obtain "depth information" in two different ways. First, think about the simple observation that small craters extend only to shallow depths—and hence "sample" only those rocks near the surface. Larger craters extend to greater depths—and hence sample not only those rocks near the surface but also those rocks at greater depths. Thus we see why samples collected from different sized craters may be greatly different. Secondly, we know from studying craters on Earth that rocks from different depths were thrown to different distances when the crater was formed. We have even watched through slow motion photography the material excavated from depth by a large explosion; we have traced it through the air and seen it land at a particular distance. Thus by collecting rocks at various distances from a crater, we can obtain samples of the rocks that lie at different depths. Such samples are very important and will be collected at several craters.

The study of the vertical changes in rocks, termed stratigraphy, provides the basic data necessary to construct the history of the Moon. (For example, many facts about the geological history of the Earth have been read from the rocks exposed in the walls and bottom of the Grand Canyon.) Thus samples obtained at different elevations are quite important. Samples originally on the tops of the mountains at the Apollo 17 site (figure 6) can now be collected near the bottom of the mountains. But how do we know that samples now lying at the bottom really came from the top? We have seen similar relations on Earth. In addition, we can actually see from orbital photographs of the site that some boulders have rolled down slopes, left trails behind them, and now occur at the bottom ends of their trails. Of course material from all heights will be mixed together. One challenge to the lunar geologist is the "unmixing" of the samples and the assignment of the proper stratigraphic height to each.

Material ejected from some giant craters extends halfway across the Moon. See figure 1 for examples; the crater Tycho near the south pole is the most prominent. Material from others extends shorter distances. Everywhere on the Moon some material has been received from distant impacts. Most of the material present in the vicinity of any particular crater is undoubtedly the material that was present before the crater was formed. The exotic material, that which came from elsewhere, is probably quite rare and the amount present at the Apollo 17 site may be less than 1 part per 1,000. Only after extensive investigation of the samples back in the laboratory on Earth will we be reasonably sure about the origin of any particular sample.

Lunar Roving Vehicle

In the LM the astronauts will take with them to the surface of the Moon a four-wheeled vehicle that can be used to travel over the lunar surface and to carry equipment and rocks. It is termed the Lunar Roving Vehicle (LRV) or Rover (figure 15). It is powered by two silver-zinc, 36-volt batteries and has an individual electric motor for each of the four wheels. A photograph of the Apollo 15 Rover, taken on the Moon's surface, is shown in figure 16. A photograph of the folded Rover, taken just before it was placed in the LM, is shown in figure 17, the instrument panel in figure 18, and the Rover deployment scheme is shown in figure 19.

There is a navigation system that contains a directional gyroscope and provides information as to total distance traversed as well as heading. The instrument panel is shown in figure 18. Knowing the location of the Rover at all times is extremely important. Not only must the astronauts know where they are, but the scientists back on Earth must know where rocks are collected, observations are made, and data are taken for the traverse experiments. So the navigational information is to be recorded on the same tape recorder used for the Surface Electrical Properties (SEP) experiment. Soon after the astronauts return to Earth,

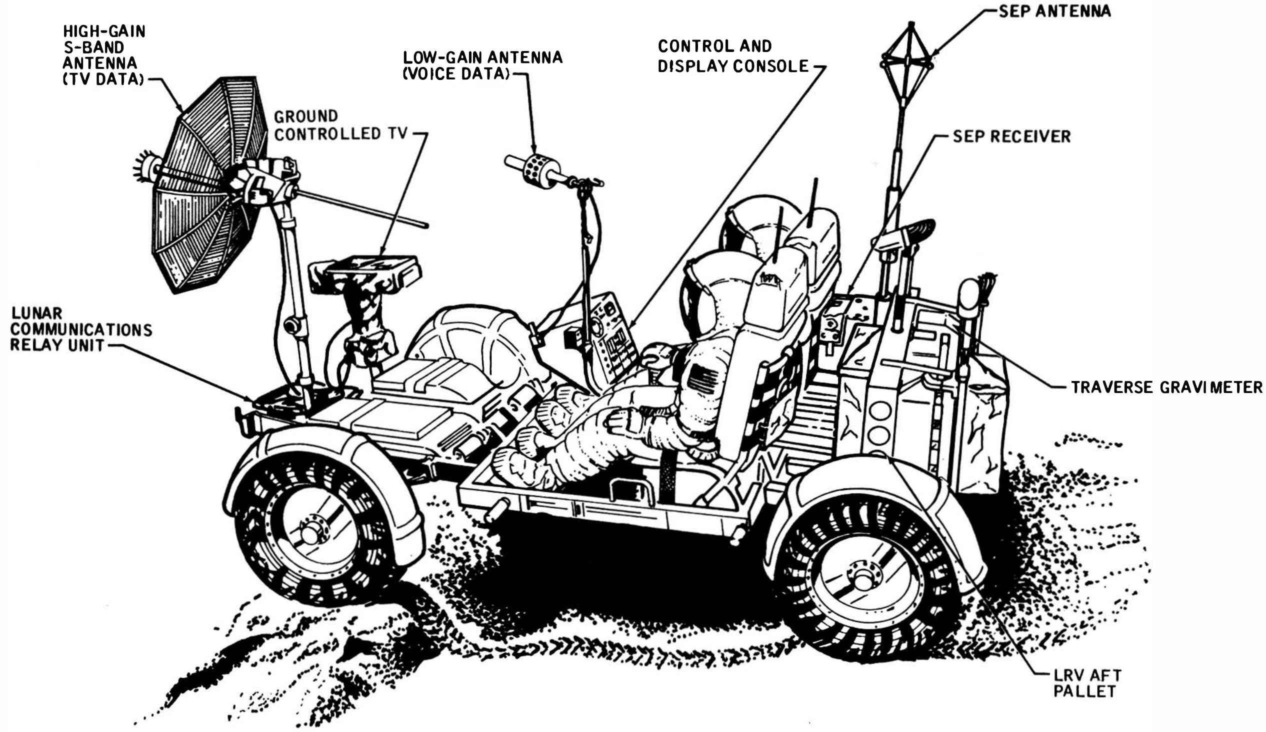


FIGURE 15.—The Lunar Rover. Both astronauts sit in seats with safety belts. About 7 minutes are required to fully deploy Rover. Although Rover weights only 500 pounds, its capacity is about 1,140 pounds. The vehicle travels about 10 miles per hour on level ground. The steps necessary to remove it from the LM and to ready it for use are shown in figure 18.

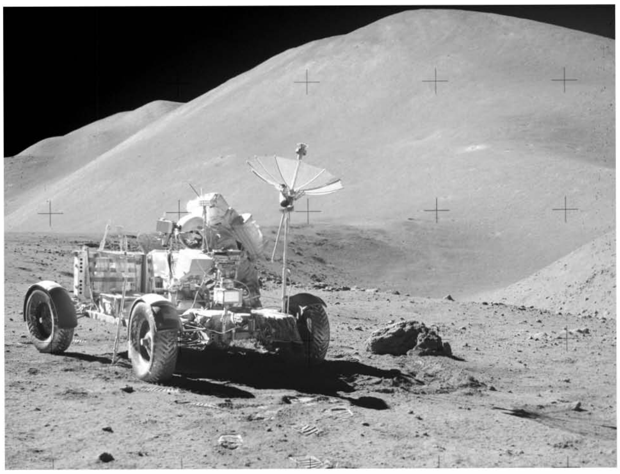


Figure 16.—The Apollo 15 Rover. Shown in the background is Mount Hadley delta, a 12,000-foot mountain. The valley on the right side of the photo is about 1,200 feet deep. On the Rover, note the high gain antenna and the TV camera in the front and the tool carrier in the rear. The scale of the photo varies greatly from the foreground to the horizon; it may be obtained from the footprints, the Rover, and the mountains in the distance. The crosses (+) in the photo are termed Risseau marks and are used to correct small distortions in the photo. NASA PHOTO AS 51–82–11121.

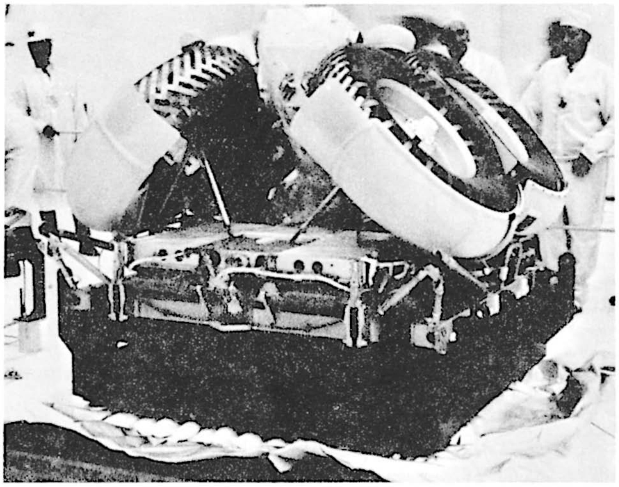


Figure 17.—Folded Rover. So that Rover would fit into the small space available in the LM, it was folded in the fashion shown here. This photo was taken at Cape Kennedy shortly before Rover was placed in the LM. NASA the photo. NASA PHOTO AS51–82–11121.

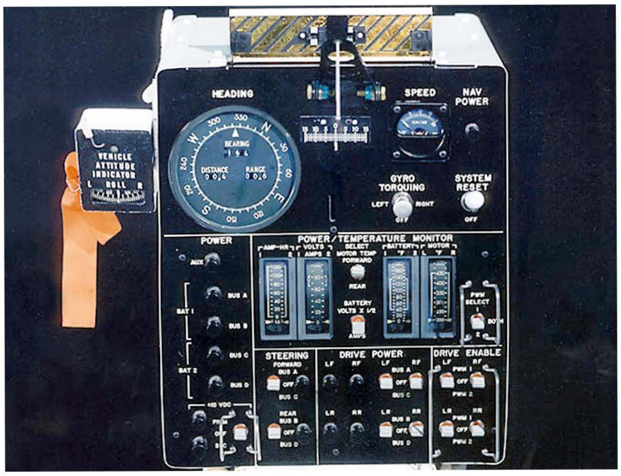


Figure 18.—Rover Instrument Panel. This panel contains all of the power switches for the Rover, an indication of the direction in which the Rover is heading, the speed at which it is traveling and the information (direction and distance) necessary to return safely to the LM. Also shown are the power and temperature of various motors. NASA PHOTO S–72–16181.

we will know the precise location of the Rover along each traverse.

In addition to the equipment carried on the Rover in earlier missions, mounted on the Apollo 17 Rover will be two science experiments that will obtain data along the route of the traverses. One experiment, the Lunar Traverse Gravimeter, or LTG, will measure the value of gravity at each stop with an extremely sensitive instrument. It can measure gravity with a precision of about one millionth the Earth's gravitational field! The other experiment, termed the Surface Electrical Properties Experiment, or SEP, will measure the electrical characteristics of the landing site. Both of these experiments are discussed in greater detail in the section on experiments.

As the astronauts ride over the surface of the Moon, they will describe the features that they see. Then at science stops, in addition to their oral descriptions, television pictures are sent back to Mission Control in Houston from the Rover. Some of these pictures may be shown over the regular TV networks.

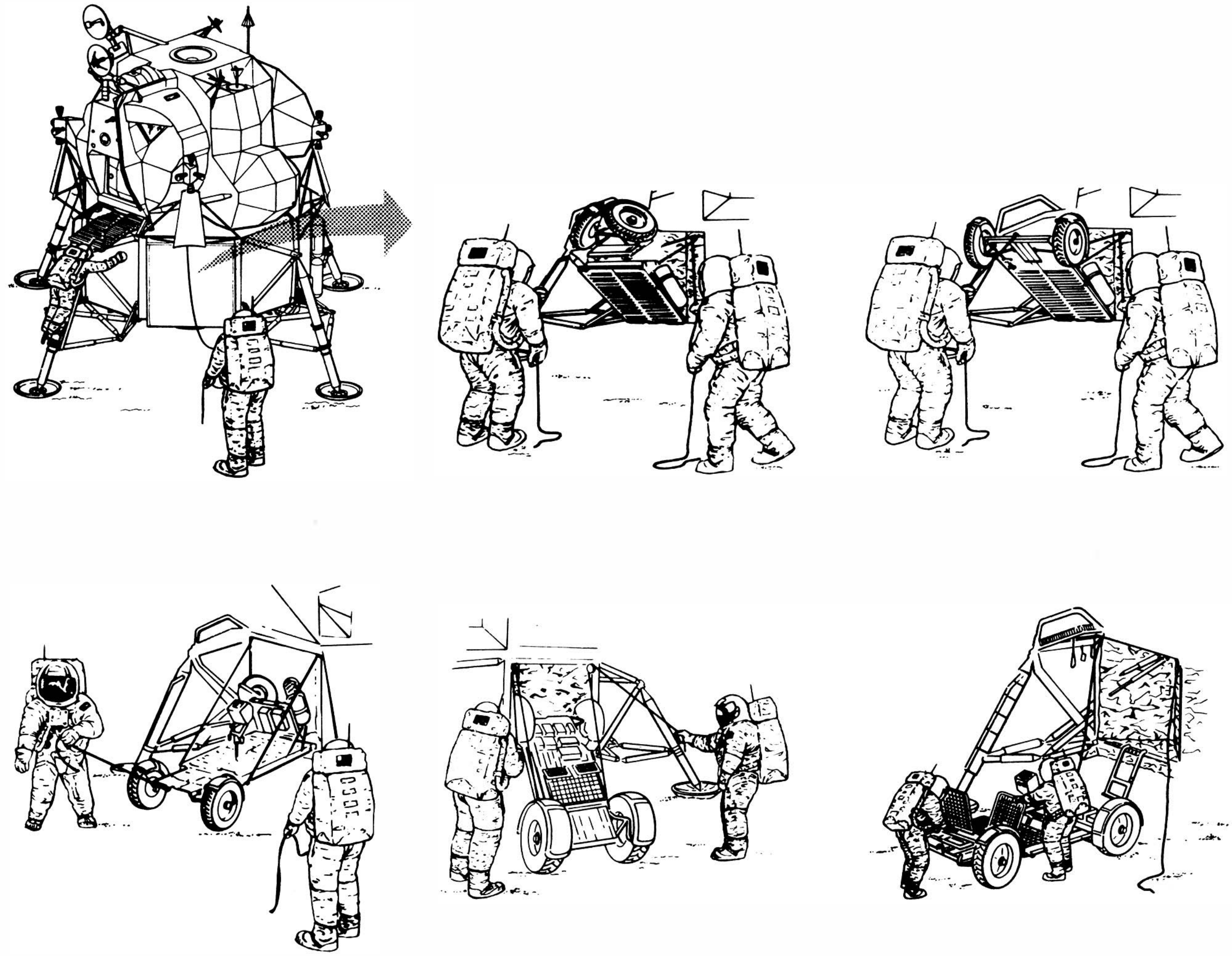


FIGURE 19.—Deployment sequence for the Lunar Roving Vehicle.

Surface Science Activities

Each of the two astronauts that descend to the lunar surface in the LM will spend about 21 hours in three periods of 7 hours outside the LM working on the lunar surface. Most of that time will be used to study geological features, collect and document samples of rocks and soil, and set up several experiments that will be left behind on the lunar surface when the astronauts return to Earth.

The surface traverses described in this guidebook, which was written about 3 months before launch, should be considered as general guides for the astronauts to follow. From previous Apollo missions, we have learned that although some minor changes in plans are likely to occur, major changes are unlikely. On each mission a few changes were made by the crew because of unforeseen conditions. Instructions to the astronauts have always been "to use their heads" in following the detailed plans and the Apollo 17 mission is no exception. In addition, the astronauts may consult over the radio with a group of scientists located in Mission Control at Houston and decide during the mission to make some changes. Undoubtedly some details of the traverses will change. Equipment changes, on the other hand, are very unlikely to occur because all of the equipment had been built and was being stowed in the spacecraft at the time of writing.

TRAVERSE DESCRIPTIONS

The planned Rover traverses are shown in figure 20. The activities at each of the stops on all three traverses and along each traverse between stops are shown in Table 2. In order to use Table 2 effectively, the reader must have scanned most of the next section, "Surface Scientific Experiments and Hardware", and to have read the section "Lunar Geology Experiment."

The numbers assigned to each of the traverse stations shown in the figures and tables of this guidebook are current at press time (1 October 1972) and are not expected to change. However, extra stations may be added or deleted, before, as well as during, the mission. These extra stations will be given a special designation to avoid confusing them with the existing stations.

During the 75-hour lunar stay, three 7-hour EVA's are planned. On EVA 1, most of the time will be spent readying the Rover, setting up ALSEP and other experiments, but about two hours will be used for a traverse to Station 1. The primary geology objectives of EVA 1 are to investigate the SUBFLOOR materials and the DARK MANTLE. The chief objectives of EVA 2 are to study and sample the base of the South MASSIF and the LIGHT MANTLE material found in the debris slide. Then on EVA 3, the astronauts will investigate and sample the North MASSIF and SCULPTURED HILLS material that lies to the north and northeast of the landing site. They will further investigate and sample the DARK MANTLE material and the SUBFLOOR material. During all three traverses, the crew will not only study geology but will also collect geophysical data. The LSP charges will be placed on the Moon. Gravity will be measured at several places with the Traverse Gravimeter. And SEP data will be obtained continuously and automatically along the traverse routes.

In the event that the Rover becomes inoperative sometime during the mission, a series of walking traverses has been planned. Because the maximum distance that an astronaut can walk safely on the Moon is set by the amount of oxygen and other supplies that he carries, the walking traverses extend only 3 to 3½ km from the LM. The general objectives of walking EVA's are the same as those for the Rover traverses. The astronauts will study and sample the North MASSIF, the SUBFLOOR, and the DARK MANTLE material

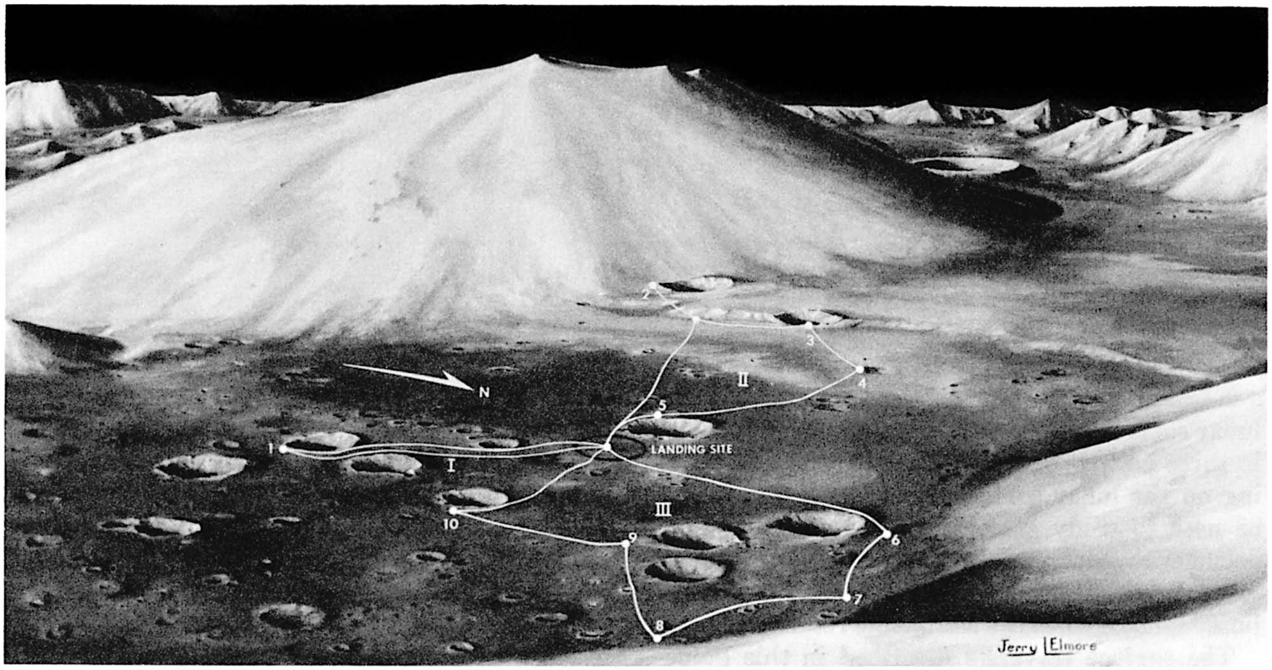


FIGURE 20A.—The traverses planned for use with the Lunar Roving Vehicle. The roman numerals indicate the three EVA's. The numbers are station stops. The station stops are keyed to the information given in Table 2. These same traverses are shown in figure 20B, an overhead view of the landing site. *Drawn by Jerry Elmore.* NASA PHOTO S–72–49760.

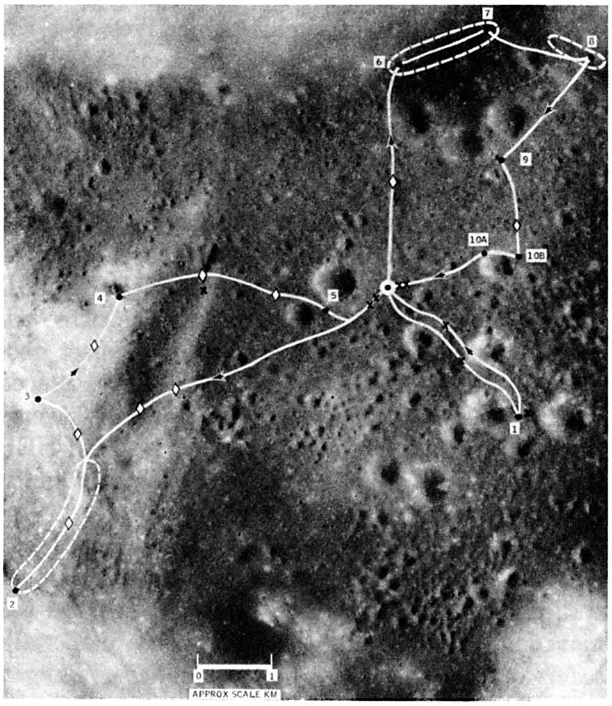


FIGURE 20B.—The traverse routes shown on the *photograph* of the site. This photo obtained on Apollo 15, has been used extensively in planning the surface activities. Locations of LRV-samples are shown with diamonds, of LSPE charges are shown with X's. Enlargements of each EVA traverse area are shown in other figures. North is at top of photo. NASA PHOTO S–72–50305.

at as many Rover traverse stations as possible. But because of the major limitation of distance, only Stations 1, 5, 6, 9, and 10 could be visited on walking traverses.

In planning for contingencies, we have placed many data into computers so that we can recall them immediately when we need them. For example, we are able to generate in the computer the view that will be seen by the astronauts from any position at the landing site and along the landing trajectory itself. In figure 21, I show the computer output for several successive views along the Taurus-Littrow landing trajectory, as well as a part of the panorama that can be seen from the LM touchdown point.

LUNAR SURFACE SCIENTIFIC EXPERIMENTS AND HARDWARE

Several different kinds of experiments will be done at Taurus-Littrow. The astronauts will collect samples of lunar material to be returned to Earth and will describe the geological features of the site. They report these descriptions over radio. (The transcript of each EVA on previous missions fills many pages!) They will set up several scien-

VIEW FROM 6000 FEET ABOVE LANDING SITE

VIEW FROM 3000 FEET ABOVE LANDING SITE

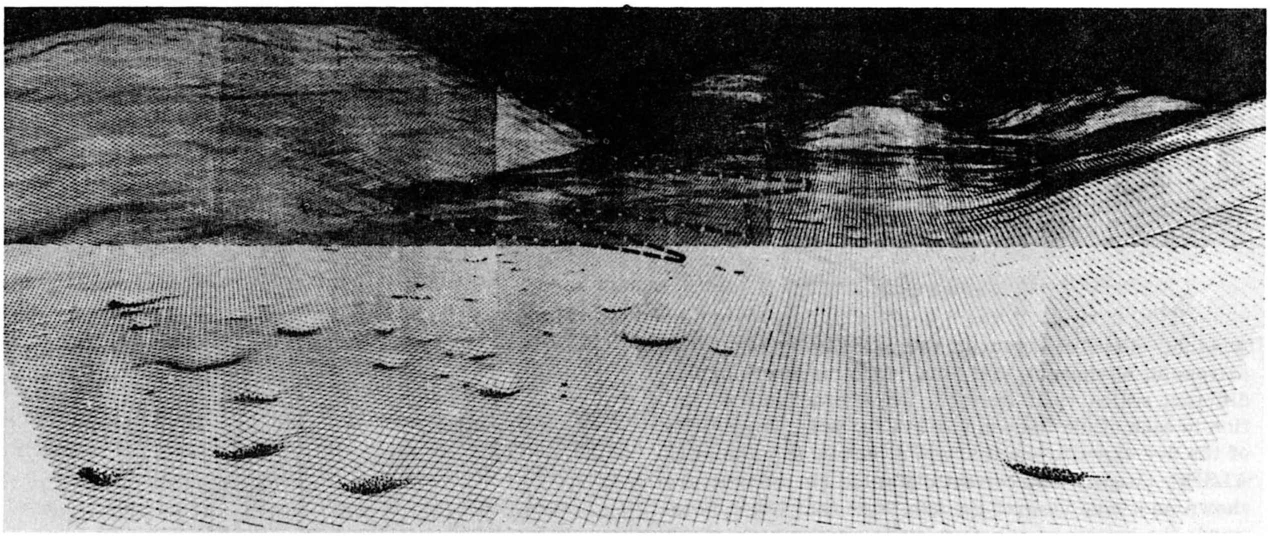
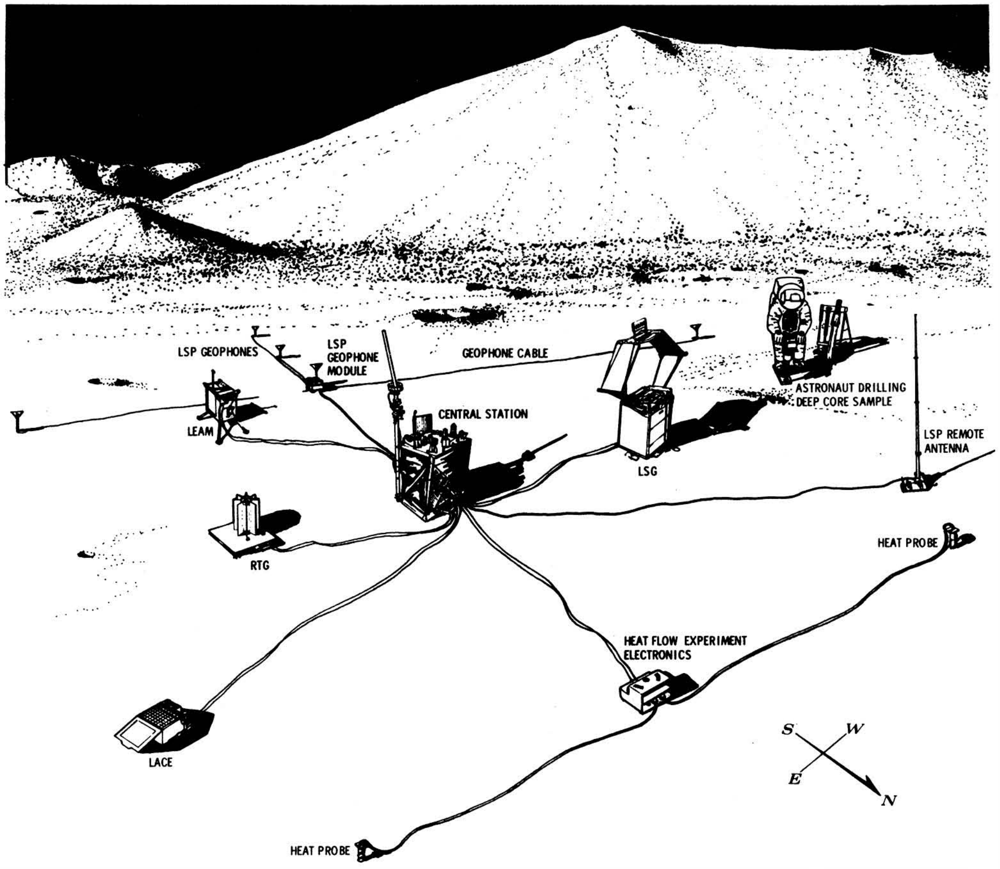


Figure 21.—Various views of the Taurus-Littrow site generated in a computer and plotted automatically. A and B are views from the LM along the trajectory. NASA PHOTO.

tific experiments on the lunar surface. The equipment for these experiments will remain behind on the Moon after the astronauts return to Earth. Data from these experiments will be sent to Earth over microwave radio links, similar to the ones used extensively for communications on Earth. And finally, three experiments, known as traverse experiments, will be done *along* the routes of the traverses. The equipment for two traverse experiments will be attached to the Rover. I think you can see that the Apollo 17 astronauts will be extremely busy! I wish now to discuss each of the experiments in approximately the sequence that they will be deployed on the Moon.

Apollo Lunar Surface Experiments Package (ALSEP)

Several of the lunar surface experiments are a part of the Apollo Lunar Surface Experiments Package (ALSEP). General layout of the equipment on the lunar surface is shown in figure 22. A photograph of the Apollo 16 ALSEP, which is similar but not identical to the Apollo 17 ALSEP, is shown in figure 23. The ALSEP central station, figure 24, although not an experiment, provides radio communications with the Earth and a means for control of the various experiments. After the ALSEP is set up, it is quickly checked out from



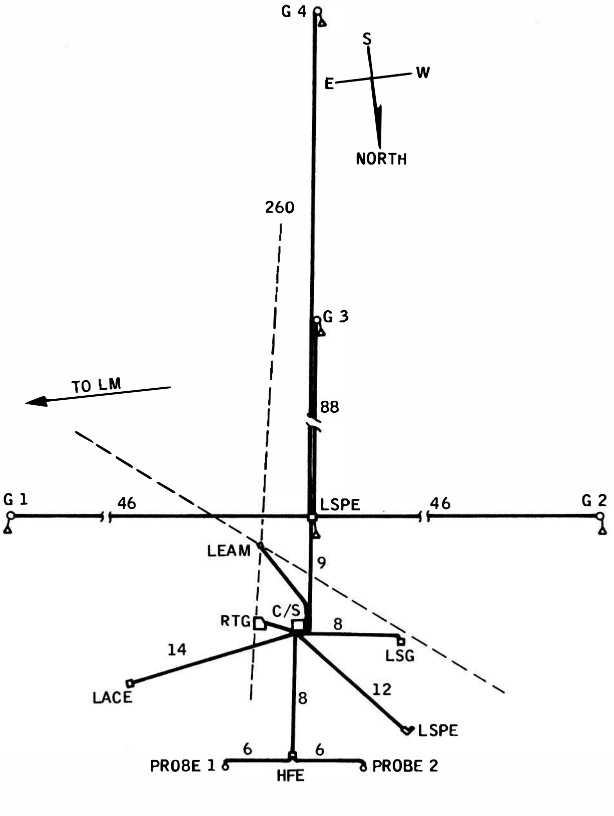


FIGURE 22.—General layout of the ALSEP. Although the astronaut, equipment, and lunar features are drawn to different scales, their locations are shown in true relation to each other. Shown here are the relative positions of the five experiments that are a part of the Apollo 17 ALSEP. (Right) The correct distances (in meters) are shown on a map view of the site. Note that North is towards the bottom of the page. NASA PHOTOS S–72–49618 and S–72–49617.

Earth and then after the astronauts leave the Moon, commands continue to be sent from Earth for control of the various experiments during the lifetime of the ALSEP. The experiments connected electrically to the central station are the Heat Flow Experiment, the Lunar Surface Gravimeter, the Lunar Atmospheric Composition Experiment, the Lunar Ejecta and Meteorite Experiment, and the Lunar Seismic Profiling Experiment.

Electrical power for the experiments on the lunar surface is provided by the decay of radioactive plutonium in a device termed a Radioisotope Thermoelectric Generator (RTG), shown in figure 25. A total of roughly 70 watts is delivered. Let me draw special attention to this power of 70

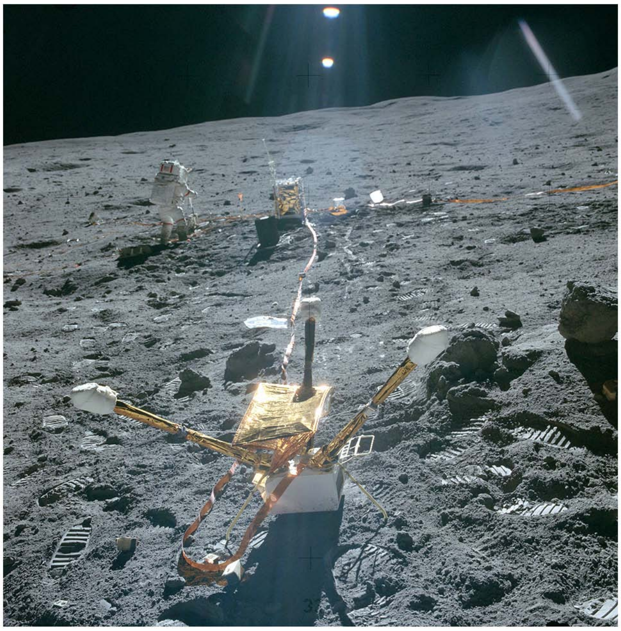


FIGURE 23.—Apollo 16 ALSEP. Note the changes in experiments between 16 and 17. NASA PHOTO AS16–113–18373.

watts. It is truly incredible that all of the experiments together, and including the radio that sends the scientific information over a quarter million miles of space to us, use no more power than is consumed by an ordinary 75 watt light bulb! The electrical wires are flat, ribbonlike cables that may be seen in figure 23. The RTG is filled with nuclear fuel after the astronauts reach the lunar surface. The fuel is carried to the Moon in a cask mounted on the side of the LM. The cask is sketched in figure 26 and its location on the LM can be seen in figure 3. The sequence of operations, to be done early in EVA 1, to fuel the RTG is shown in figure 27. The principle of operation of the RTG is very simple. The decay of the plutonium releases energy which causes the capsule to become hot, reaching about 1,300° F within a few hours after fueling. A thermopile* converts the heat energy to electrical energy.

During EVA 1, the astronauts remove the ALSEP experiment from the LM, carry it to a site some distance from the LM, and place it on the lunar surface. In figure 28, we see astronaut Al Bean carrying the Apollo 12 ALSEP. The 17–ALSEP is carried in a similar way. In figure 29, a sketch of the ALSEP pallet, you can see the packing of the individual items of the ALSEP. A sum-

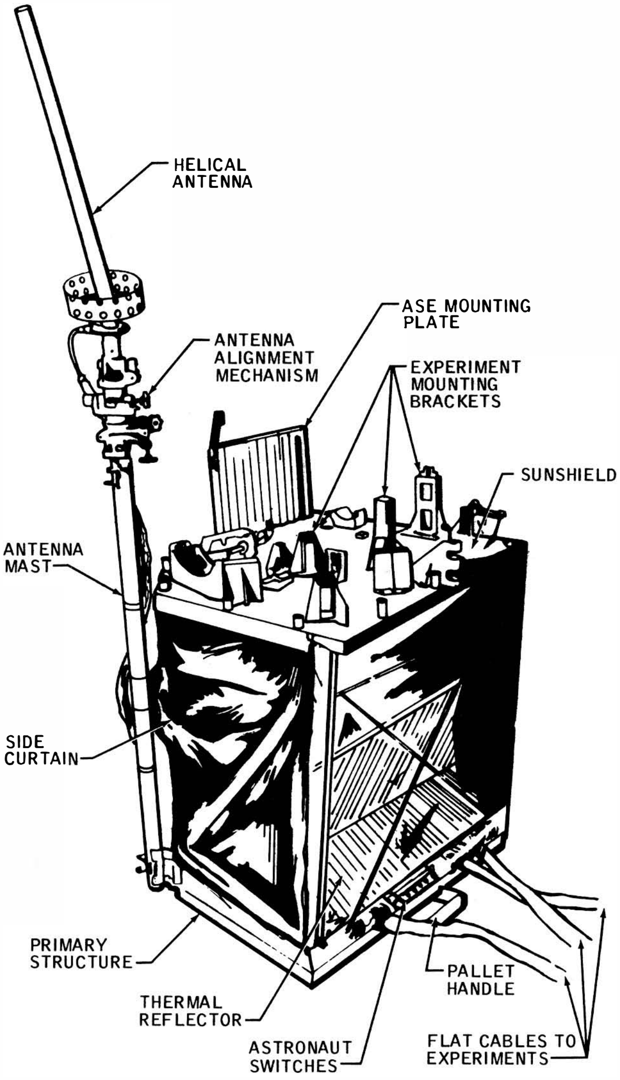


FIGURE 24.—The ALSEP central station. This equipment is connected electrically to each of the other ALSEP experiments. It is a maze of electronics that accepts the electrical signals from various experiments and converts them into a form suitable for transmission by radio back to Earth. The pole-like feature on top of the central station is a high-gain antenna. It is pointed towards the Earth. Commands may be sent from the Earth to the central station to accomplish various electronic tasks. NASA PHOTO S–72–49036.

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* Similar to the thermopiles used in the control circuits of home heating systems. Most home clothes dryers, water heaters, and heating systems that use gas for fuel and have a pilot light contain thermopiles. The thermopile is the small object that projects into the pilot light. Without doubt, you recall lighting the pilot on your water heater and waiting for a short time (usually 1 minute) for the thermopile to become sufficiently hot—and hence generating power—that the pilot would remain lighted.

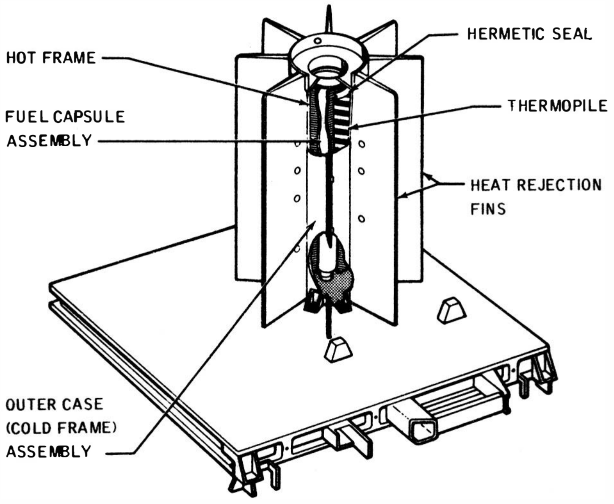

Figure 25.—Radioisotope Thermal Generator. This equipment provides all of the power used by the ALSEP. It furnishes continuously about 70 watts. NASA PHOTO S–71–29730.

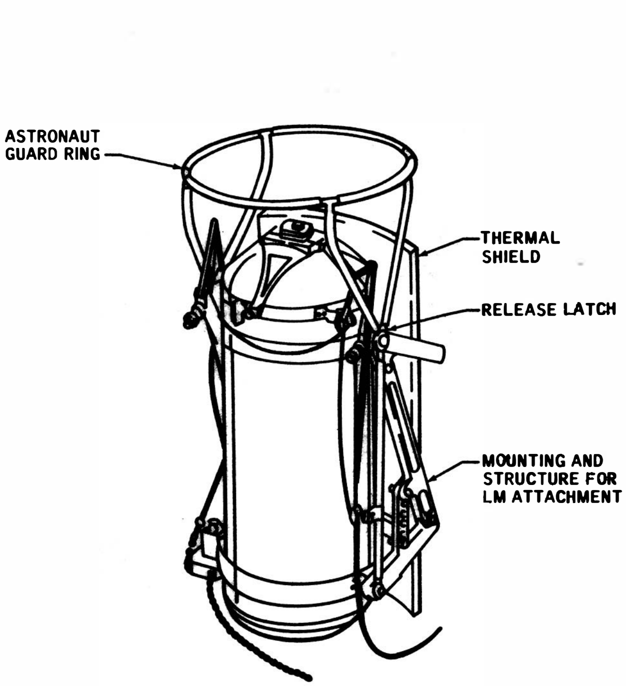

Figure 26.—Fuel cask. The fuel, radioactive plutonium, for the RTG is carried to the Moon in this cask, which is mounted outside the LM.

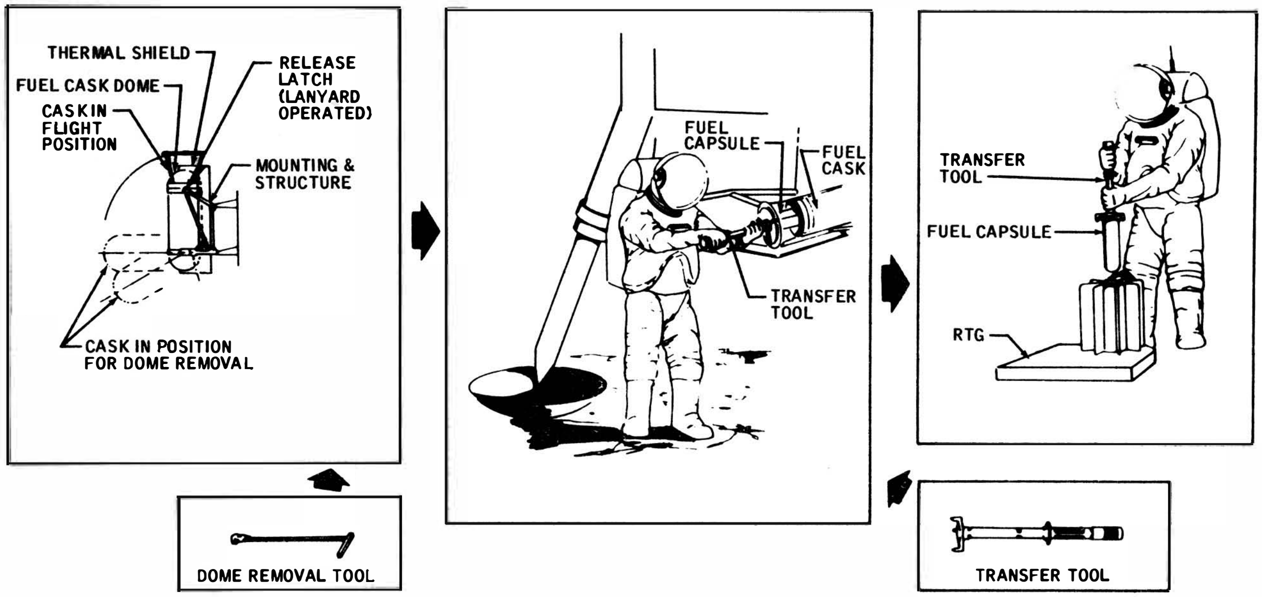

Figure 27.—Fueling of RTG. The sequence of operations to be done by one of the astronauts on the Moon to place the capsule of radioactive fuel in the RTG is shown here. The fuel capsule is very hot and so it is handled very carefully. NASA PHOTO S–72–50295.

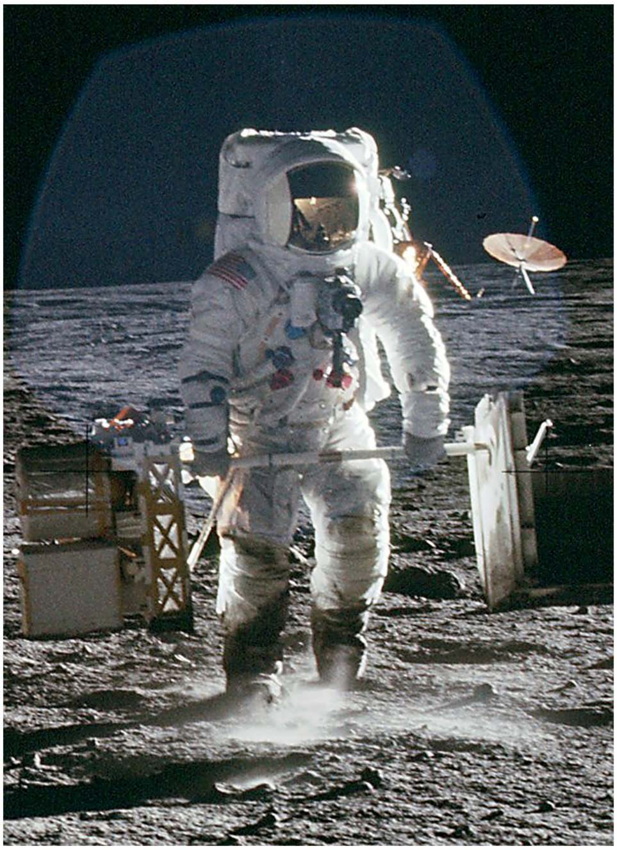

FIGURE 28.—Astronaut Al Bean carrying the ALSEP to its Apollo 12 location. There was no Rover on that mission and the ALSEP location was roughly 100 yards from the LM. The edge of the LM and an S-band antenna are shown in the background. The halo is caused by reflections in the camera lens systems; the halo was not present on the Moon. On Apollo 17 the same technique will be used to carry the ALSEP. NASA PHOTO AS12–46–6807.

mary of the ALSEP operations is given in Table 3. The layout plan for the various ALSEP experiments on the Moon is shown in figure 22.

A list of *all* science experiments of the entire Apollo Program, including those of this mission, is given in Table 4. A list of the Principal Investigators and their institutions is included in Table 5. Finally, you will find in Table 6 a list of the companies that have contributed significantly towards the design, building, and testing of the scientific equipment of the entire Apollo Program.

Heat Flow Experiment (HFE)

Heat flows from hot regions to cold regions. There is no known exception to this most general law of nature. We are certain that the interior of

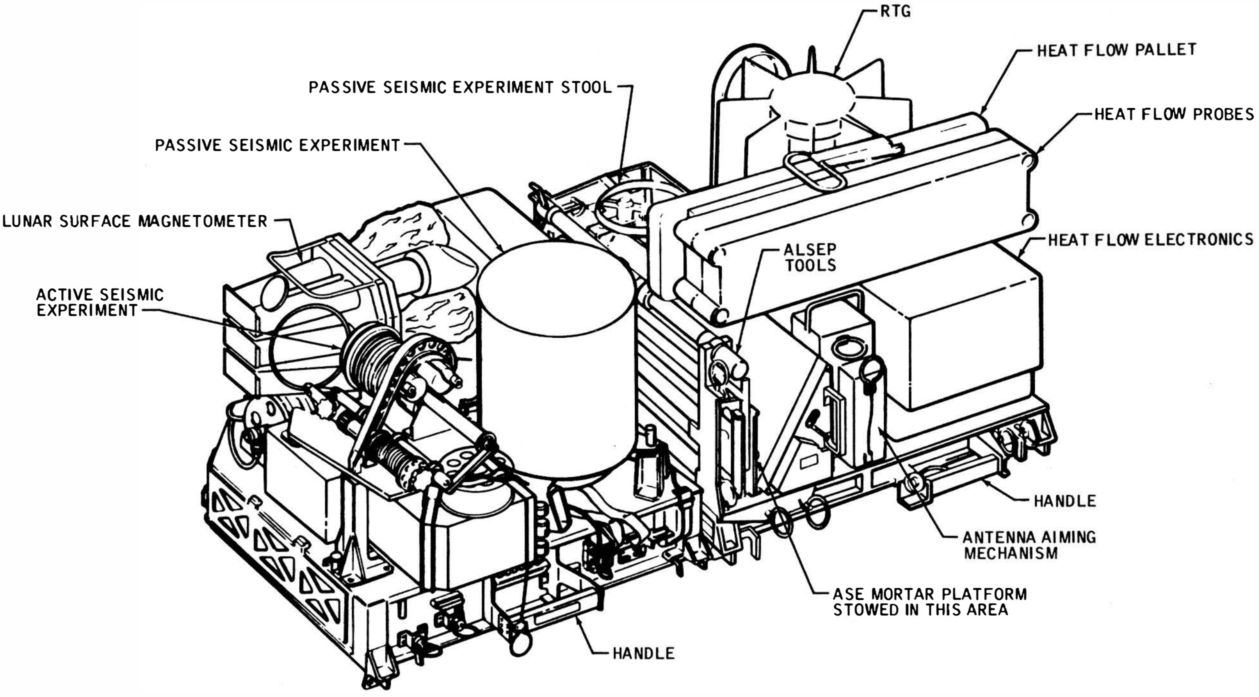

FIGURE 29.—ALSEP pallet. The ALSEP is carried to the Moon in the LM on this pallet. Note how tightly the individual items are packed in order to save space. NASA PHOTO S–72–16330.

the Moon is warm. It may be hot, possibly as hot as 1,200° C. Therefore heat flows from the interior of the Moon to the surface where it is then lost into cold space by radiation. The Heat Flow Experiment (HFE) will measure the amount of heat flowing to the surface at the Taurus-Littrow site.

A similar measurement was made at the Apollo 15 site, the magnificent Hadley-Apennine region. Some of the details were seen over television by millions of viewers. You may recall the problem of drilling the hole into which the astronauts inserted the temperature sensors. That problem was caused by the failure of the drill to expel the cuttings from the hole. The drill was redesigned and worked satisfactorily on Apollo 16. However the HFE was destroyed on Apollo 16 when an astronaut tripped over the cable connecting the HFE to the Central Station.

But let me continue with the main story of heat flow. At the Apollo 15 site, we measured a value about ¾ unit.* Let me explain this unit in the following way. If we were able to store the heat that flows to the surface of the Moon through a square foot from the interior during an *entire year*, it would just be enough to melt a layer of ice 1/10 inch thick. Not very much heat, is it? Perhaps. Yet on Earth, the average heat flow is only about twice that value and it has produced our mountains, it causes the earthquakes so familiar in California and other regions of the United States as well as many parts of the Earth, it produces the volcanoes, and so on. I have always been awed by how much nature can do with so little per year! Of course I must add, for so long a time, and that is the key.

But by comparison with the Earth, the Moon is seismically rather quiet. Earthquakes on the Earth exceed one million per year. On the Moon, there may be 300 to 400. And they are much smaller than the ones on Earth. We are not yet sure why.

At the present time, the heat flowing to the surface of the Moon from the interior has been produced mostly by slow decay of the natural radio-active elements thorium, uranium, and potassium. Measurements made directly on the lunar samples returned to Earth by previous Apollo missions have revealed the presence of significant amounts of these elements. The normal spontaneous change of these elements into other elements slowly releases energy. The process is similar to that used in nuclear reactors on Earth to generate electrical power from uranium. In the Moon, most of the energy appears in the form of heat which raises the temperature of the interior of the Moon.

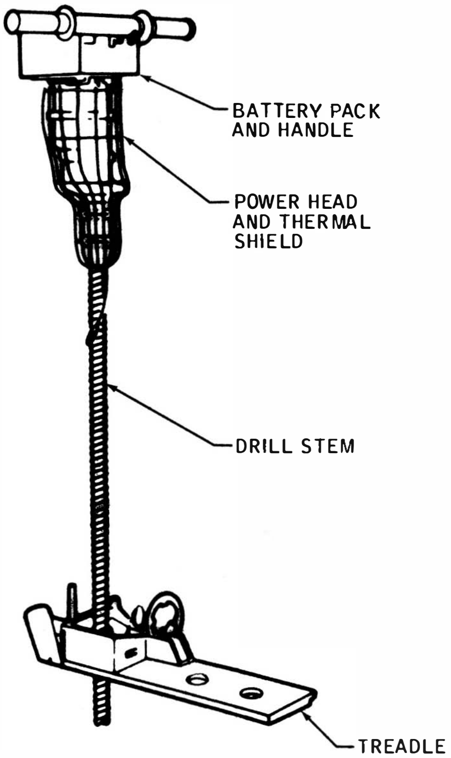

FIGURE 30.—Lunar surface drill. This drill will be used to drill holes on the Moon to a depth of about 10 feet. It is electrically powered and operates from batteries. The treadle is used to steady the drill stem and to deflect cuttings from striking the astronaut. Two holes are used for the heat flow experiment and a third one is used to obtain samples for study back on Earth. A rack, used for holding the drill stem, is sketched in figure 22.

In addition to the amount of radioactive material present, the internal temperature of the Moon depends on other things. The properties of lunar rocks and soil are equally important. The thermal conductivity of a material is a measure of the relative ease with which thermal energy flows through it. Rather well-known is the fact that metals are good conductors and that fiberglass, asbestos, and bricks are poor conductors. Most of us would never build a refrigerator with copper as the insulation. Values of the thermal properties of rocks are closer to those of fiberglass than those of copper and other metals. Rocks are fairly good insulators. The lunar soil is a very good insulator.

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* The "unit" here is micro calories/square centimeter/second.

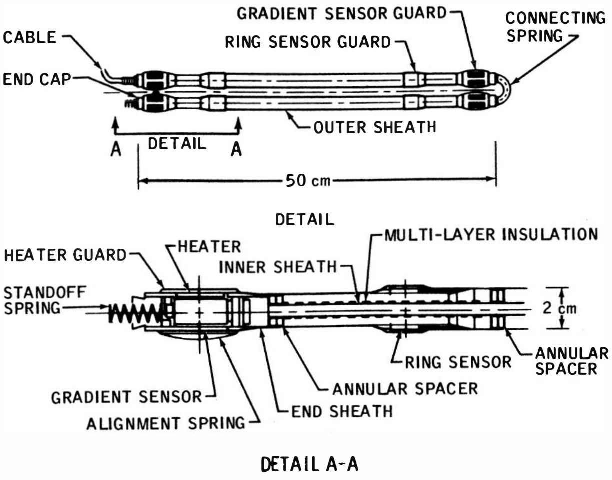


Figure 31.—Details of the Heat Flow Probe. The probe is shown here in the way that it is carried to the Moon, folded to save space. The connecting spring allows the probe to be straightened before placing it in the hole. In addition to the platinum sensors contained in the probe and shown in this figure, the cable contains several thermocouples.

The HFE has been designed to measure the rate of heat loss from the interior of the Moon. To obtain this measurement at the 17-site, two holes are to be drilled into the surface of the Moon by one of the astronauts to a depth of about 8 feet by means of the drill sketched in figure 30. After each hole is drilled, the probes sketched in figure 31 are placed in the holes. The probes contain very precise temperature sensors (platinum resistance thermometers) for the lower parts of the holes. The connecting cables contain several thermocouples (which also measure temperatures but with lower precision) which will be located in the upper portions of the holes. See figure 32. The thermal properties of the rocks will be measured by the equipment that is placed in the hole; they will also be measured on samples that are returned to the Earth.

Because the temperature of the rock is disturbed by the drilling process, the various measurements for heat flow will be taken at regular intervals over several months. As the residual heat left around the hole from the drilling dissipates with time, the temperatures measured in the experiment will approach the undisturbed temperatures of the Moon.

The HFE is important because knowledge of the rate of heat flow lets us set limits on the internal temperature and on the amount of radioactive elements now present in the Moon. You see, the amount of such radioactive material already measured in the lunar samples on Earth is embarrassingly high! We know that such samples cannot be representative of the whole Moon, because if they were, then the Moon's interior would be molten throughout. Yet we are sure that it is mostly solid throughout. By establishing limits on the radioactivity, we will come closer to a correct understanding of the thermal history of the Moon.

Incidentally, the value of heat flow measured at the 15-site was completely unexpected. It was at least twice the value that most scientists had anticipated. So I think you can understand why we are particularly anxious to see if the Apollo 17 measurements confirm this surprising result.

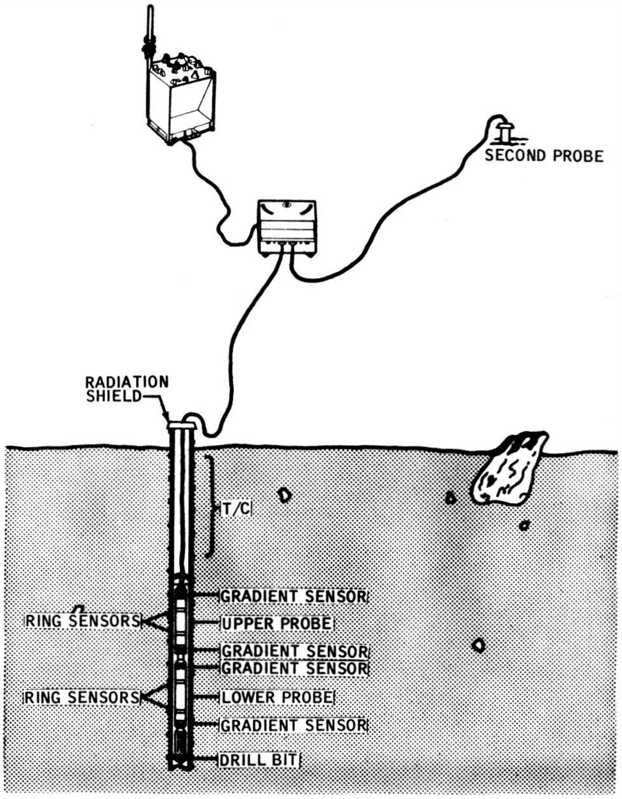


Figure 32.—Heat Flow Experiment. Probes are placed in two holes drilled in the lunar surface with the drill shown in figure 30. One hole is shown in the figure as a section to show the various parts. The gradient is the difference of temperature at two points divided by the distance between the points. Heat flow is determined by measuring both the gradient and the thermal conductivity; heat flow is the product of gradient and thermal conductivity. The symbol T/C indicates thermocouples that are present in the upper part of the holes.

Lunar Surface Gravimeter (LSG)

When electrons are accelerated, they radiate electromagnetic energy. Exactly that process is used to "broadcast" radio programs and television programs. When masses are accelerated, they *should* radiate gravitational waves, as predicted by the general theory of relativity. Efforts to confirm the existence of gravitational waves have been successful only recently. Dr. Joseph Weber has detected gravitational waves that pass through the Earth and come from the direction of the center of our galaxy. See the May 1971 issue of *Scientific American* for a very readable and exciting account of the work of Weber and associates in their efforts to detect gravitational waves on the Earth. In fairness, I must say that many knowledgeable scientists would disagree today with the view that gravitational waves have now been detected!

The primary purpose of the Lunar Surface Gravimeter (LSG) is to search for the presence of propagating gravitational waves in space. Such waves should interact with *both* the Moon and the Earth in certain diagnostic ways. In effect, the LSG experiment will use both the Moon and the Earth as gravitational antennas.

The interaction of the Moon with propagating gravitational waves sets up very characteristic patterns of vibration of the entire Moon—resembling in some ways the ringing of a bell. Similar vibrations would be set up in the Earth. The unequivocal demonstration of the presence of such gravitational waves will be the detection of these characteristic modes of vibration of *both* the Moon and the Earth simultaneously. Thus equipment will be operated on both the Earth and the Moon to test for this condition. The Earth has a high background noise level due to the pounding of the oceans on the coasts, the variations of atmospheric pressure, and the constant rumblings of earthquake activity. Excitation of certain overtones of the Moon should be observable because of the lower noise level. Such observations would be evidence of the interaction of the Moon with gravitational waves.

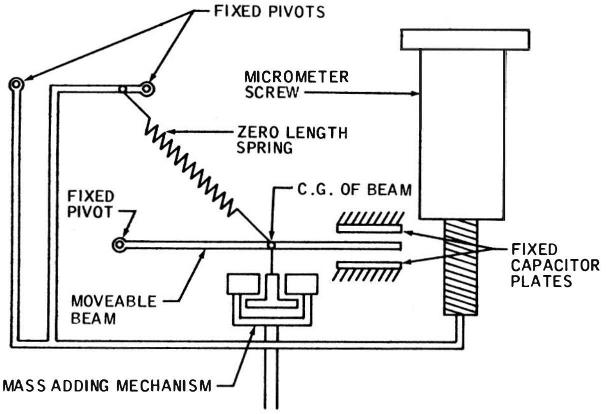


FIGURE 33.—Elements of the Lunar Surface Gravimeter. A mass is suspended on a very special spring. Most of the assembly is made of fused quartz glass. The length of the spring is not really zero but the effect of this particular geometry makes the spring appear to have zero length. Motion of the beam (and hence of the mass) is detected and measured electrically with the capacitor plates.

The equipment that is used for the measurement of such vibrations is an extremely sensitive gravity meter. The heart of such equipment is a very fancy, very tiny, and very delicate version of the old style spring balance, the one on which a pan was suspended on a spring scale.

This mechanism is shown in figure 33. It was developed many years ago for use on the Earth by LaCoste and Romberg. Most of the individual parts, including the main spring, are handmade of iron and aluminum alloys. This mechanism has been used for many years to measure gravity in laboratories (with extremely high precision) and in the exploration of the Earth for oil and gas. So, its characteristics are extremely well known. But the adaptation of this well known and extensively used mechanism to the lunar environment has not been easy because of the very stringent requirements of long life (at least 2 years), of no opportunity for maintenance or repair, of the extreme precision necessary, and of the need to operate remotely and reliably on the Moon. For example, the temperature of the equipment cannot vary more than one thousandth of a degree during any half hour. The equipment will measure variations in lunar gravity as small as one part in 10^{11} (i.e., 100 billion).

The external appearance of the LSG equipment is shown in figure 34.

The LSG will gather data that not only can be used to look for propagating gravitational waves but can be used also for several other extremely important measurements. For example, the deformation of the Moon due to tidal forces caused by the changing positions of the Earth and the Sun will be measured. On the Earth, we are all familiar with the ocean tides. But did you know that the solid rock at every place on the Earth deforms in a similar way? It does! Only the heights differ. Oceanic tides are several meters high, those of the solid Earth are usually less than a half meter. Knowledge of the exact deformation of the Moon's surface due to the tidal forces will allow us to determine the internal structure of the Moon.

And finally, the LSG will serve as a single axis seismometer. Thus some seismic information from the Apollo 17 site will be available for comparison with the seismic data from the Apollo 12, 14, 15, and 16 sites.

There is probably no better example in today's world of science of an experiment that is being done primarily for scientific purposes but which holds such great promise for uncountable practical benefits to mankind in the years ahead. The practical utilization of *gravitational* waves may lead to benefits that far exceed those gained from the practical utilization of *electromagnetic* waves. Many of the feats described by yesterday's science fiction writers will be commonplace tomorrow.

Lunar Atmospheric Composition Experiment (LACE)

In this experiment we measure with a mass spectrometer, the composition and density of gas molecules in the thin lunar atmosphere. Early instruments and the basic technique were developed shortly after the turn of the century. The principle can be understood by referring to figure 35. Gases enter the instrument through a gas inlet manifold and pass through an electron beam. The electrons in the electron beam knock loose one or more electrons from the gas molecules to produce ions. An ion is merely a gas molecule which has lost one or more electrons. It has both mass and charge. The ion proceeds on through the instrument and is focused into a narrow beam. It then passes through a *magnetic* field. Now the flow of charged particles constitutes electric current flow, and current flowing in a magnetic field will have a force exerted on it. This statement is the basic principle of all electrical motors. It is one of the basic concepts of physics. It was discovered many years ago. Each time that you start your automobile engine, you close a switch which causes current to flow in a conductor through a magnetic field with the result that a force is exerted on the conductor and (hopefully, at least for my car) the engine starts.

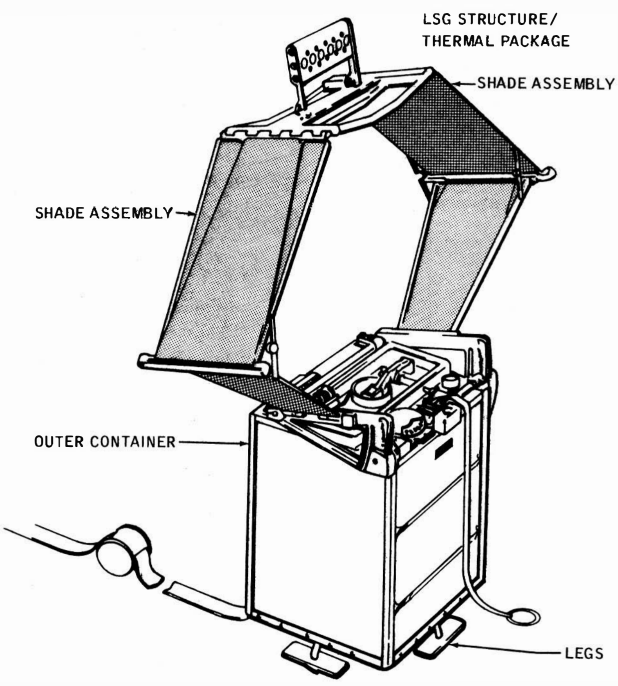


FIGURE 34.—Lunar Surface Gravimeter. The large structure on top of the LSG box shades the box from the Sun's direct rays to help with the extreme temperature control required of this equipment. NASA PHOTO S–72–49039.

In the spectrometer, the force that is exerted on each ion depends upon the strength of the magnetic field, upon the velocity with which the ion is moving, and upon the number of electrons that were lost. In the magnetic field, the ion follows

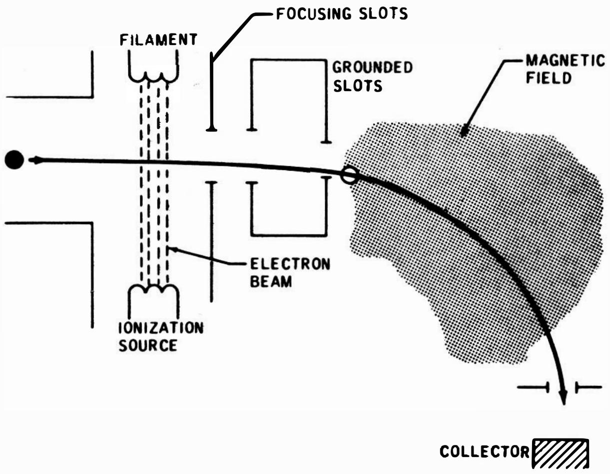


FIGURE 35.—Principle of the mass spectrometer. The magnetic field is perpendicular to the plane of the paper. See discussion in text. NASA PHOTO S–72–50319.

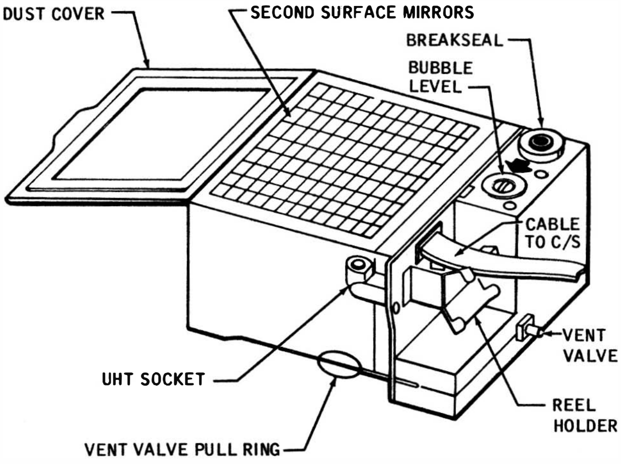


FIGURE 36.—Lunar Mass Spectrometer. This box contains a magnet, ion source, and associated electronic components. Data are transmitted to Earth through the ALSEP central station.

a circular path. The radius depends, in addition to the factors just mentioned, upon the mass of the ion. By changing the velocity with which the ions travel and measuring the number of ions that pass through the small opening into the collector, we can, in effect, determine the masses of the ions that are present. Essentially this same procedure is used in the Apollo 17 mass spectrometer.

The external appearance of the LACE equipment is shown in figure 36. The box contains all of the components shown in figure 35 plus some rather sophisticated electronics. The mirrors are used for cooling the package. The astronauts set the LACE on the Moon's surface, level it and connect the electrical cable to the ALSEP central station. The dust cover is opened on command from Mission Control after the astronauts have left the Moon. (Dust has an extremely bad effect on the radiating properties of surfaces. There is a long history of minor difficulties associated with dust on radiating surfaces of equipment deployed on the lunar surface in the Apollo Program.) The data are sent to Earth over the ALSEP telemetry link.

Several sources of gas for the lunar atmosphere are known to exist. Volcanoes, even though dormant and not erupting liquid rock, vent such gases as carbon monoxide, hydrogen sulfide, ammonia, sulphur dioxide, argon, and water vapor. Detection of such gases in the lunar atmosphere and the accurate measurement of their relative amounts will help us understand the chemical processes that occur inside the Moon. Another major source of gas for the Moon is the Sun which ejects matter more or less continuously. This material spreads throughout the solar system and is termed the solar wind. The solar wind is very tenuous and moves with the speed of a few hundred miles per second. Perhaps you recall on earlier missions that we carried a sheet of aluminum foil (like the familiar household item used to wrap food) in which we actually trapped individual particles of the solar wind. The particles include atoms of many chemical elements such as hydrogen, helium, neon, argon, and so on. The particles of the solar wind strike the lunar surface, are neutralized, and are eventually released as a nonelectrically charged gas. Estimates of the composition of the solar wind and the losses of gas from the Moon's environment indicate that neon should be the most abundant gas of solar origin in the lunar atmosphere.

And finally there are many sources of gas created by man's exploration of the Moon—the rocket engine of each Apollo mission, the lunar roving vehicle, the liquids that are vented from the descent stage on landing, the ALSEP experiments, and even the astronauts themselves.

A slightly different mass spectrometer was carried in the CSM on Apollo 15 and 16. About 140 hours of data were obtained in lunar orbit and about 50 hours were obtained during the transearth coast. Many gases were clearly present. The data have not all been analyzed at the time of writing this booklet, and I cannot give you the final interpretation. But at first look, it seems that rather significant quantities of gas are in orbit around the Moon; there was also a decrease by a factor of 5 to 10 in the amount of gas measured during the trip back to Earth. We now believe that the liquids dumped from the spacecraft quickly froze and then continued to orbit the Moon with the spacecraft. Hence we are anxious to measure the atmospheric gases near the surface of the Moon.

Lunar Ejecta and Meteorites Experiment (LEAM)

The Lunar Ejecta and Meteorite (LEAM) Experiment is designed to measure the direction of travel, speed, and mass of micrometeorites arriving at the surface of the Moon. A second major objective of the experiment is to measure similar properties of any lunar particles that are ejected from the Moon by large meteorite impacts.

The basic sensor used in the LEAM experiment is shown in figure 37. An impinging dust particle travels through the front film where it produces an electrical pulse and impacts upon the rear film where it produces a second electrical pulse. From the time lapse between the electrical signals produced at the front and rear films, the particle's speed can be determined. From the speed of the particle and the amplitude of signals produced at the films, the mass of the dust particle can be determined. The front and rear films are each divided into 16 segments forming 256 basic sensors. The direction of travel is ascertained by relating the site (segment) of the front film impact to the site (segment) of the rear film impact. A microphone attached to the rear film plate independently (but in coincidence) measures a product of the velocity and mass of the particle and serves as a check on the other detection systems.

In setting up the LEAM, the astronauts must level it; set its orientation with respect to lunar north; and connect it to the ALSEP central station. The external appearance of the LEAM is shown in figure 38.

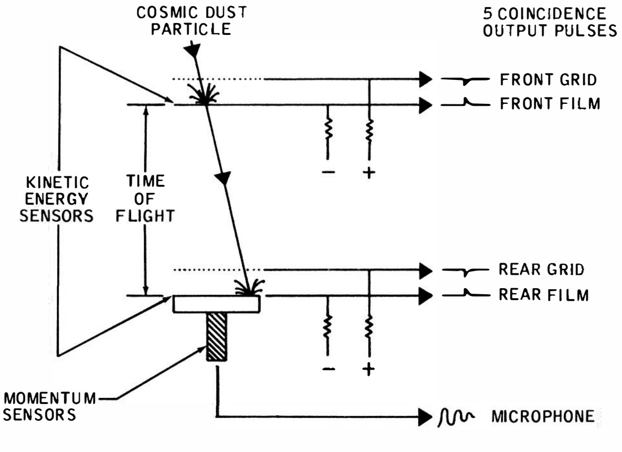


FIGURE 37.—Basic sensor of the LEAM experiment. See text for discussion.

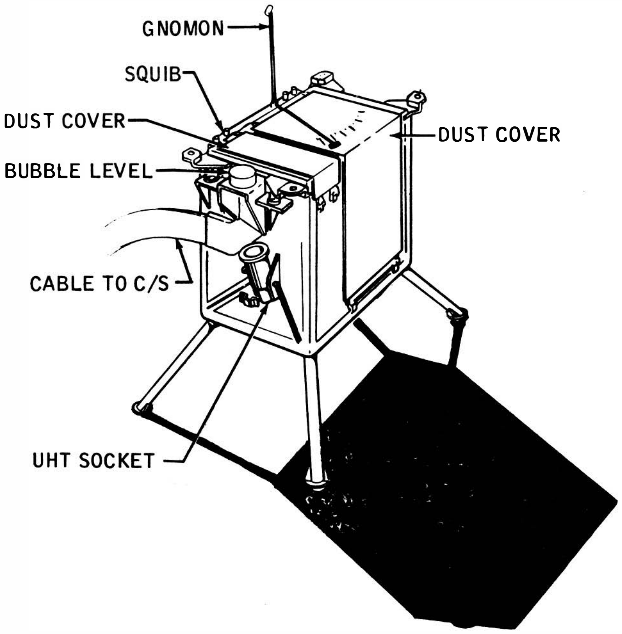


FIGURE 38.—Appearance of the LEAM equipment. The squib, a small explosives device, is used to "blow" the dust cover from the LEAM equipment after the astronauts leave the surface of the Moon.

The existence of small dust particles in space has been known for many years. In passing through our Milky Way Galaxy, our Earth and solar system intercept clouds travelling at speeds greater than 50 miles per second. Another source of "cosmic dust" which impacts upon the Moon and upon Earth's atmosphere is debris from comets which partially disintegrate as they pass near the Sun. The high altitude rocket research, started in the United States in 1949, used very sensitive microphones to detect meteorites striking the skin of the rocks. Hundreds of such measurements were made in the United States, the Soviet Union, and other countries. The conclusion drawn universally from those measurements was that an extremely high concentration of cosmic dust existed near the Earth. Indeed, in the period immediately preceding manned flight in space, some astronomers predicted that astronauts would have to become accustomed to the rather constant pinging that micrometeorites would make when striking their spacecraft. The early spacesuits were carefully designed to protect against such hazards, and accordingly, were very bulky.

We believe today, though, that the concentration of dust in space is considerably less. Why? Because more sophisticated measurements of the quantity of cosmic dust by an experiment onboard one of the unmanned spacecraft, Pioneer 8, revealed that the concentration of cosmic dust was at least one million times lower than indicated by early rocket measurements. We are very excited about the opportunity of performing micrometeorite impact studies on the lunar surface over a long period of time.

Lunar Seismic Profiling Experiment (LSP)

The Lunar Seismic Profiling Experiment (LSP) is similar in principle to previous seismic experiments flown to the Moon but greatly different in design. The equipment consists of several geophones—really just electronic stethoscopes like the stethoscope used by doctors to listen to your heartbeat—with which to listen for sound waves in the Moon, eight packages of high explosives, and the necessary electronics equipment to control the experiment and to process the data for relay to Earth by the ALSEP central station. From analysis of the data we should detect any layers of rock beneath the surface of the Moon (to depths of 1 km.), measure the depths to them, and determine the velocity of sound in the rocks. Because sound waves travel with different velocity in different kinds of rocks, we can even infer the kinds of rock present in the subsurface!

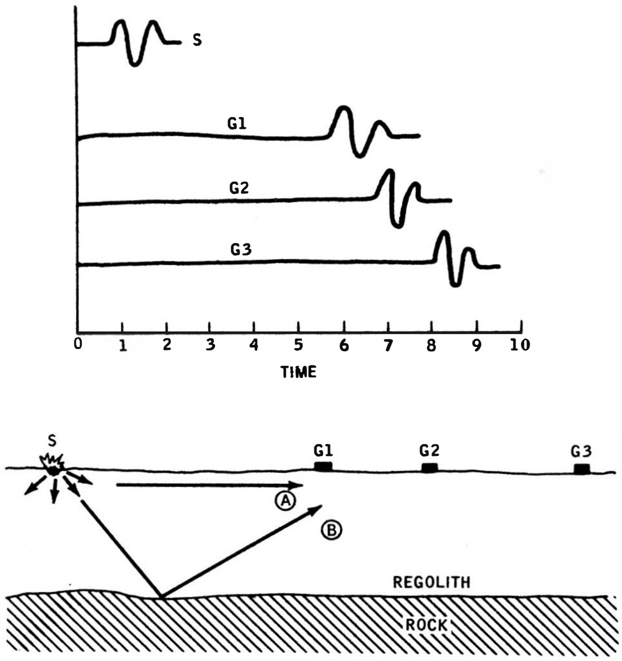


FIGURE 39.—Principle of the Lunar Seismic Profiling Experiment. The geometry of the experiment is shown in the lower figure. At the source, the explosion creates sound waves that travel in all directions. Some of these waves (marked A) travel in the direction of the three geophones, G1, G2, and G3. The relative times of the source and the arrivals at the three geophones are shown in the upper figure. In the actual case, the signals continue ringing longer than is shown in this figure; the signals have been abbreviated for clarity. If there is a layer of rock beneath the lunar soil, and the depth to it is less than 3 – 4 km., then some of the elastic energy (marked B) is returned to the surface. Such waves arrive at the geophones later than the direct waves.

The principle upon which this experiment is based is indicated in figure 39. The sound waves produced at the source travel through the lunar soil and rock to the geophones. The geophones "hear" the sound waves and send them over the ALSEP telemetry link to Earth. The time of the source explosion and the times at which the waves arrive at each geophone are measured precisely. The velocity of the waves in the lunar soil is obtained by dividing the distance from the source to each geophone by the time required for the waves to travel. Note that both distance and time must be known accurately. We expect to measure the distance to each explosive package to a few meters. The electronic circuits will provide times that are accurate to two-thousandths of a second.

Any layers of solid rock at Taurus-Littrow will reflect some sound energy towards the surface. The reflected waves travel farther than the direct waves and so arrive at each geophone later; and their electrical signals are sent to Earth also. From the amount of time required for the reflected waves to arrive at the geophones, (and the velocity of travel obtained from the direct wave), we can determine the depth of the reflecting surface.

This technique is a modification of one that is used very extensively on Earth by industry to search for oil and gas.

The explosives source is extremely interesting. I am sure that you appreciate the immense concern of everyone for the safety of the astronauts. After all, even the 1/8 pound charge, if detonated prematurely, *could* be disastrous to the mission. I personally believe that the LSP explosive package is completely safe. NASA's safety engineers agree with me.

In figure 40 the explosive package is shown schematically. The three rings marked "Astronaut Pull Ring" are pulled by the astronaut when the package is set in place on the Moon. Each of these rings controls independent safety devices inside the package; all three events must occur for the explosives to be detonated. One of the rings starts a timer that runs for approximately 90 hours, at the end of which the explosives may be detonated. The second ring controls a sliding plate that is used to physically prevent the detonator from exploding the main charge. The third ring controls a timing mechanism which activates a battery energizing the explosive package. The activated bat-

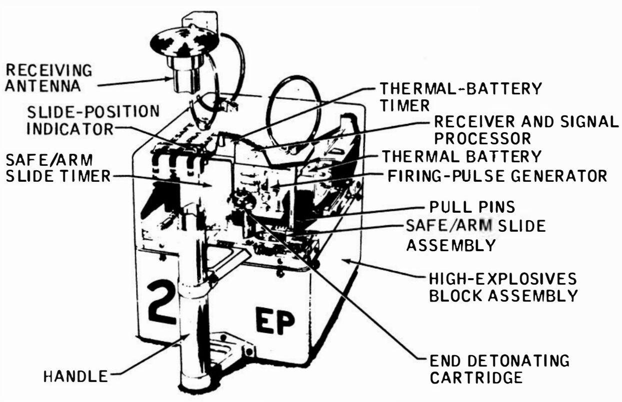


Figure 40.—The Lunar Surface Profiling Explosives Package. This package contains high explosives in the lower compartment and extensive safety devices in the upper compartment. Three independent events must occur simultaneously *after* the three safety rings are pulled for the charge to be detonated.

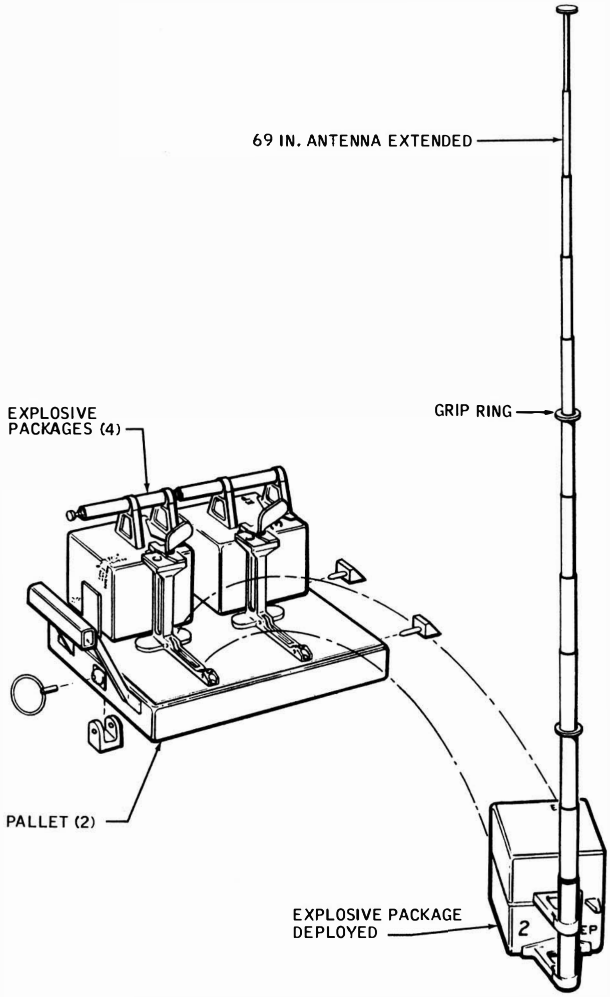


Figure 40B.—Lunar Seismic Profiling Packages on Pallet. Four packages are stowed on each pallet. As each package is removed and placed on the Moon, the antenna is extended and the three rings are pulled.

tery provides electrical energy to the receiver and firing circuitry for one minute. Only then can the package be fired by a radio signal sent from the Earth to the LSP Transmitter. Thus three independent events are required for a package to explode: (1) the sliding timer must move the slide to a firing position, (2) the battery timer must activate the battery before the slide moves to a "safe" position, and (3) the radio signal to fire must be received and processed within a 1 minute "time window." And finally, if the unit is not detonated within 2 hours of the correct time, then the sliding plate will move to a "resafe" position. A visual indicator which can be seen on the upper left hand part of the case (figure 40) will indicate that the unit is again "safe."

On EVA Nos. 1, 2, and 3, the astronauts will carry with them the explosives packages for the LSP. They will place the explosives packages at eight selected spots along the traverses and shown in figure 41. The packages with smaller amounts of explosives will be placed near the ALSEP site, those with larger amounts will be placed farther from the ALSEP site. Then approximately 90 hours after each explosives package has been armed—and the astronauts are on their way home—each explosive package will be detonated. We expect to see the explosion of the nearby charges with the TV camera which should continue to operate for a few days after lift-off. The planned sequence of firing the individual packages is shown below.

Charge size (lb)	Charge number	Distance from ALSEP (km.)	Time after deployment to detonation (hour)	Time after liftoff to detonation (hr:min)
1	6	1.3	91	24:18
3	5	2.0	92	26:52
½	7	.8	93	28:08
⅛	4	.16	91	43:23
6	1	2.4	92	48:45
¼	8	.25	94	51:40
¼	2	.25	93	74:42
⅛	3	.16	94	75:46

Lunar Geology Experiment (LGE)

Most of the time spent by the *surface* astronauts during the three EVA's will be devoted to investigating various geologic features at the landing site

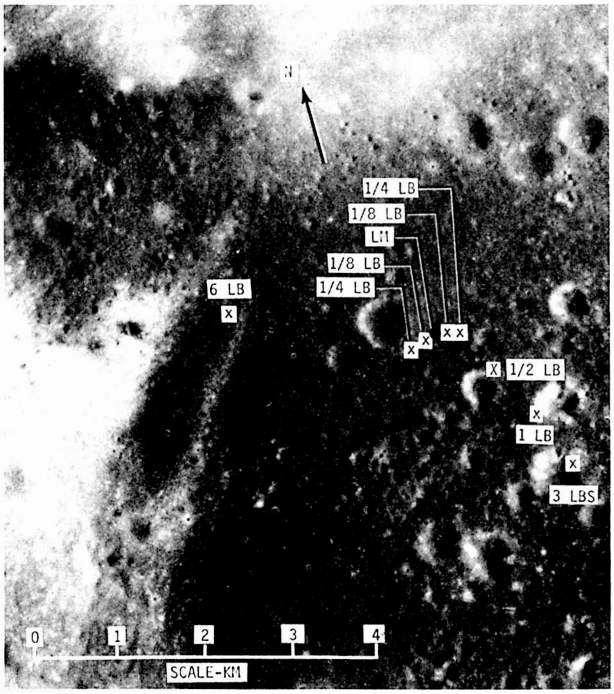


Figure 41.—Location of Lunar Seismic Profiling Experiment explosive charges.

and to collecting samples of rocks. Many detailed photographs will be obtained to supplement the verbal descriptions by the astronauts. Samples of the rocks present at the site will be bagged and brought back to Earth. The astronauts will use several individual pieces of equipment to help them with their tasks. In this section, I describe briefly the goals of the experiment as well as the individual items used to study the geology of the Taurus-Littrow region and to collect samples for return to Earth.

Lunar geologists have as their goal the reading of the historical record of the Moon for the past 5 billion years. That record has been preserved in the lunar rocks. One part of it is seen in the shape of the outer surface of the Moon. Another part is present in the distribution of different kinds of rocks over the surface of the Moon. And still a third part is given by the nature of the lunar interior. At the Taurus-Littrow site, we plan to study thoroughly several features. Rocks produced by the event that caused the Serenitatis Basin will surely be present. They should provide the information needed to read an important chapter in lunar history. Many samples will be collected at the landing site. After the samples reach Earth, they will be studied extensively by nearly eight hundred scientists all over the world. The minerals present in them will be identified. The ages of the rocks will be read from their built-in radioactive clocks. Such physical properties as thermal expansion, velocity of sound waves, electrical conductivity, and many others will be measured. The value of all these measurements is greatly increased by knowing the geologic setting of the rocks. To provide the details of that geologic setting is one function of the Lunar Geology Team led by Prof. William Muehlberger. They use the observations made by the astronauts. They study the rocks brought back to Earth and relate them to the things on the Moon they can see through high-powered telescopes. And they restudy the existing lunar photographs in relation to the rocks. Another function, of course, is to integrate the knowledge obtained from study of the Taurus-Littrow site into the geological understanding of the whole Moon.

In the process of collecting rocks for the geologic experiment and for the investigations on Earth, several items of equipment are used. Let's discuss them.

On the first few Apollo flights, the astronauts, soon after they had first set foot on the Moon, collected a small (1–2 lbs.) sample of rock and soil. It was appropriately termed contingency sample. It was stowed onboard the LM immediately so

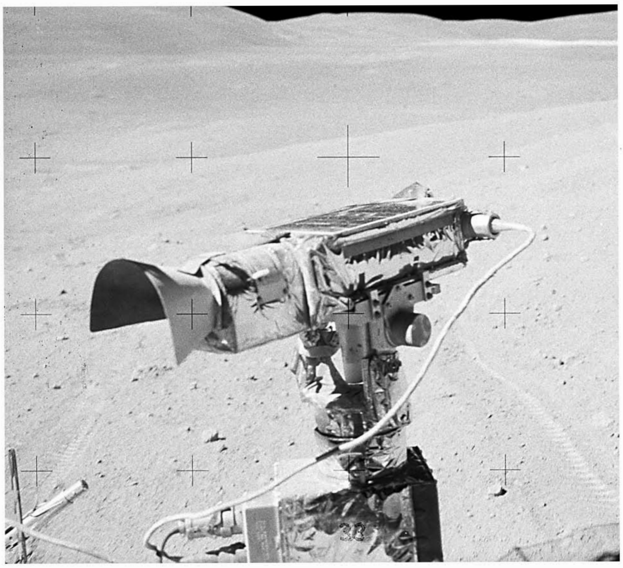


Figure 42.—Apollo 16 television camera. A similar camera will be carried onboard Apollo 17. After the Rover is placed in operation the TV camera will be mounted on it. The camera is controlled from Mission Control in Houston. NASA PHOTO AS16-106-17373

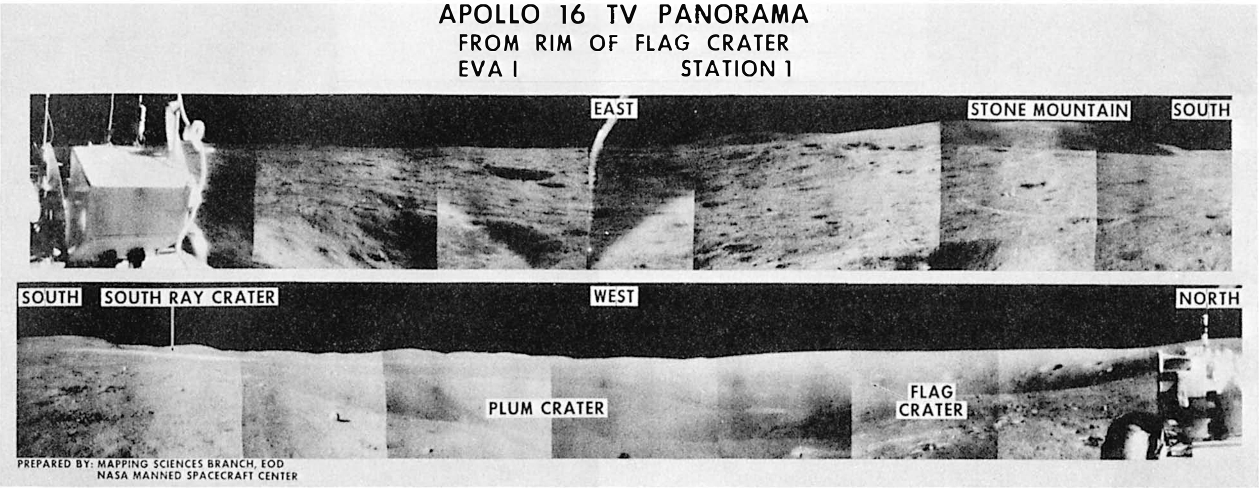


Figure 43.—Apollo 16 television panorama. This panorama was made from photographs of the television screen taken during Apollo 16 EVA 1. The TV camera was located on the rim of Flag Crater. You could have made a similar panorama from photographs taken of your own television set. NASA PHOTO S–72–35970.

that at least some material would have been obtained if the mission had had to be ended abruptly. A special collecting tool was used. On Apollo 16 though, we did *not* collect such a sample in order to save both time and weight. Neither do we plan to collect one on Apollo 17. Instead we plan to collect this sample only if the mission is aborted early in the first EVA. One astronaut carries a regular sample bag in his pocket. If it becomes apparent that the mission is likely to be aborted, then he will quickly fill the bag and stow it in his pocket for return to the LM. Perhaps the contingency sample provides the best illustration of our desire to obtain the most "science" during the stay on the Moon. You might think that the 5 minutes and 1-pound-tool needed to collect the sample are both very small. And they surely are. But we believe that our new "if-needed-procedure" will give us the same insurance against returning with no sample and also give us an additional 5 minutes to collect other, more valuable samples.

Observations made on the lunar surface of the various geological features are very important. The TV camera allows us on Earth to follow the astronauts and to "see" some of the same features, though not nearly so well as the astronauts see them. A photograph of the Apollo 16 TV camera, similar to the one on this mission, is shown in figure 42. The TV camera will be mounted on the Rover during the traverses. Its location can be seen in figure 15. The value of the TV camera to the scientists working on Apollo 17 is very great because they can follow the actions of the astro-

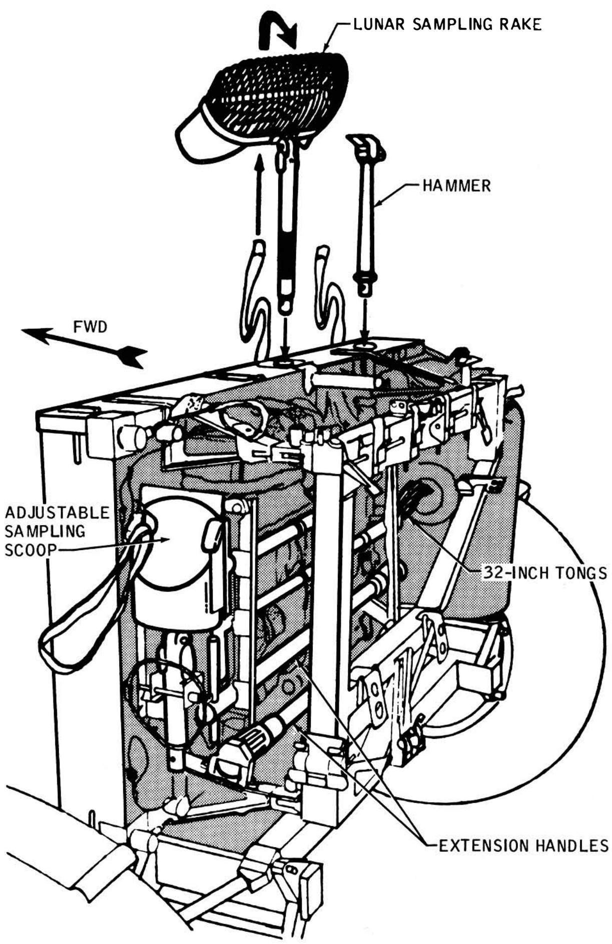


Figure 44.—Lunar Geological Hand Tools. This equipment is used to collect samples of rock and soil on the Moon. The frame is mounted on the Rover. See text and subsequent figures for details.

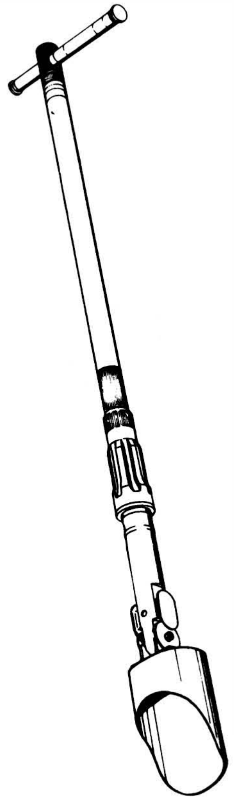


Figure 45A.—Scoop with extension handle. Its use in Appollo 12 is shown in figure 45B.

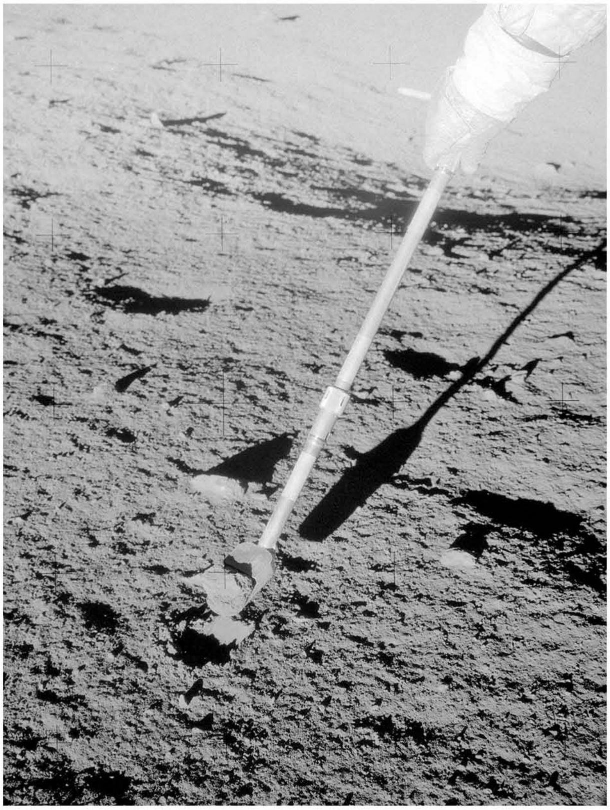


Figure 45B.—Note the small rock in the scoop. NASA PHOTO AS12-49-7312.

Figure 46.—Tongs shown in use on Apollo 12 to collect a small rock. NASA PHOTO S-71-31075.

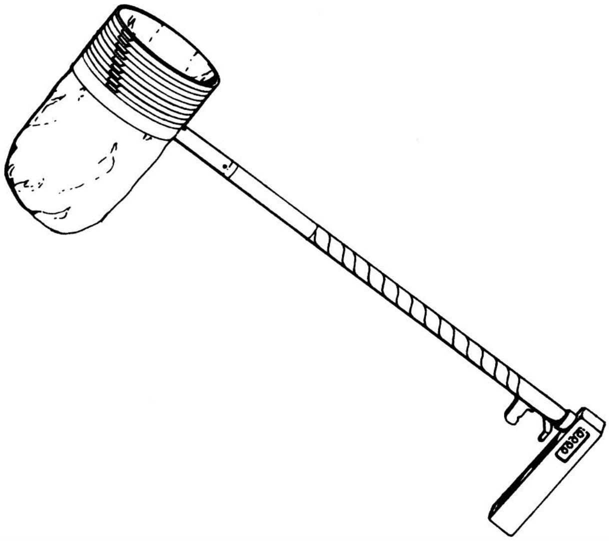


Figure 47.—LRV Sampler. This tool will be used by the astronauts to collect samples of the Moon while seated on the Rover. The tool contains several nested bags. As each bag is used, it is removed and stowed. NASA PHOTO S-72-50308.

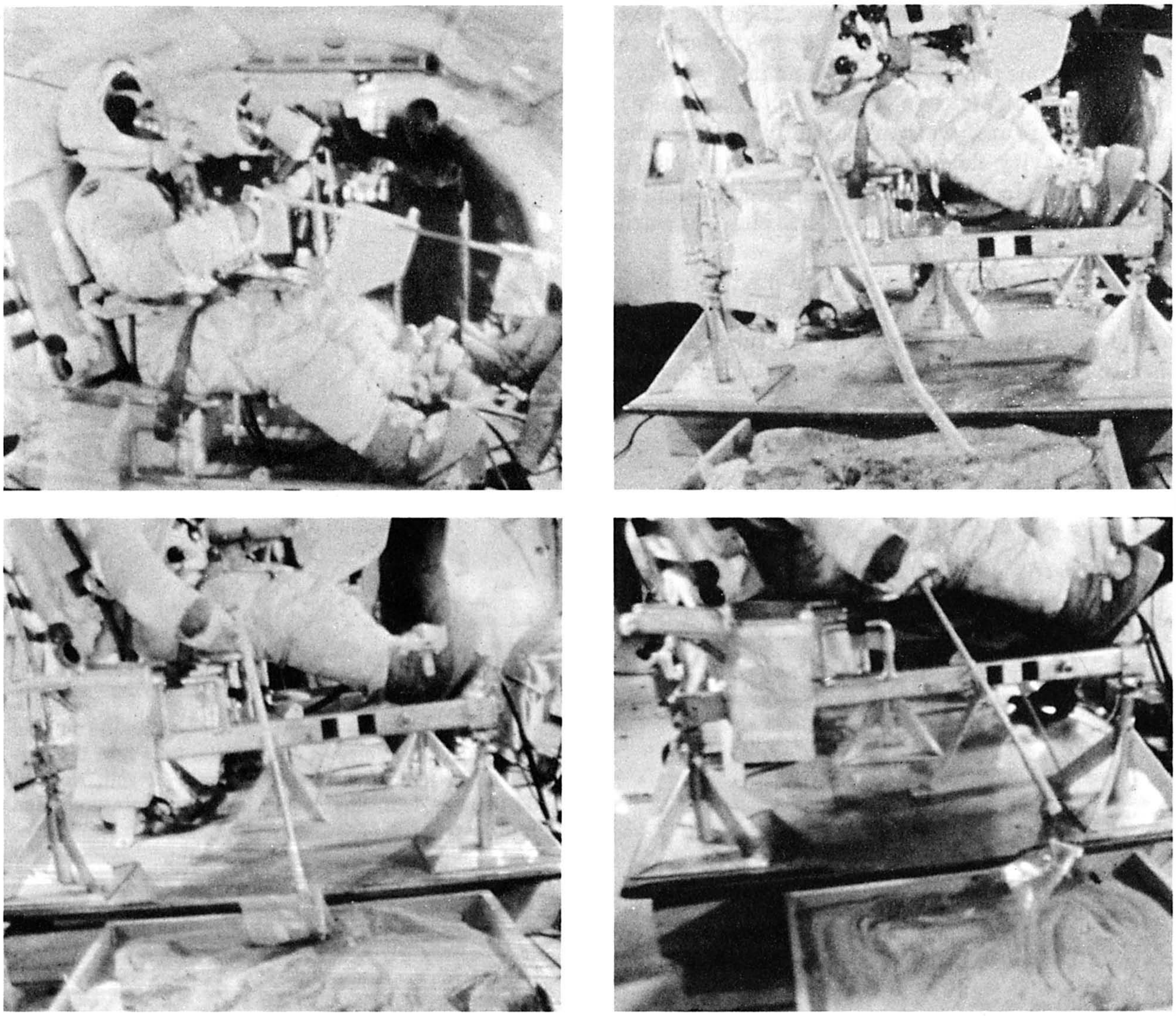


Figure 48.—Testing the LRV-Sampler in one-sixth gravity. The airplane flies arcs to balance the Earth's gravity. Several early designs of the LRV-Sampler were tested by Schmitt for ease of use and performance. Note the mocked up parts of the Rover. NASA PHOTO.

nauts, they can observe and photograph through the TV system features that may be missed by the crew, and they can *see* the site—rather than just *hear* it described. The quality of the images is shown in figure 43, an Apollo 16 panorama made from photographs of the TV screen.

Other tools used by the astronauts, together with an aluminum frame for carrying them, are shown in figure 44. The hammer is used to drive core tubes into the soil, to break small pieces of rocks from larger ones, and in general for the same things that any hammer might be used on Earth.

Because the astronaut cannot conveniently bend over and reach the lunar surface in his space suit, an extension handle is used with most tools. The scoop (figure 45) is used to collect lunar soil and occasionally small rocks. The tongs, shown in figure 46, an Apollo 12 photograph, are used to collect small rocks while the astronaut stands erect.

Another sample collecting tool, to be used for the first time on Apollo 17, is termed the LRV-Sampler. It is shown in figure 47. With it, the astronaut can collect samples from the Rover without getting off. As we plan to use this tool on the Moon, the driver stops the Rover momentarily while the other astronaut scoops material from the Moon. The Rover then proceeds along the traverse. This tool has not been used before on the Moon but it has been tested thoroughly (like the other tools and equipment used previously). Shown in figure 48 is one such test being done in ⅙ gravity. By flying an airplane (a KC 135 in this instance) in a upward arc, we can partially balance the Earth's gravity field and simulate for about 30 seconds the Moon's gravity. The effect is similar to that felt when an elevator traveling upward stops.

The drive tubes (figure 49) are used to collect core material from the surface to depths of 1 to 3 feet. The core remains in the tubes for return to Earth. Preservation of the relative depths

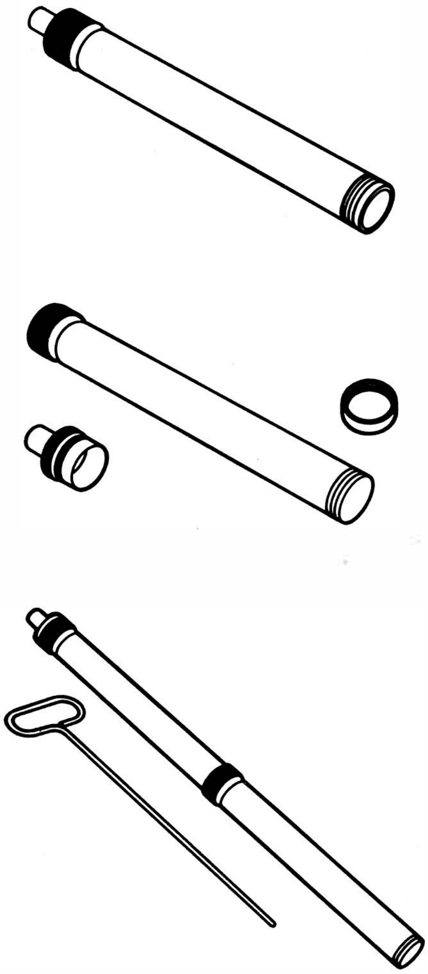


Figure 49.—Drive Tubes. These tubes, about 18 inches long, are pushed or driven into the lunar surface to collect samples as a function of depth. A single tube is shown in the top of the figure, a double tube at the bottom. Two or even three of them may be joined together to obtain a longer core. Their use in Apollo 14 may be seen in figure 50.

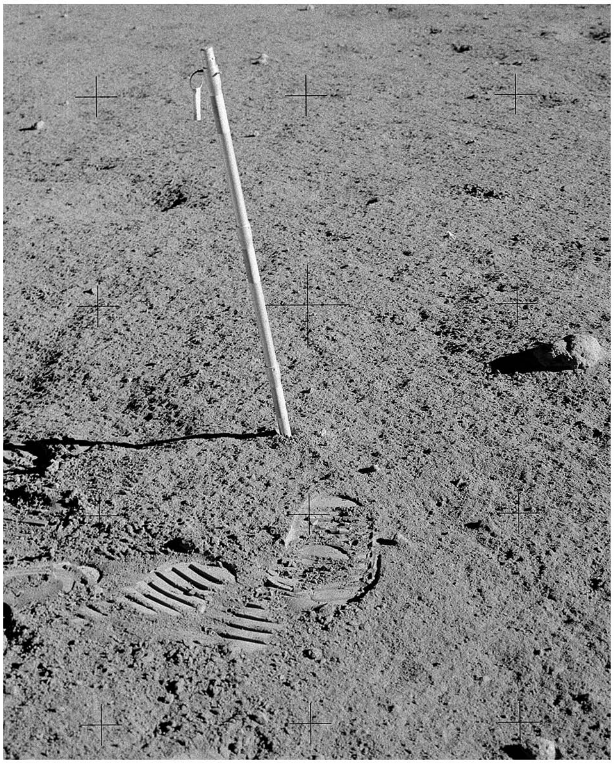


Figure 50.—Drive tube in lunar surface at Apollo 14 site. The relative difficulty of driving the tube into the surface is an indication of the strength of soil. Note in addition the footprints, rocks, and small craters. NASA PHOTO S-71-31082.

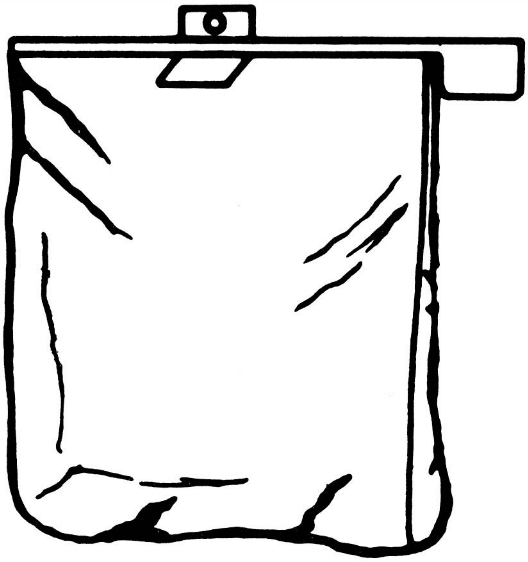


Figure 51.—Lunar sample bag. The bag resembles the familiar kitchen item "Baggies." It is made of Teflon. A strip of aluminum is used to close the bag. Each bag has a number printed on the aluminum strip for identification.

of the core material is especially important. The drive tubes were originally suggested about 7 years ago by the late Dr. Hoover Mackin, a geologist. Shown in figure 50 is a drive tube that was driven into the Moon's surface on Apollo 14.

After the surface samples are collected, they are placed in numbered sample bags made of Teflon (figure 51). Most of us know Teflon as the "wonder material" that coats kitchen pots and pans to prevent sticking. It is used for our sample bags chiefly because it contains no objectionable foreign material (such as lead) that would contaminate the samples, can be made readily into bags, and has certain desirable vacuum characteristics. These bags are about the size of the familiar kitchen storage bags for sandwiches. After a sample is bagged, the thin aluminum strip is folded to close the bag and prevent the samples from becoming mixed with others. The bags are finally placed in the sample return containers, sketched in figure 52, for return to Earth. The Apollo Lunar Sample Return Container (ALSRC) is about the size of a small suitcase. It is made of aluminum and holds 20 to 40 lbs. of samples. You will likely hear it called the *rock box.*

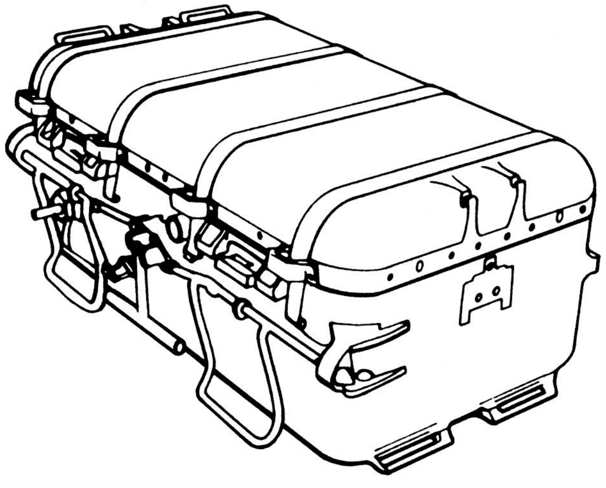


FIGURE 52A.—Apollo Lunar Sample Return Container. Made of aluminum, this box is used to return Lunar samples to Earth. It is about the size of a small suitcase but is many times stronger. The ALSRC has changed very little since it was first used on Apollo 11. It is affectionately nicknamed the "rock box." NASA PHOTO S–72–49032.

On each mission, the astronauts collect some rocks that are too large for the regular bags. You may remember the words of Apollo 12 Astronaut Pete Conrad, "Oh boy, I want that rock. There is a dandy extra grapefruit-sized-type goody. Man, have I got the grapefruit rock of all grapefruit rocks." That particular rock was not brought to Earth but rolled down a crater wall in another experiment. On Apollo 17, such large rocks will be placed in big bags that are made of Teflon also. For the journey to Earth, these big bags are to be stowed in various places in the CM cabin.

A special container, termed Special Environmental Sample Container (SESC), is used to col-

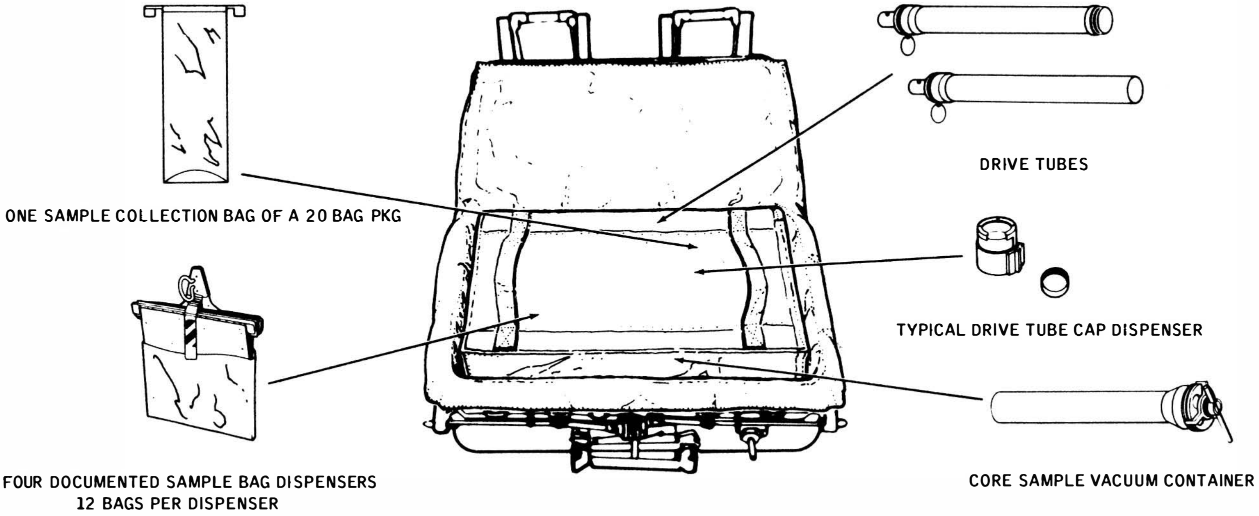


FIGURE 52B.—Apollo Lunar Sample Return Container. Various items are packed in each of the rock boxes for the journey to the Moon. Shown in this sketch are those items contained in one of the rock boxes on Apollo 17. NASA PHOTO S–72–49031.

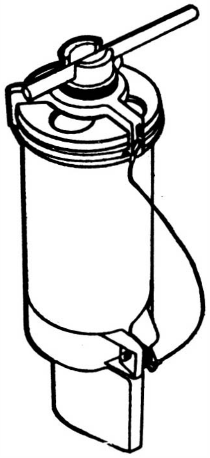


FIGURE 53A.—Special environmental sample container. This container has special vacuum seals to prevent gases and other materials from entering the container and being adsorbed on the surfaces during the journey to the Moon. They also prevent contamination of the samples by rock exhaust gases and the Earth's atmosphere during the return journey.

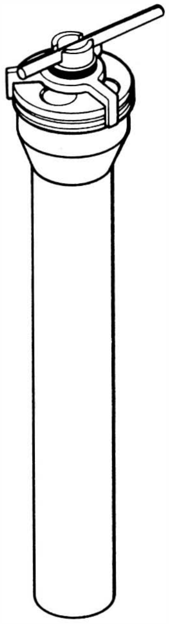


FIGURE 53B.—Special environmental sample container for core tube. This model is about twice as long as the other version. It will be used to store a drive core tube for return to Earth under vacuum conditions. It is our hope to preserve this sample completely uncontaminated. NASA PHOTO S–72–49042.

lect material on the surface of the Moon for specific purposes. (See figure 53.) This container has pressure seals to retain the extremely low pressures of the Moon. It is made of stainless steel. On Apollo 17, one drive core sample will be returned in an elongated version of this container. This sample will be collected in such a manner that it will have very little contamination with either organic or inorganic materials from Earth. The largest sources of biological contamination are the astronauts themselves; the suits leak many microorganisms per minute and the lunar rocks collected on previous missions have all contained some organic material (a few parts per billion). I believe it unlikely that *any* of the organic material present

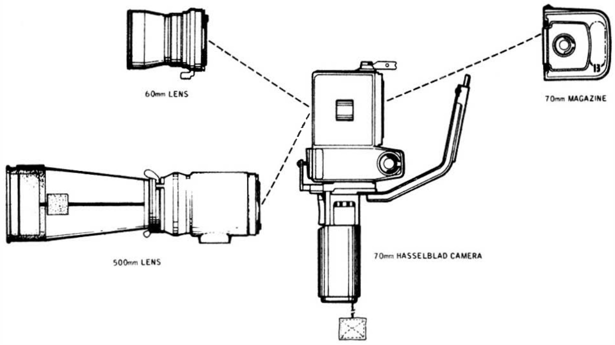
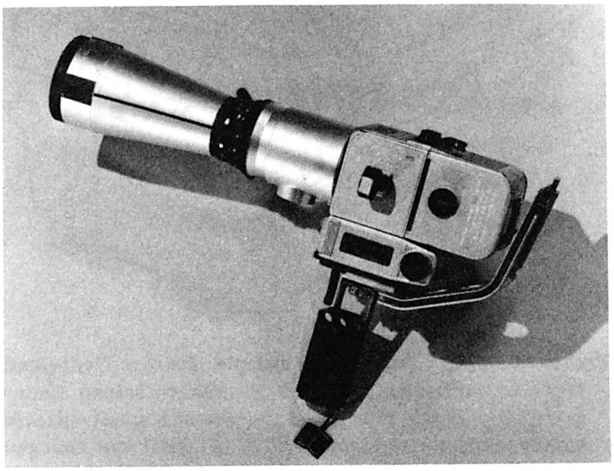


FIGURE 54.—Hasselblad camera. The film, which may be black and white or color, is 70 mm wide. The camera is electrically operated. NASA PHOTO.



on the Moon before the astronauts' landing was biologically formed but some researchers would disagree with me. This question is still being intensely investigated.

The Hasselblad cameras used by the astronauts (figure 54), although very similar to the ones available in camera stores, were especially adapted for use on the Moon. (Many photographs of the Moon have been obtained already. Representative sets of Apollo photos as full color lithographs suitable for framing can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. See bibliography, page — for descriptions of the sets available.) The film is 70 mm. wide, exactly twice as wide as the familiar 35 mm. film. The color film is similar in characteristics to Ektachrome-EF daylight-type. The black and white film has characteristics like Plus X. The primary purpose of the cameras is that of documenting observations made by the astronauts. Especially important is the careful documentation of rocks that are collected for study

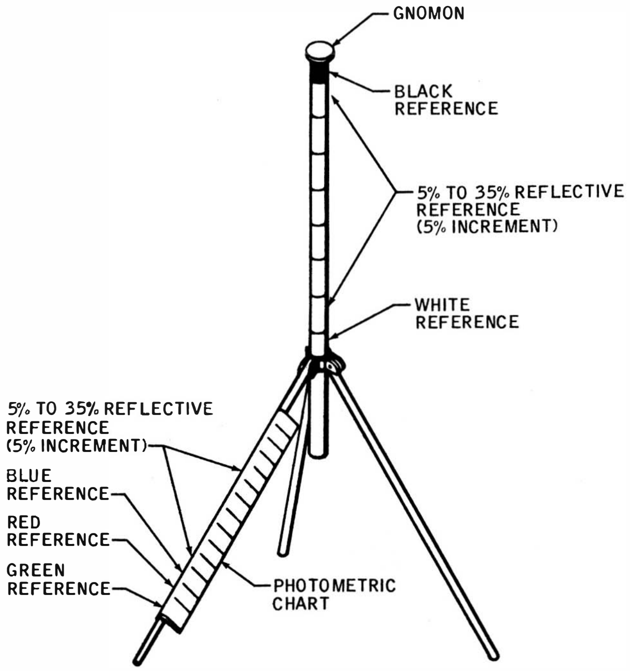


Figure 55.—Gnomon. This device is used to provide a physical scale and to calibrate the photometric properties of the samples on the Moon. It can also be seen in figure 56, an Apollo 14 photograph. The long central rod swings freely and indicates the vertical. Its shadow is used to determine direction from the known position of the Sun. NASA PHOTO 72–49042.

back on Earth. Ideally, several photographs are taken of each rock: (1) before collection with the Sun towards the astronaut's back, (2) before collection with the Sun to the side of the astronaut, (3) before collection a third photo to provide a stereo pair, and (4) after collection a single photo to permit us to see clearly which sample was collected. A device, termed gnomon, and illustrated in figure 55, is included with these pictures to provide a scale with which to measure size and a calibration of the photometric properties of the Moon's surface. In addition to these photographs, a fifth one is desirable to show the general location of the sample with respect to recognizable features of the lunar surface. An example from Apollo 14 is seen in figure 56. The photos taken before collection and after collection show clearly which rock was removed.

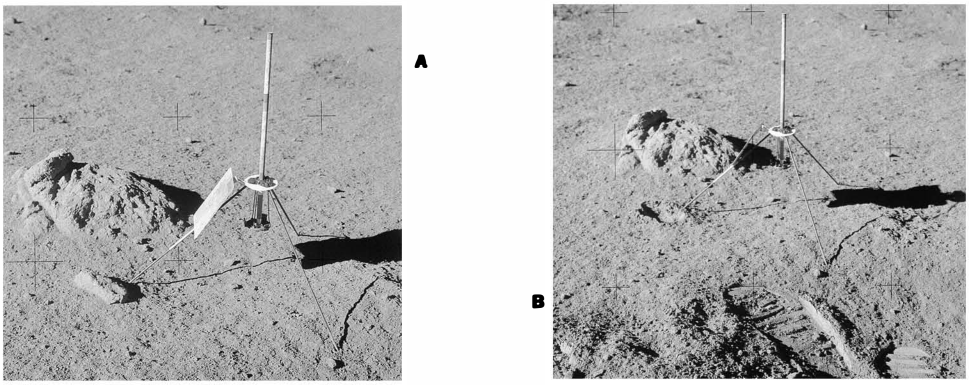
At all stations, still more documentation is desirable. Panoramic views are obtained by shooting many photographs which include the horizon while turning a few degrees and sidestepping one or two paces between snapping each successive photo. The photos have considerable overlap. After return to Earth, the overlap is eliminated and the photos pieced together to yield a composite view of the Moon's surface as seen from a particular spot. The composite photo is usually called a pan, short for panoramic view. One example from Apollo 16 is shown in figure 57. Others from Apollo 14 and 15 may be seen in the July 1971 and February 1972 issues of National Geographic Magazine. In addition, the overlapped regions are used for stereoscopic viewing of the surface. Truly three-dimensional views are obtained in this way. An example of such a stereo pair is shown in figure 58.

Marble-sized rocks from the Moon have proven to be especially valuable in lunar science. They are large enough to allow an extensive set of measurements to be made, yet small enough that many of them can be collected. Accordingly, we designed and built a tool and used it on Apollo 15 and 16 to collect many such samples. It is termed a rake, although the resemblance to the familiar garden tool is now slight. It is illustrated in figure 59 and 60. We expect to use it again on Apollo 17.

The Apollo Lunar Surface Drill (ALSD), used to drill the two holes for the heat flow experiment and illustrated in figure 30, is used also to drill a third hole from which the samples are saved. The drill bit for this purpose is hollow and allows rock and soil to pass into the hollow drill stem. These samples, referred to as core, are about ¾-inch in diameter. Individual pieces of rock are likely to be button-shaped and ¼-inch thick. A few pieces may be larger. Most of the material will probably consist of lunar soil. These samples should not be confused with the samples obtained with the drive tubes which are also termed core. This equipment can drill and collect solid rock, if any is encountered, whereas the drive tubes can collect only material that is small enough to enter the tube. After the hollow drill stem has been drilled 10 feet into the Moon, friction along the sides makes its removal by hand very difficult. Thus the astronaut uses the core extractor sketched in figure 61 to pull the drill stem with its precious contents from the hole.

Soil Mechanics Experiment (SME)

The mechanical properties of the lunar soil are important for both engineering and scientific reasons. Future design of spacecraft, surface vehi-



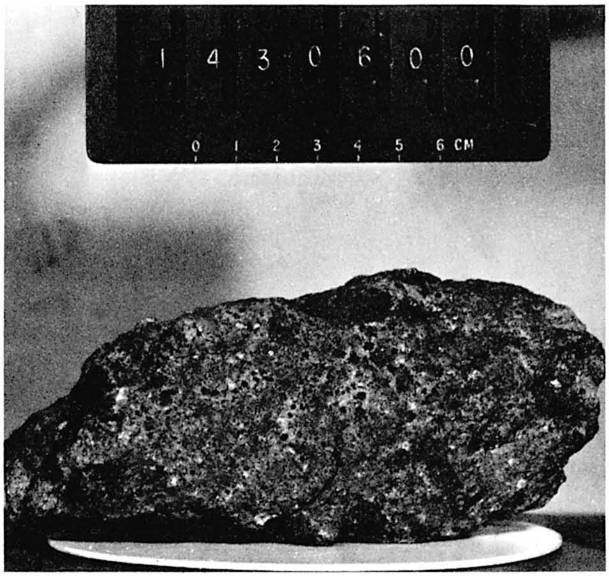


FIGURE 56.—Photographic documentation of lunar samples. These three Apollo 14 photographs indicate clearly the method used to identify the rocks that were collected. The shadows in A, together with knowledge of the time that the photo was taken, have been used to orient the specimen. A location photo (not shown) allows us to determine the relative location of this sample with respect to others collected during the mission. Photo A was taken before the rock was collected. Photo B was taken after collection. Photo C was taken in the laboratory after the Apollo 14 mission had returned to Earth. The field geology team led by Dr. Gordon Swann, identified the rock in photos A and B as sample 14306 and deduced from photo A the orientation on the lunar surface. NASA PHOTO S–71–31077, AS14–68–9462.

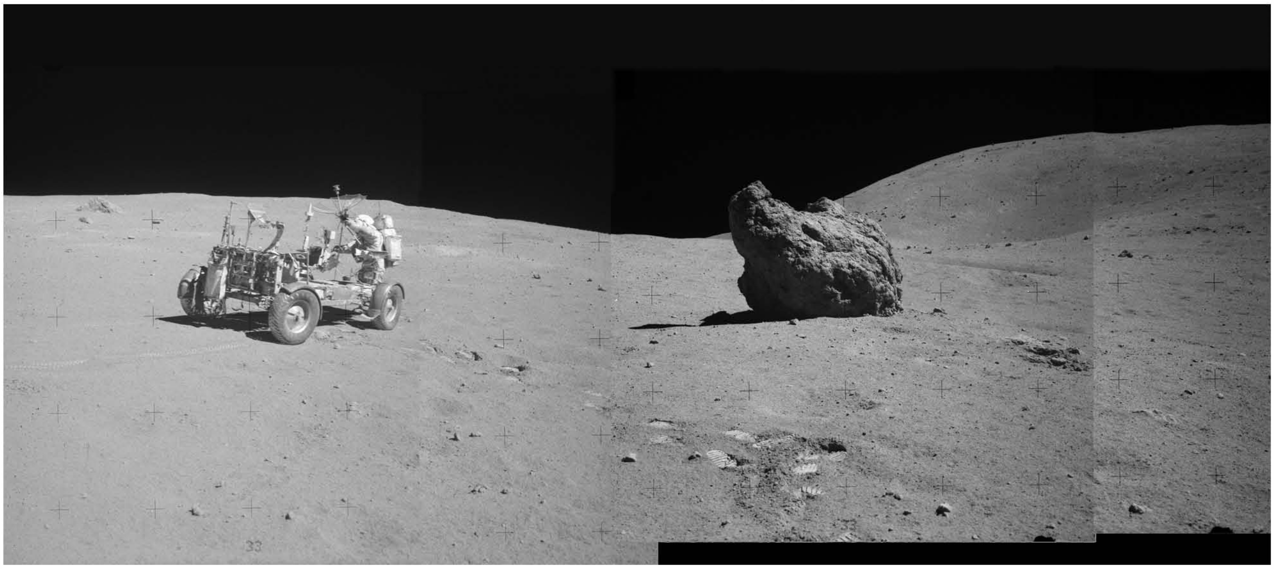


FIGURE 57.—A portion of a panoramic view obtained on Apollo 16. The method of piecing together several photos is clearly shown. Also, the difficulties of fitting the edges of the photos can be imagined from the mismatches evident here. Panoramas from Apollo 14 may be seen in the July 1971 issue of National Geographic magazine. Note the tracks of Rover and the astronaut footsteps. NASA PHOTO S–72–38175.

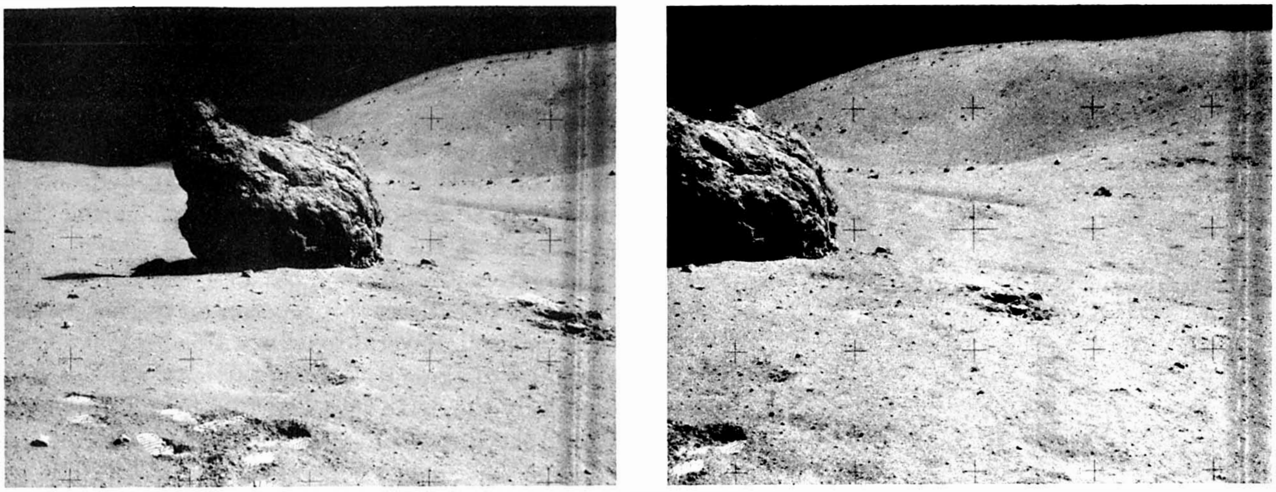


Figure 58.—Apollo 16 stereo photographs. The same photographs used to produce figure 57 were used for this figure but here we used the overlapping parts that were eliminated to make the panoramic view. See figure 8 for instructions on stereo viewing. NASA PHOTOS AS–16–106–17393 and –17394.

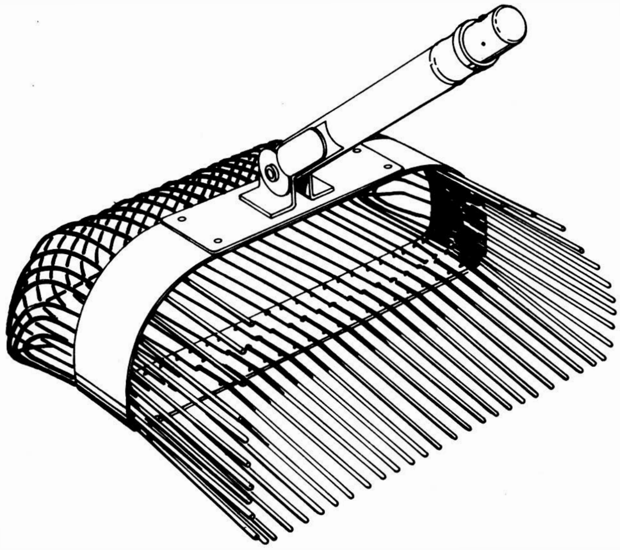


Figure 59.—Rake. This tool was used on Apollo 15 and 16 to collect marble-sized rocks. It will be used again on Apollo 17.

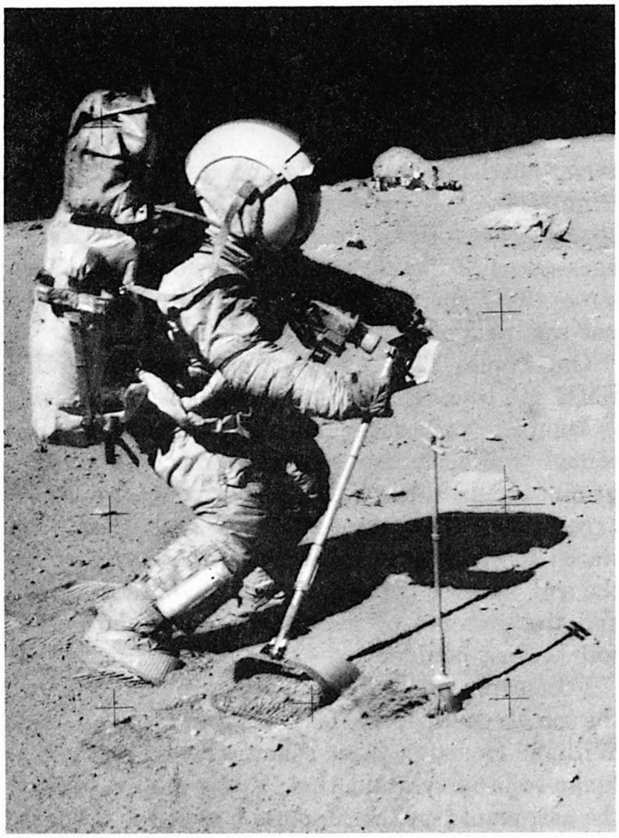


Figure 60.—An Apollo 16 astronaut is shown here using the rake during his visit to Descartes. The tongs are seen standing upright. NASA PHOTO AS16–106–17340.

cles, and shelters for use on the Moon will be based, in part at least, on the data collected in the soil mechanics experiment of this mission. From previous missions we have learned that the mechanical properties are generally similar to those of terrestrial soils of comparable particle size. Indeed, the distributions of particle sizes and particle shapes, together with the density of the soil seem to control the physical properties. Densities of soil on the Moon range from 1.0 to 2.0 gm/cm^3,

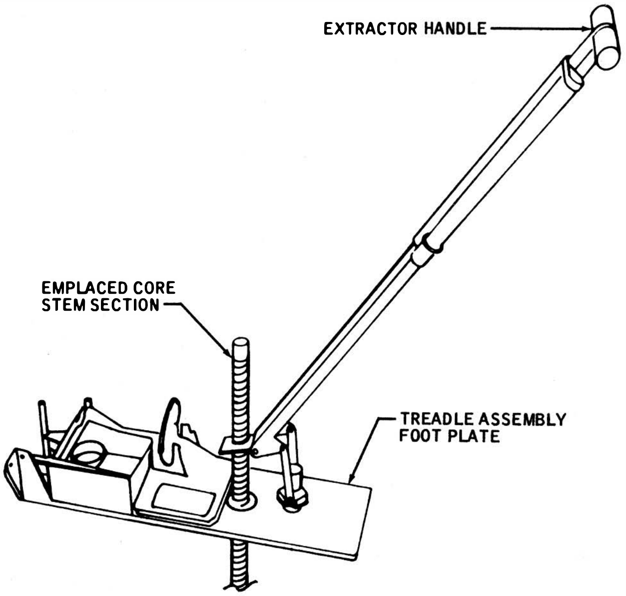


FIGURE 61.—Core stem extractor. After the hollow core stem has been drilled to a depth of about 10 feet, the drill head (shown in figure 30) is removed. The treadle is then moved to the position shown here and the extractor is used in a fashion similar to that of an automobile bumper jack to pull the core stem from the Moon. NASA PHOTO S–72–50284.

even though the individual particles average about 3 gm/cm^3. The porosity (the fraction of open spaces in the soil) of the outer few cm of soil averages about 40 percent at the previous sites. The strength of the soil varies from 2 to 20 pounds per square foot.

On Apollo 17, no special equipment for the SME will be carried to the Moon. This experiment is completely passive and the data will be obtained indirectly from observations and photographs made during the performance of other experiments. The astronauts have been alerted to watch specifically for such features as layering in the soil, surface patterns, slight changes in color, and the presence of fillets (the accumulation of soil against boulders).

Footprints on the Moon also provide data on the soil. Indeed, John Havland, Jim Mitchell, and William Houston, three scientists who study the lunar soils—have said that "every step taken by the astronauts on the Moon is a step for soil mechanics, provided the footprint is photographically documented." The weight of the astronaut (plus any load) on the Moon and the characteristics of his footprint can be readily interpreted in terms of the physical properties of the lunar soil. So can similar information from the Rover tracks. Such other items as the quantity of dust blown from the Moon by the exhaust from the descending LM, the depth to which the LM footpads sink, the amount of dust thrown up by the wheels on the Rover while traveling, and the depth of trails left by boulders that rolled down slopes, are all important factors in estimating the properties of the lunar soil. And of course, the cores (from the drive tubes and the deep drill core) provide direct information on the nature of the lunar soil. Several figures in this booklet show examples of these data from earlier missions; see especially the drive tube and foot prints in figure 50 and the Rover tracks in figures 42 and 57.

Surface Electrical Properties Experiment (SEP)

The Surface Electrical Properties Experiment (SEP) uses radio waves to "see" down into the Moon in much the same way that a doctor uses X-rays to "see" broken bones. We may be able to see into the Moon as deeply as a few kilometers. Several colleagues and I have worked on this experiment for several years in anticipation of using it on the Moon. It is an entirely new experiment and has never been used for the exploration of the Earth.

With SEP, we will look for layering in Taurus-Littrow's rocks and soils. We will look for large boulders that are completely buried and cannot be seen by the astronauts. We will even look for water in the subsurface—though we do not expect to find any. Our experiment will be carried on the traverses of the second and third EVA's.

The SEP equipment is rather simple in concept. We use a radio transmitter to generate radio signals that are extremely stable, a dipole antenna * that is laid on the Moon's surface by the astronauts, and a radio receiver that is carried on the rear of the Lunar Rover. The actual data are recorded on a tape recorder which is similar to the home-style cassette tape recorders and which is brought back to Earth by the astronauts. The

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* Dipole antennas are familiar to most people in the form of "rabbit ear" antennas used with home TV sets. By extending the two arms along a straight line, you produce a true dipole antenna. The SEP antenna differs chiefly in length. It is 70 m tip-to-tip. The Apollo Lunar Sounder Experiment also uses a dipole antenna.

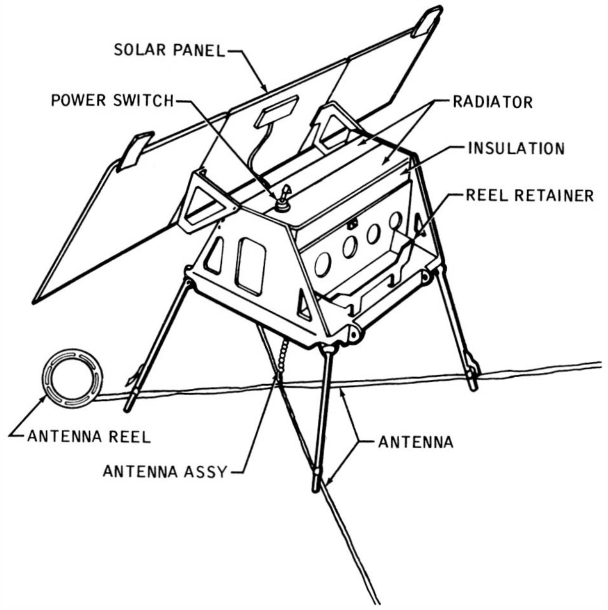

FIGURE 62.—SEP transmitter. The panel on top of the transmitter contains solar cells that convert the Sun's energy into electrical energy. The astronaut sets the transmitter on the surface of the Moon, roughly levels it, adjusts the solar cell panel to point directly towards the Sun, and extends the antennas. NASA PHOTO S–72–49042.

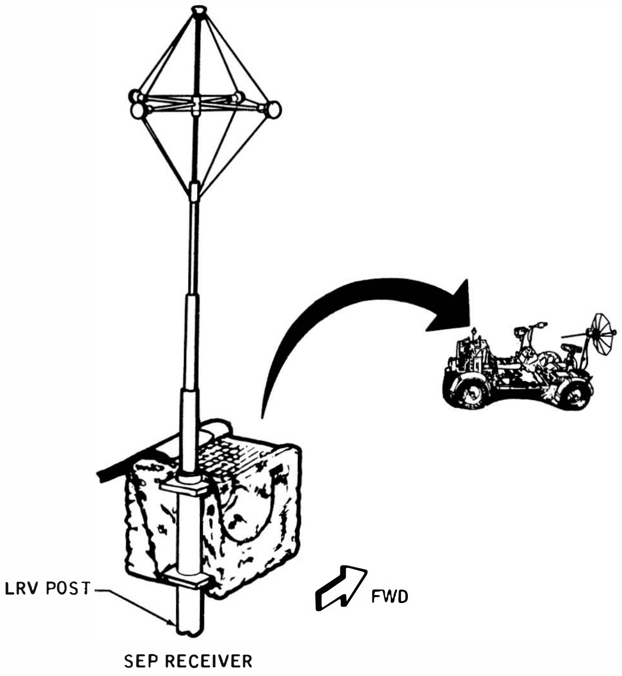

FIGURE 63A.—SEP receiver. The receiver is mounted on the rear of the Rover. Data, measured while the Rover moves along a traverse, are also recorded automatically on a cassette tape recorder. NASA PHOTO S–72–49033.

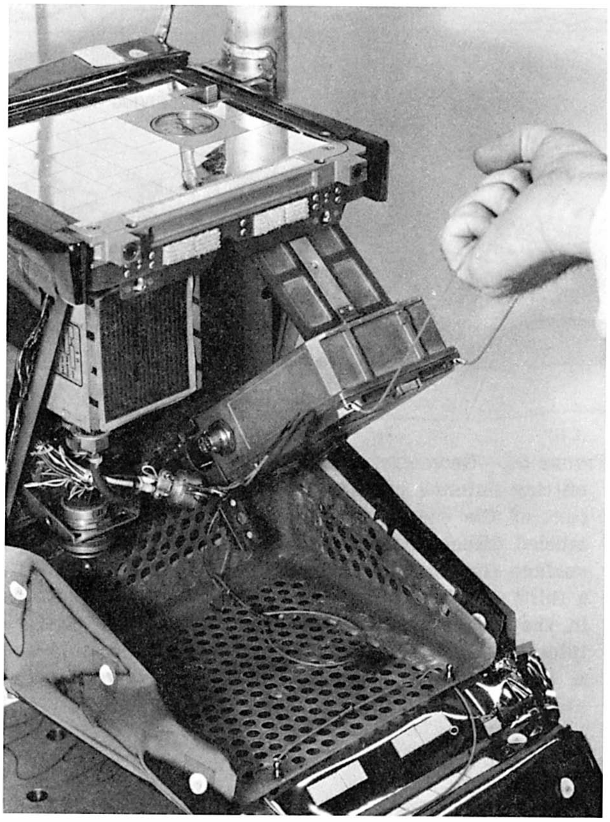

FIGURE 63B.—Removing the SEP tape recorder. After EVA 3, the cassette tape recorder is removed by the astronauts from the SEP receiver and stowed in the LM for return to Earth. The entire recorder is brought back because of the difficulty of removing the cassette. Shown also in this figure is the thermometer (on top of the box) that measures the internal temperature of the SEP receiver.

transmitter and its antenna are shown in figure 62. The receiver is shown in figure 63. The transmitter uses power directly from the Sun generated by solar cells in the large panel on top. The receiver uses internal batteries.

The basic principle of SEP, interferometry, is a familiar one in science, engineering, and technology. It is also familiar to you although you may not yet realize it. It involves only the interference of two or more waves to produce a "synthetic wave." For example, the pattern produced by the two sets of waves on the surface of a pond when two pebbles are dropped at the same time a few feet apart, is an interference pattern. The colors produced by a thin film of oil is also an interference phenomenon. And finally, "ghosts" on your TV screen are the result of interference. In figure 64, the geometry of SEP is shown. Energy

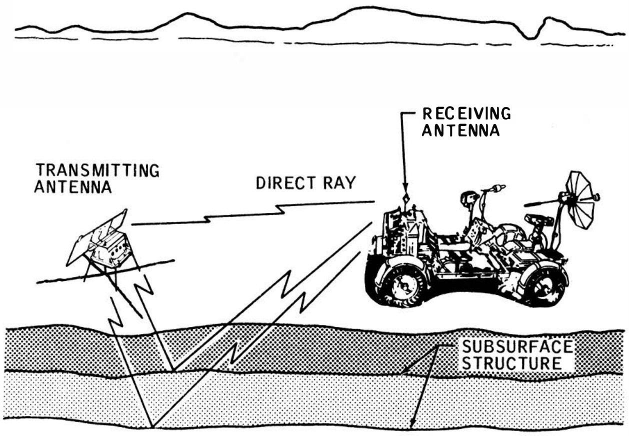

FIGURE 64.—Geometry of the SEP experiment. The transmitting antenna radiates energy in all directions. One part of the energy travels above the Moon's surface, labeled direct ray. Another part travels just below the surface (but omitted in the figure for simplicity). Still a third part is reflected from any subsurface structures in the Moon. All of these waves combine to produce interference patterns. This figure is schematic only and is not drawn to a uniform scale. NASA PHOTO S–72–49037.

in the form of radiowaves radiates from the transmitting antenna. Some of the energy travels *above* the Moon's surface directly to the receiver and some travels *below* the surface to the receiver. The combination of these two waves produces an interference pattern. By detecting and measuring this interference pattern, we can determine two things about the Moon: (1) the speed of radiowaves in the subsurface, and (2) the ease of propagation of radiowaves in the Moon. This second property, termed attenuation, is one of the characteristic properties of materials. In addition to these two waves, a third may also be present. Any subsurface layer will reflect energy back towards the surface and it too will produce an interference pattern. This additional interference makes the analysis of our data more complicated but adds greatly to the information about the Moon's interior.

Energy will be returned to the surface not only by rock layers but also by such reflecting surfaces as large boulders, breaks in the rocks (geologically speaking, faults), and any major changes in the electrical properties of the lunar soil and rocks. Thus a complete analysis of the data will reveal the presence of such features.

On the Moon, we will actually use two transmitting antennas because the characteristics of the dipole antenna on the Moon are different when viewed *along* the antenna from those viewed *perpendicular* to the antenna. We also use radiowaves of several frequencies—1, 2.1, 4, 8.1, 16, and 32.1 Megahertz. Because the depth of penetration into the Moon depends upon the frequency of the radio signal, this set of frequencies will allow us to examine the lunar subsurface to several depths and with good resolution at each depth.

Lunar Traverse Gravimeter Experiment (LTG)

Minute variations in the value of gravity on the surface of the Earth have led to major discoveries about the rocks hidden from sight beneath the surface. In Colonel Everest's geographical survey of India, about 100 years ago, the existence of "roots" beneath the Himalayas was discovered. The "roots" were really just a deficiency of mass beneath the mountains. That relation has since been shown to be true for many other mountains. Similarly ocean areas have "antiroots," that is high density rock lies at a shallower depth under the oceans than elsewhere. On a smaller scale, variations in the value of gravity have been used to look at rocks beneath the surface, often to find either oil or ore bodies. For example, in the early 1930's, oil was discovered around salt domes. Because salt domes are usually lighter than the surrounding rocks and hence cause a small decrease in the value of gravity immediately above the dome, the value of gravimeters in the search for oil became obvious. Gravimeters are instruments which can detect extremely small variations in the value of gravity. The effect of a salt dome, for instance, is often not larger than 2 or 3 millionths of the value of gravity. To detect this effect accurately, the precision of the gravimeter has to be better than a 10 millionths part of gravity!

Gravimeters have also been used to study valleys and the rocks beneath them in such areas as the southwestern United States. There, bedrock outcrops on the mountains but is buried in the valley beneath thick deposits of loose, highly porous materials termed alluvium. Because the density of the alluvium is less than the density of the bedrock, the gravity values are less over the valley than over the ranges. By measuring the gravity differences, the thickness of the alluvium in the valleys can be determined.

The objective of the LTG on the Moon is to solve

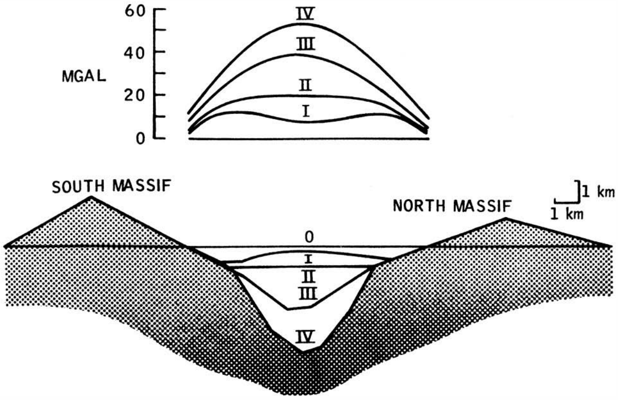

FIGURE 65.—Gravity at Taurus-Littrow. The shape of the bedrock surface beneath the valley strongly influences the values of gravity. Shown here are the *calculated* values of gravity that would be produced by various shapes. Comparison of the actual data obtained on the Moon with these curves will help us choose the correct shape. (Figure courtesy—M. Talwani.) NASA PHOTO S–72–50290.

a problem somewhat similar to the "valley gravity" problem. In the Taurus-Littrow area, two mountains of highland material lie on either side of the valley (figure 6). The valley floor is covered everywhere with the thin regolith and with the DARK MANTLE material which may be thin. There are also thin superficial deposits of the LIGHT MANTLE material. But the principal formation in the valley is the so-called SUBFLOOR UNIT whose thickness is unknown. In figure 65, a profile across the valley, four possible thicknesses of the SUBFLOOR UNIT are indicated by the curves labelled I, II, III, and IV. The corresponding gravity variation is plotted on top (one mgal is roughly equal to 1 millionth of the value of gravity on Earth). From these curves we see that the gravity effect is minimal if the MASSIF material is buried beneath a thin SUBFLOOR UNIT. However, if the SUBFLOOR UNIT is several kilometers thick, the gravity effect will be large.

In a general way, large variations in the value of gravity at Taurus-Littrow will suggest "lumpiness" in the shallow part of the lunar crust, whereas small variations of gravity will favor ideas of uniform horizontal layering to great depth.

The LTG equipment uses a principle that is quite old but uses it in a way that is rather new. The frequency of vibration of a mass suspended freely on a spring depends upon the value of gravity as well as several other parameters. If the values of these other parameters are known, then the frequency of vibration can be used to determine the value of gravity. In the lunar equipment, the frequency of the vibration of the spring is measured electronically, an easy measurement to make with extremely high precision. Any variations in the value of gravity will be seen as variations in the frequency of vibration. (Actually, the mass is suspended *between* two springs, as shown in figure 66, but the analysis here is still essentially correct.) The unit is quite smiliar to those used in the guidance systems of missiles and is termed a vibrating string accelerometer, or VSA.

The LTG will be mounted on the rear of the Rover. At each stop, the astronauts will read the instrument and report the readings over the voice communications link to Mission Control. Those readings are *not* the values of gravity but must be converted through calibration tables. The external appearance of the equipment is shown in figure 67.

Lunar Neutron Probe Experiment (LNP)

The Lunar Neutron Probe Experiment (LNP)

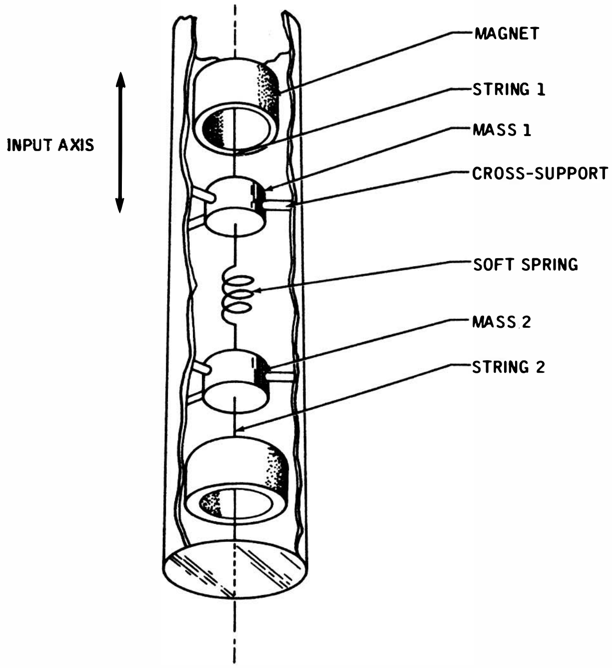

FIGURE 67.—Lunar Traverse Gravimeter. With this unit, the astronaut will measure the variation of gravity at several different spots on the Moon. The instrument will normally be mounted on the rear of the Rover. The inset shows the control buttons and the digital meter. NASA PHOTO S–72–49035.

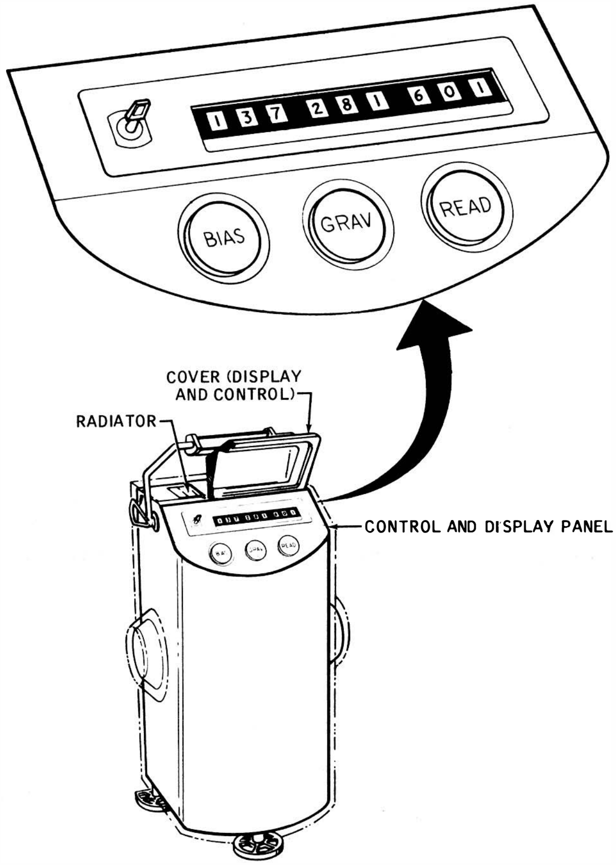

FIGURE 66.—Elements of the Lunar Traverse Gravimeter. Shown here is a schematic section of the vibrating string accelerometer, the sensor in the Traverse Gravimeter. The frequencies of vibration of the two strings depend on the value of gravity. From minute variations in the frequencies, measured electronically, we can measure minute changes in the value of gravity.

is an outgrowth of some rather sophisticated studies of the first samples returned from the Moon on Apollo 11. Those early studies showed clearly that nuclear reactions on the Moon involved neutron* capture on certain isotopes of the elements gadolinium and samarium, as well as other nuclei. The way in which these materials are distributed with depth in the Moon can be measured on cores obtained with drive tubes as well as the deep drill. Such data are extremely important to lunar science because they help us understand the physical processes that have produced lunar soil and that contribute to the continued mixing (or gardening, as some prefer to call it). With some plausible assumptions, even the time since a particular sample had been on the surface of the Moon can be estimated rather precisely. The primary purpose of the neutron flux experiment is to obtain data on the Moon that are needed for such estimations. Specifically, the LNP experiment will obtain data on the rates of neutron capture and measure their variations with depth beneath the lunar surface. The experiment will also provide some information on the energies carried by lunar neutrons.

The technique by which the LNP data are to be gathered is rather interesting. Neutrons inter-

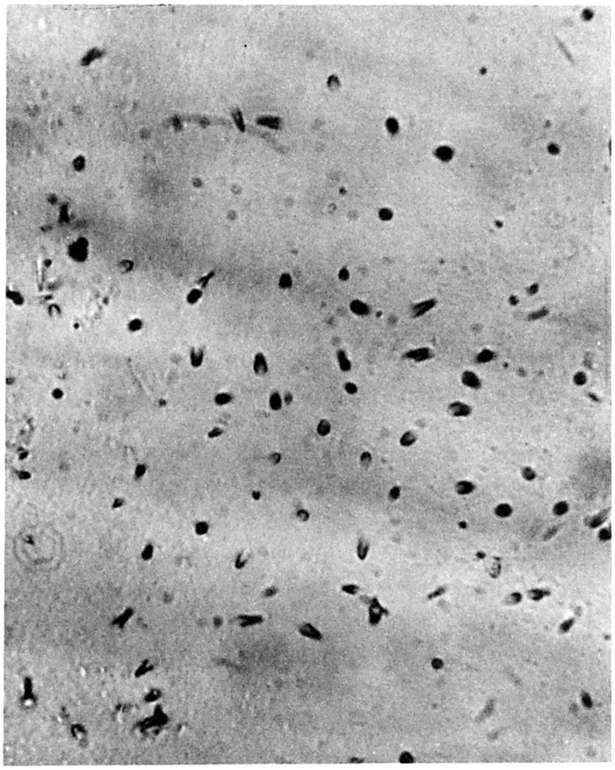

FIGURE 68.—Particle tracks. In the Lunar Neutron Probe, neutrons interact with boron nuclei to produce alpha particles. The alphas then interact with a plastic to yield tracks like those seen in this photograph. (PHOTO COURTESY—D. BURNETT.)

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*Neutrons, protons, and electrons are the "building blocks" of atoms. The proton has a large mass and a positive electrical charge. The electron has a small mass, about .05 percent that of the proton, and a negative electrical charge. Neutrons have a mass rather close to the mass of a proton but unlike the proton, the neutron has no electrical charge. Atomic nuclei contain neutrons and protons but electrons occur only outside the nucleus. Neutrons outside the nucleus are unstable and change into other particles. Neutrons do not interact with electrons that surround the atomic nucleus but do interact with the nucleus itself.

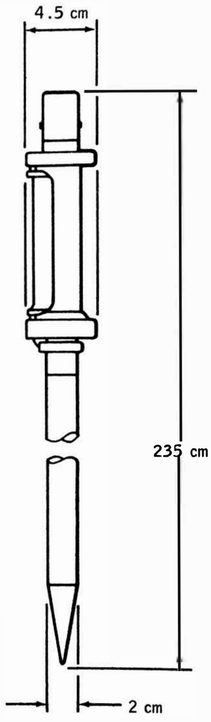

FIGURE 69.—Lunar neutron probe. The LNP is carried to the Moon in two sections and then assembled before being placed in the deep drill hole.

act readily with boron* and produce alpha particles. The alpha particles, in turn, react readily with a particular plastic to produce microscopic tracks. The appearance of the tracks is shown in figure 68.

The appearance of the probe is shown in figure 69. The equipment consists of a probe in which the boron and plastic are separated until the astronauts reach the Moon. After the deep drill hole has been completed, and the core removed, the LNP will be placed in the hole. It will be placed in the hole during EVA 1 and then removed late in EVA 3, remaining in the hole for more than 40 hours. Before placing the probe in the hole, the boron is rotated so that it is adjacent to the plastic. Thus when neutrons interact with the boron, alpha particles are produced and, in turn, produce tracks in the plastic. After the probe is removed from the hole, the boron is again separated from the plastic for the journey back home. After the return of Apollo 17, the plastic will be examined microscopically in the laboratory and the number of tracks counted as a function of depth.

Cosmic Ray Detector Experiment (CRD)

Cosmic rays are just particles that have extremely larger energies and very high velocities. Their velocity is almost, but not quite, the speed of light. They are mostly protons and alpha particles (see section "Lunar Neutron Probe" for discussion). But 1 to 2 percent of the cosmic rays consist of the nuclei (that is, atoms with one or more electrons removed) of heavier elements. The cosmic rays seem to arrive from all directions and, although their origin is not yet known with certainty, they come from outside our solar system.

In addition to cosmic rays, the CRD equipment will detect low energy solar wind particles. The Sun has streaming out from it continuously a very thin gas that is composed of electrons, protons, hydrogen, helium, neon, certain other gases and other nuclear particles. (These are the elements we can measure directly; presumably all other elements are present too.) This very thin gas from the Sun is called the solar wind. The CRD experiment records the solar wind particles as well as cosmic rays.

The CRD experiment was flown on Apollo 16 but a solar flare occurred on April 17 and produced many particles. The tracks caused by the solar flare particles are both larger and more numerous than the tracks produced by the normal solar wind particles and cosmic rays, making the reading of the "normal record" very uncertain. So, the CRD experiment will be flown again on Apollo 17 in order to do those things that had been expected for the Apollo 16 flight. Of course, the Apollo 16 flare data are also very important because they carry information about the composition of the interior of the Sun. They are currently being studied.

In the CRD experiment, we obtain actual records of the particles. Plates of several special materials (some resemble plexiglass), shown in figure 70, are carried on the outside of the LM to the Moon and then brought back to Earth. The passage of particles through the material is recorded in the form of tiny tracks. The characteristics of these tracks seen through a microscope, tell us the kind of particle and, of course, its direction of travel. Some of the great interest in this experiment is due to the possibility that new elements may be discovered!

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*Boron is one of the elements. It is obtained from deposits in California's Mojave Desert. Two of its compounds, boric acid and borax, are household items. A third, boron nitride, is as hard as diamond (which had been thought to be the hardest substance of all).

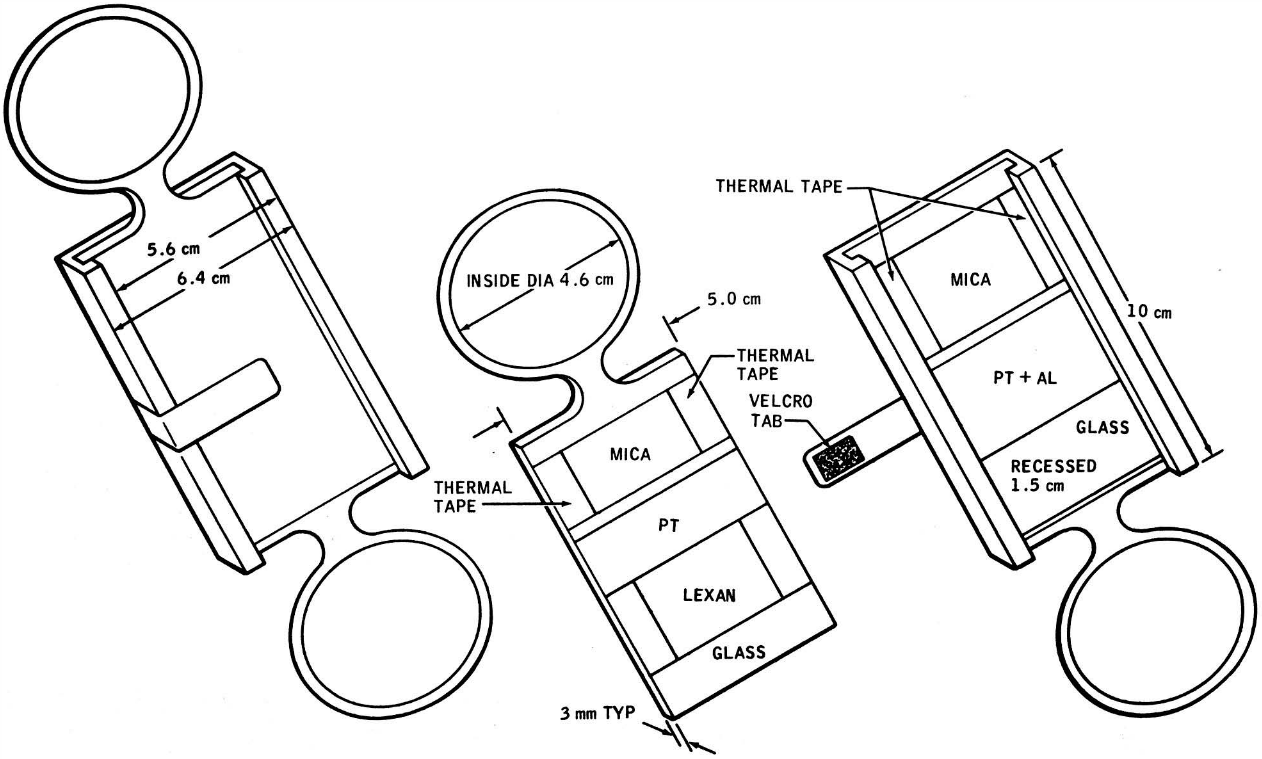

FIGURE 70.—Cosmic ray detector experiment. Small pieces of mica, aluminum, and other materials are exposed to particles in space. The passage of energetic particles through these materials, produces damage along their path. After return of the CRD, to Earth, the tracks are chemically etched so they can be seen with a microscope. The three separate pieces shown in the sketch slide together for transport to the Moon and for return to Earth.

Introduction to Orbital Science

At each landing site on the surface of the Moon, the astronauts' activities are limited to distances of a few miles. In comparison with the total area of the surface of the Moon, the regions explored by the astronauts on foot or with the Rover are miniscule. They are frequently referred to as "point" samples. The desirability of extending our observations to larger areas is obvious. Indeed, several things can be done *in orbit* about the Moon that will allow us to extrapolate from the data obtained on the surface to the rest of the Moon. One of these things is photography; many photographs have been obtained from the command module on each of the previous Apollo missions. Both the number and quality of photographs obtained from lunar orbit on Apollo 15 and 16, and scheduled to be obtained on 17, have been greatly increased over those of earlier missions.

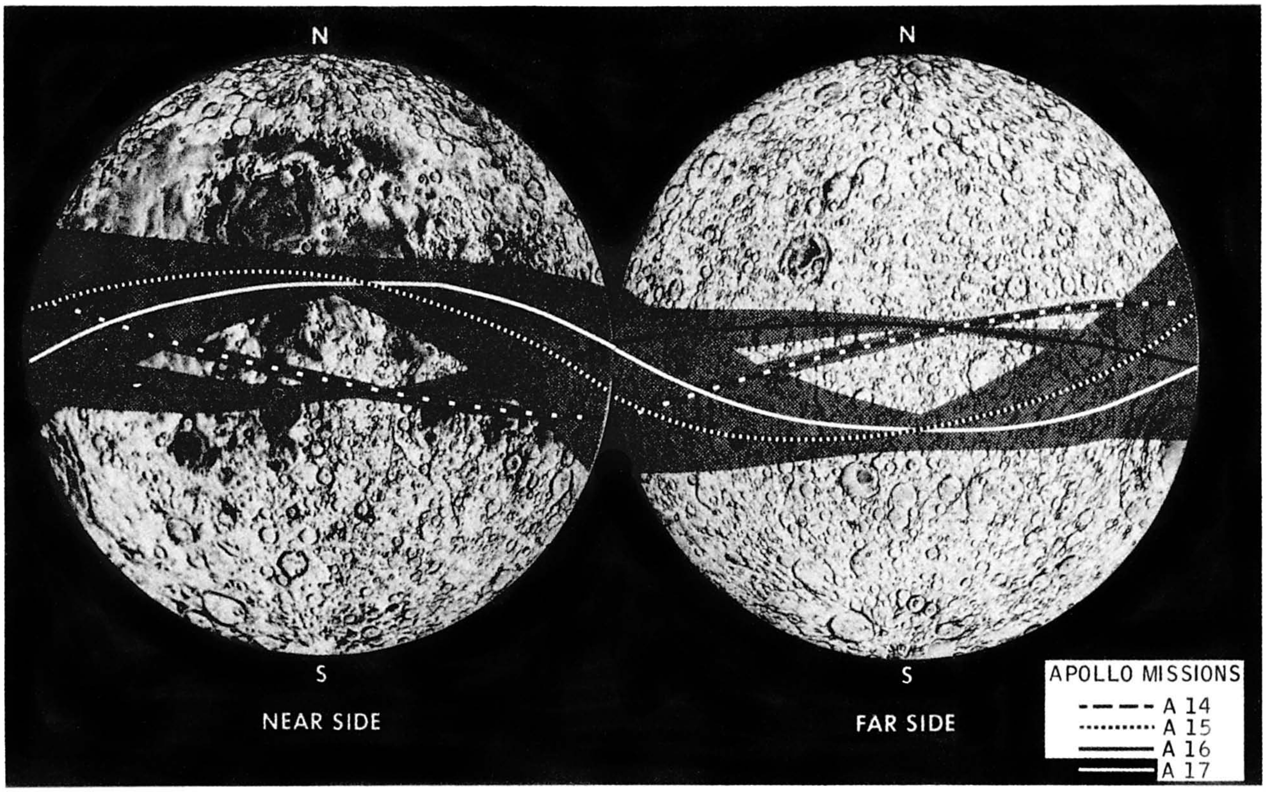

Figure 71A.—Orbital path coverage for Apollo 15 and 16. Because the landing site of Apollo 15 was located well away from the equator, the command module covered a rather large area of the Moon's surface. Data from the "chemical group" of experiments indicate the distribution of certain elements on the Moon's surface. The coverage of the farside of the Moon, never seen from Earth, is especially valuable. Almost 10,000 photos were obtained during Apollo 15. If the 8 × 10 prints were laid side by side, they would extend almost 2 miles. BASE MAP COURTESY OF NATIONAL GEOGRAPHIC SOCIETY.

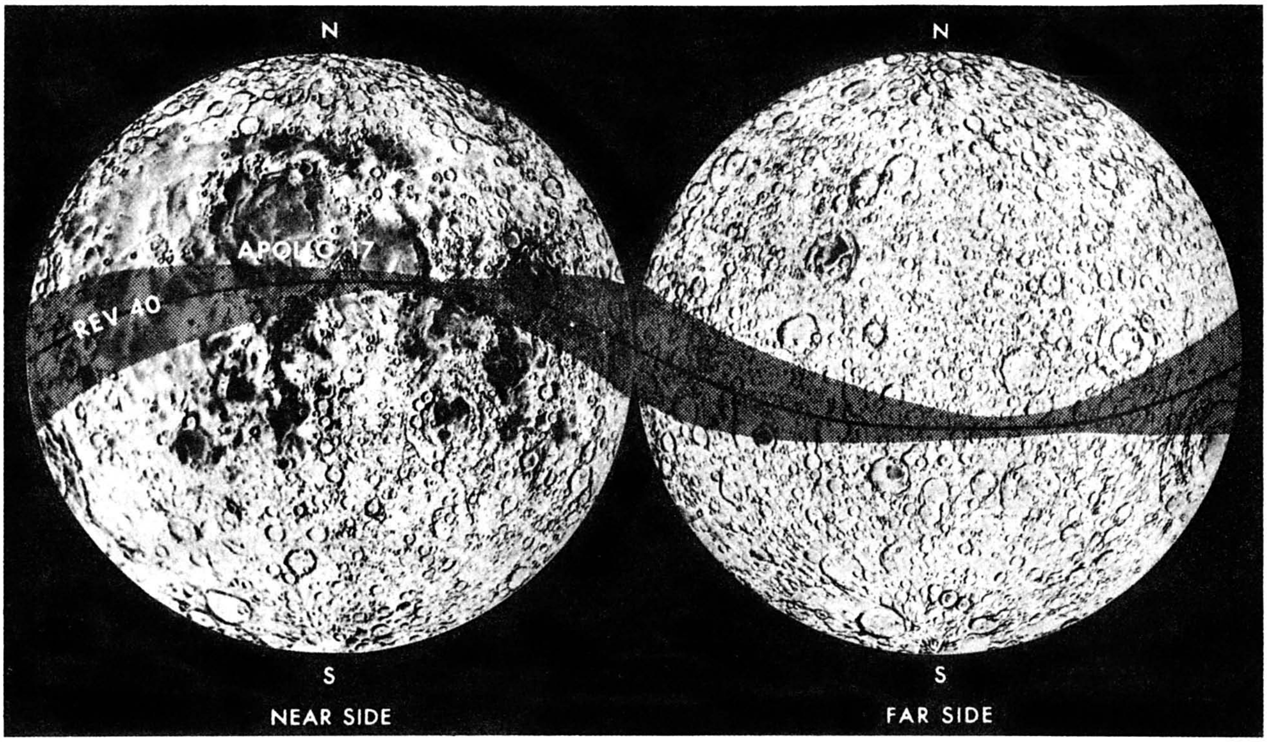

FIGURE 71B.—Orbital coverage for Apollo 17. See also caption for figure 71A. BASE MAP COURTESY OF NATIONAL GEOGRAPHIC SOCIETY.

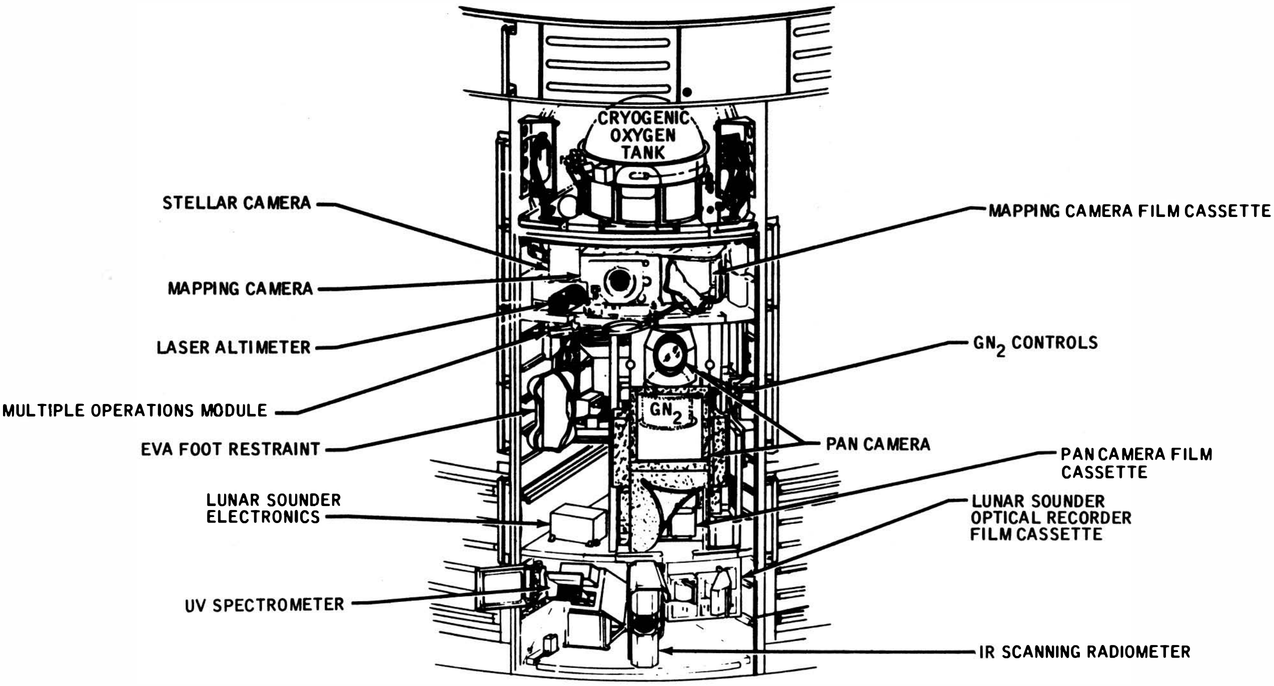

FIGURE 73.—SIM Bay. Shown here is the location within the scientific instrument module (SIM) of the equipment for each orbital experiment. Before the CM is separated from the SM the film cassettes must be retrieved.

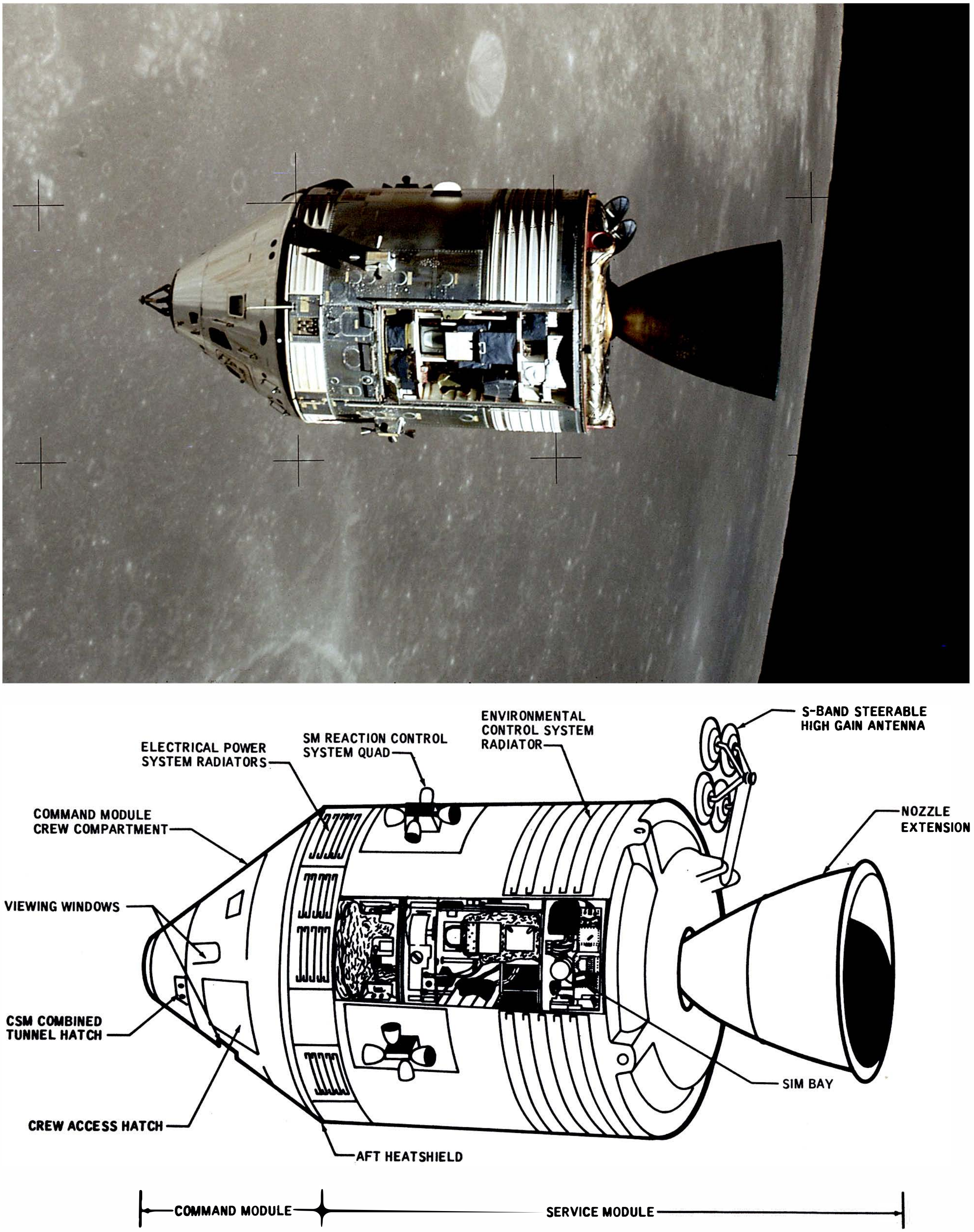

FIGURE 72.—Location of Scientific Instrument Module (SIM) in the Service Module. The Apollo 15 photo was taken from the LM with the Moon for background. NASA PHOTO AS15–88–11972. Sketch shows details and names.

Several things other than photography can be done from lunar orbit. In these next few sections I will describe them.

The region of the Moon that was examined with orbital experiments on Apollo 15 and 16 is shown in figure 71A. The coverage for the present mission, Apollo 17, is shown in figure 71B.

The total coverage for these three missions will exceed 20 percent of the Moon's surface for several of the orbital experiments and will exceed 5 percent for each of them.

Although some photographic tasks will be done in the CM, most of the experiments for the orbital science will be done with equipment located in the SM. The various orbital experiments include the following—Lunar Sounder, Infrared Scanning Radiometer, Far Ultraviolet Spectrometer, and S-Band Transponder. Only the S-Band Transponder has been flown before. The other three experiments are new. The equipment for the orbital science experiments are all housed in a section that is termed scientific instrument module (acronym SIM). The location of the SIM in the service module is shown in figure 72. The location of the equipment for the individual experiments in the SIM is shown in figure 73. The names and addresses of the principal investigators of each orbital experiment are given in Table 5.

Orbital Science Activities

The door that covers the scientific instrument module (SIM) will be jettisoned about 4½ hours before the spacecraft reaches lunar orbit. The door will continue past the Moon and be lost into space. By removing it *before* reaching lunar orbit, the astronauts keep the debris out of lunar orbit and remove the possibility of later contact with the door.

The initial lunar orbit is an ellipse with maximum distance from the Moon of 170 nautical miles and minimum distance 60 nautical miles. A nautical mile is 15 percent larger than a statute mile. A few hours later, a rocket burn places the spacecraft into a 60 x 14 nautical mile orbit from which the LM will descend to the Moon after another 18½ hours. During this 18½-hour period, the SIM experiments and cameras will scan the lunar surface. The S-Band Transponder experiment also will be performed.

Then shortly before the LM touchdown, another burn of the orbiting CSM's rocket engine will circularize the orbit at 60 nautical miles. During the next 3 days while the LM remains on the surface of the Moon, all of the orbital experiments will be performed. The CSM will change the plane of its orbit about 6 hours before the LM liftoff so that it will be in the proper place to rendezvous with LM.

After rendezvous, various items, including the lunar samples, photographic film, and the SEP tape recorder, will be transferred from the ascent stage to the command module. Then the LM, of no further use to the astronauts, separated from the CSM (i.e., undocked), will be crashed onto the Moon's surface at 20° N., 30° E., to provide a source of energy (i.e., an artificial moonquake) for the seismic experiments.

The total time in lunar orbit during which the SIM experiments and photography can be performed is about 6 days. None of the individual experiments will operate for the full time. The maximum time used by any experiment in lunar orbit is roughly 60 hours. Some experiments interfere with each other and so cannot operate simultaneously. For the cameras, the maximum operating time is set by the amount of film which can be stored in the supply cassettes.

LUNAR ORBITAL SCIENTIFIC EXPERIMENTS AND HARDWARE

In this section, I discuss each of the orbital experiments and the nature of the equipment. I hope to provide enough information so that you can understand the nature of each experiment. On the other hand, I do not intend to write a complete

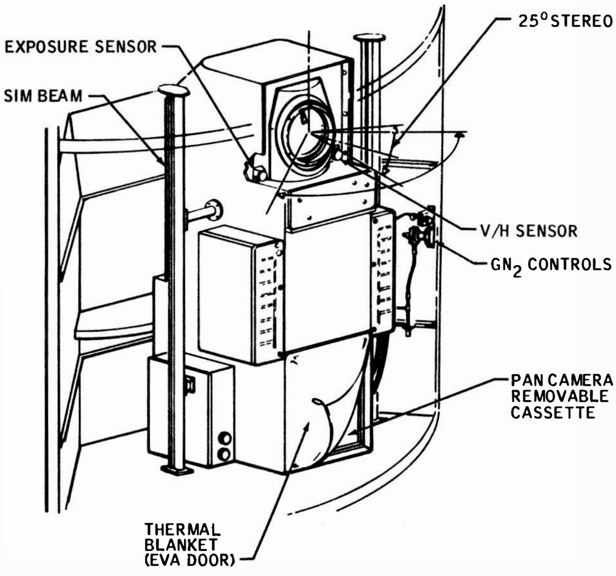

FIGURE 74.—24-inch panoramic camera. In operation, the camera lens rotates continuously and scans a total of 108° across the flight direction. The entire camera tilts 25° forward and backward along the track of the spacecraft to provide stereo coverage. The film cassette is retrieved by the CM pilot on EVA in space.

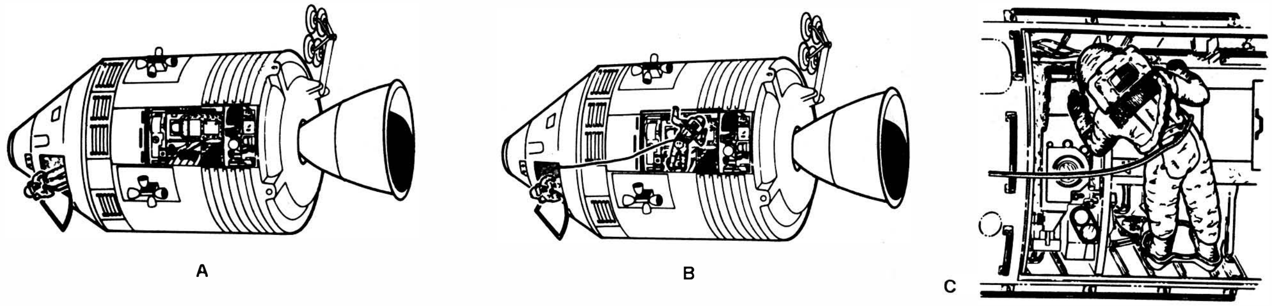

FIGURE 75.—Retrieving film from the SIM. In A, the astronaut is shown egressing through the CM hatch. All three astronauts must wear spacesuits to protect themselves against the vacuum of space. In B, an astronaut has moved to the vicinity of the SIM and is preparing to remove the film from the panoramic camera. He holds himself to the spacecraft by inserting his feet into special footholds, termed golden slippers because they were formerly gold colored. In C, he is removing the film cassette from the mapping camera. The other astronaut documents the procedure with photos and verbal descriptions. He also helps by passing the cassettes to the astronaut in the CM for storage. NASA PHOTO S-72-16232.

textbook on the physics of lunar experiments. It is my hope that I can provide enough elementary information on each experiment for you to understand how it works. I hope then to show you a brief glimpse of the results that were obtained on the Apollo 15 and 16 missions. Undoubtedly there are many surprises yet to come from those data; results from Apollo 17 will surely be equally exciting.

Photographic Tasks and Equipment (PTE)

The purposes of the orbital photography are to obtain high resolution panoramic photographs of the Moon's surface, to obtain high quality metric photographs, and to obtain elevation of the surface of the Moon along the ground track. Two cameras and a laser altimeter, all mounted in the SIM, are used. The location of each of the cameras is shown in figure 73.

The 24-inch panoramic camera, figure 74, is used to obtain high resolution panoramic photographs with both stereoscopic and regular (technically termed monoscopic) coverage of the Moon's surface. Several automatic features have been incorporated into this camera. For example, the camera lens rotates continuously in a direction across the path of the orbiting spacecraft in order to provide the panoramic scanning (hence the name of the camera). The whole camera tilts forward and backward to provide stereo coverage. An exposure sensor, figure 74, measures the brightness of the Moon and adjusts the camera shutter automatically. And finally, the V/H sensor, figure 74, detects the ratio of the forward velocity to the height of the spacecraft above the Moon's surface and automatically corrects for it, thus removing the blur that would result from motion of the spacecraft. All in all, I think that even the most avid camera enthusiast would agree that the 24-inch pan camera is a very fancy one. You might be interested in knowing that, from an orbital altitude of 60 miles, this camera will provide an image on the film of objects as small as 3 to 6 feet on the Moon's surface.

The astronauts must be careful to protect the camera's sensors from exposure to the Sun. Of course the "guards" against this happening are the people in Mission Control in Houston. Several of these sensors have no provisions to prevent damage if the Sun is viewed directly.

A low speed black and white aerial-type film is used. The cassette must be retrieved by one of the astronauts, normally the CM pilot, during an EVA. The sequence of operations is indicated schematically in figure 75. See also figure 76, a photograph from an earlier mission. Note the hose which is used to provide oxygen outside the CM. The back pack here is the Oxygen Purge System (OPS), similar to the PLSS in providing oxygen; it is used only in the (unlikely) event that the hose-supply fails. The training for an EVA in space, such as that needed to retrieve the film from the SIM cameras, is done in a very large water tank at MSC. See figure 77. A training mockup simulates the Command and Service Modules and the astronaut practices in a spacesuit.

Another camera in the SIM is the 3-inch mapping camera sketched in figure 78. It is really two cameras in a single assembly. Photographs of the

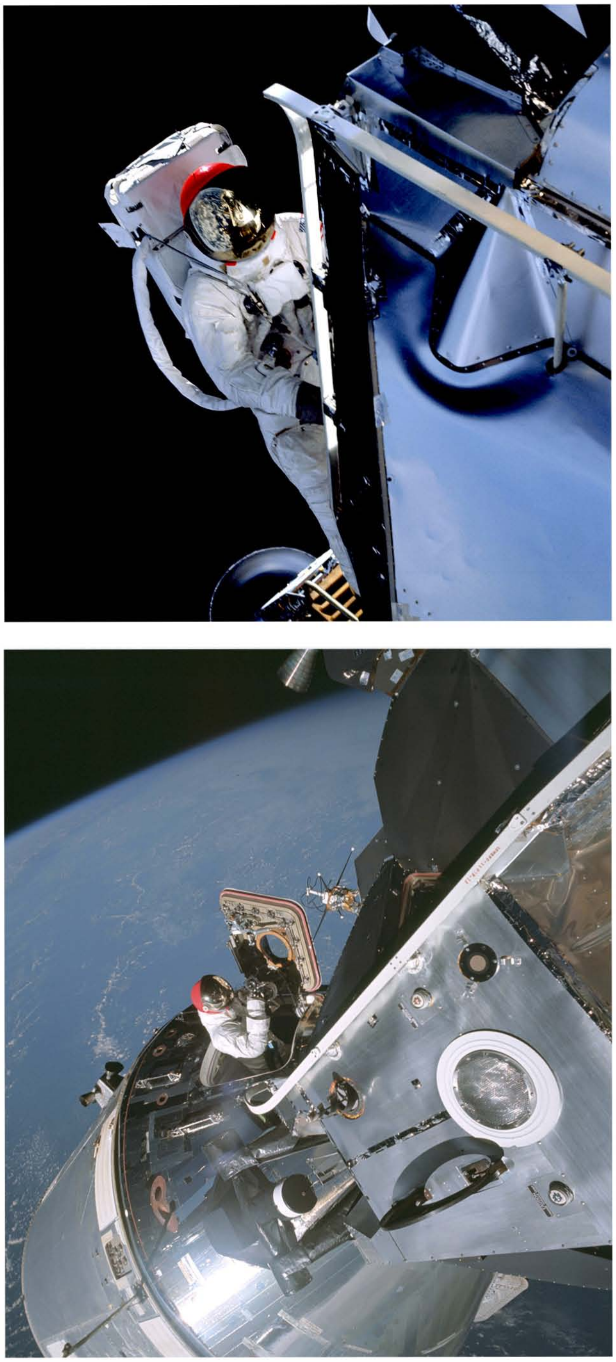

Figure 76.—EVA in space. Work in space when an astronaut is outside the protective shell of the spacecraft is always exciting. It is also dangerous and the astronaut must be extra careful. On Apollo 17, the film from the cameras in the SIM must be recovered in this way. Shown here is Astronaut Schweickert during an EVA on Apollo 9. The umbilical hose that connects him to the spacecraft furnishes oxygen and also prevents him from drifting away. Astronaut Dave Scott in the hatch is describing the activities of Schweickert and taking documentary photos. NASA PHOTOS AS9–19–2995 AND AS9–02–3064.

Figure 77.—Training for a space EVA. Shown here in the very large water tank is the mockup of a spacecraft. The CM Pilot practices in the reduced weight environment of the water. NASA PHOTO S–72–49971.

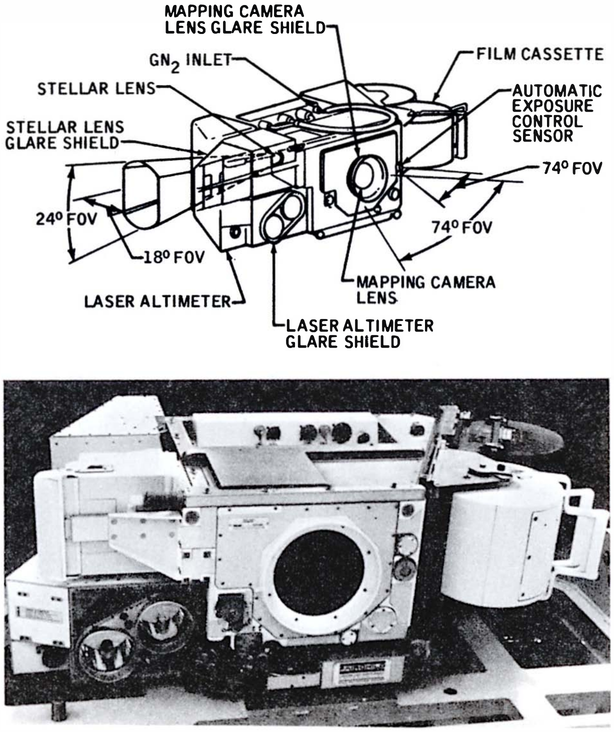

Figure 78.—Three-inch mapping camera and laser altimeter. This unit contains two complete cameras, one for photographing the Moon's surface, another for photographing the stars to obtain precise orientation of the camera in space at the time each photo is taken. The laser altimeter provides data on the altitude of the spacecraft with a precision of 1 meter (about 1 yard). The film cassette is retrieved by the CM pilot before the CM is separated from the SM. The location of this camera in the SIM bay is shown in figure 73. Above, we see a simple line drawing. Below, we see a photo of the camera. Gaseous nitrogen is used to maintain pressure in the camera.

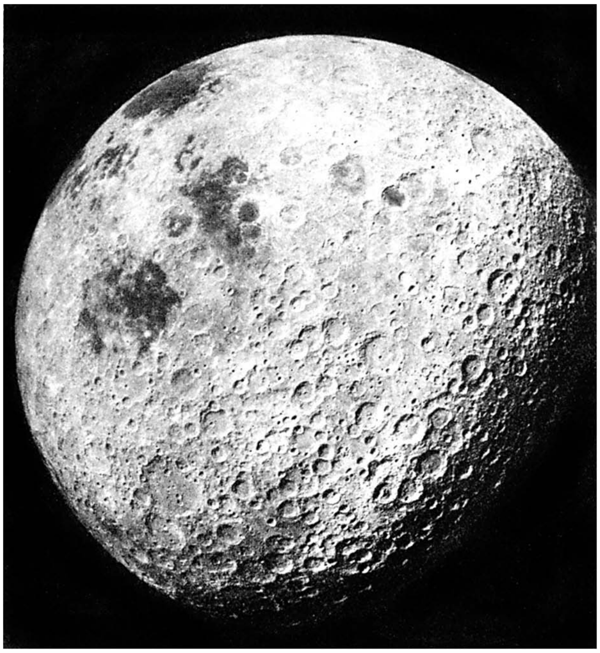

FIGURE 79.—Apollo 16 view of a near-full Moon. This view was photographed with the Apollo 16 Metric Mapping Camera shortly after the astronauts left lunar orbit on their journey towards the Earth. This view cannot be seen from Earth. We are looking generally westerly towards the large, circular Mare Crisium on the horizon. The more circular mare area is Mare Smythii. Most of the mare shown in this picture are on the side of the Moon opposite the Earth. Note especially the many craters with flat bottoms and central peaks. The central peaks are often 2 to 3 miles high. NASA PHOTO FRAME NO. 3023, APOLLO 16 METRIC CAMERA.

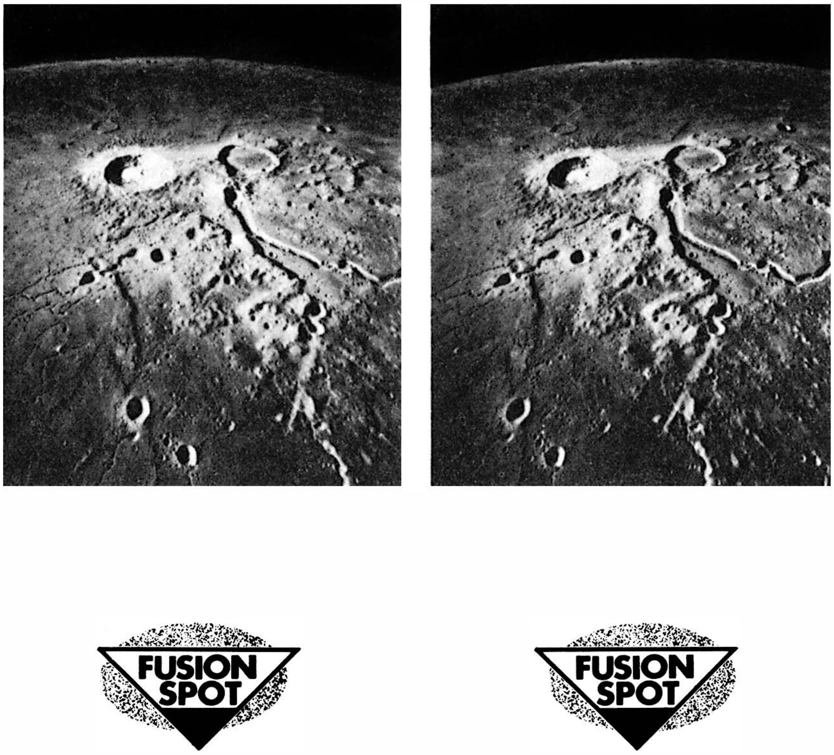

FIGURE 80.—Southward oblique view of Crater Aristarchus and Schroter's Valley. This stereo pair of photos was obtained on Apollo 15 with the mapping camera. See caption of figure 8 for instructions on stereo viewing. Arranged by Earl E. Krause. NASA PHOTO APOLLO 15 MAPPING CAMERA—FRAMES 2609 AND 2610.

lunar surface are obtained through the 3-inch cartographic lens and photographs of the starfield are taken through a different 3-inch lens pointed out to the side. From these stellar photographs, the exact orientation of the camera can be determined later. The mapping camera also has automatic exposure control, but forward motion compensation is manually controlled by the astronaut. Our purpose in using this camera is to locate very precisely the surface features of the Moon. The resolution is considerably poorer than that of the pan camera being only 60 feet. But the metric camera provides photographs with extremely small distortions and on which points can be located with very high precision. (A basic rule of camera design is that we cannot obtain in the same camera *both* the lowest distortion possible and also the maximum resolution possible! Hence we have used two cameras: one designed for high resolution, the other for high precision and minimum distortion.)

The film used in the 3-inch camera is an intermediate speed black and white film commonly used in aerial photography.

Shown in figure 79 is a photograph taken of a near-full Moon by the mapping camera on Apollo 16 shortly after the rocket burn that sent the spacecraft towards Earth. This view, which cannot be seen from Earth, is looking generally westerly. Another example of photography of the Moon with the mapping camera is shown in figure 80, a stereo photograph of the crater Aristarchus and Schroeter Valley.

The Laser Altimeter (LA)

The laser altimeter is used to obtain the elevation of the surface. It operates in much the same way that radar does. A pulse of light, produced by the laser, travels to the Moon's surface and is reflected back to a detector. The time of travel is measured. Since the speed of light is known (about 186,000 miles/second), we obtain the distance from the spacecraft to the Moon's surface. The orbit of the spacecraft is monitored continuously with tracking stations on Earth. The position of the spacecraft is known with rather high precision—say a few feet. The laser altimeter gives the distance between the spacecraft and the Moon's surface with a resolution of about 3 feet. Thus by substraction, we get the elevation of the lunar surface.

The results of the Apollo 15 laser altimeter for one revolution are shown in figure 81. They are very exciting. Analysis of those results shows that the center of mass of the Moon is displaced about 1½ miles from the center of volume in a direction that is approximately midway between Mare Serenitatis and Mare Crisium. We have known for about 2 years that these two maria are the sites of the two largest gravity anomalies on the front side of the Moon. (See the section "S-Band Transponder" for the discussion of gravity on the Moon.)

The two lowest elevations along the single revolution of Apollo 15, about 2½ miles, are in Mare Crisium and Mare Smythii. There were earlier indications (from the land mark tracking data) that Mare Smythii was topographically low. The Apollo 15 laser data showed clearly that the ringed Maria Serenitatis, Crisium, and Smythii are truly basins and are 1¼ to 2½ miles deep, Oceanus Procellarum is rather smooth and is depressed about ½ mile. The Apennines are rather high standing, about 1½ miles.

Apollo Lunar Sounder Experiment (ALSE)

The Apollo Lunar Sounder Experiment (ALSE) uses radar techniques to see into the Moon, possibly to a depth of 1½ km. Radio waves at one of three different frequencies (5, 15, and 150 Megahertz) are radiated from antennas mounted on the Service Module (SM) and shown schematically in figure 82. After a very short time, less than one-thousandth of a second, the transmitter is turned off and a radio receiver is turned on. The radio wave travels to the surface of the Moon where some of it is reflected and some enters the Moon. The portion that enters the Moon may be reflected by layers of rock within the Moon. The various reflected parts of the radio wave are detected by the antennas and delivered to the receiver where they are amplified and then recorded. The character of the reflected waves can tell us a great deal about the subsurface layers and the time needed for return tells us the depth of the layers.

After the radio signal has been amplified in the receiver, it is then converted to *light* signals and recorded optically on photographic film. Location of the optical recorder, as well as the other equipment for ALSE, is shown in figure 73. The film is

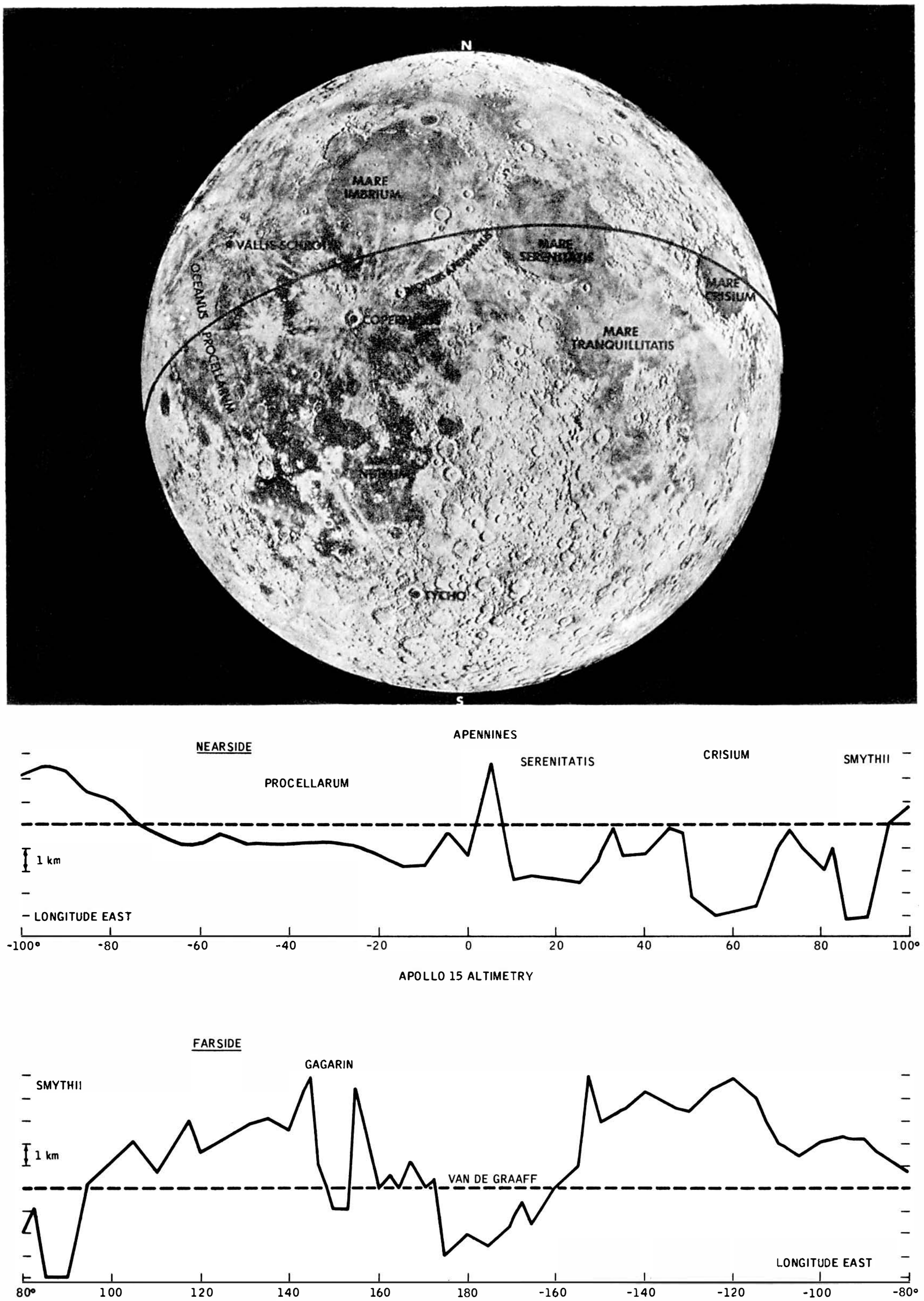

FIGURE 81.—Results of the Apollo 15 Laser Altimeter. Data are shown for one revolution only. The elevation of the surface of the Moon along that single ground track (above) is shown in diagram. The dashed line represents the elevation of a sphere with radius of 1737 km. Based on work of William Kaula in the Apollo 15 Preliminary Science Report. NASA PHOTOS S-72-16337 AND S-72-16322.

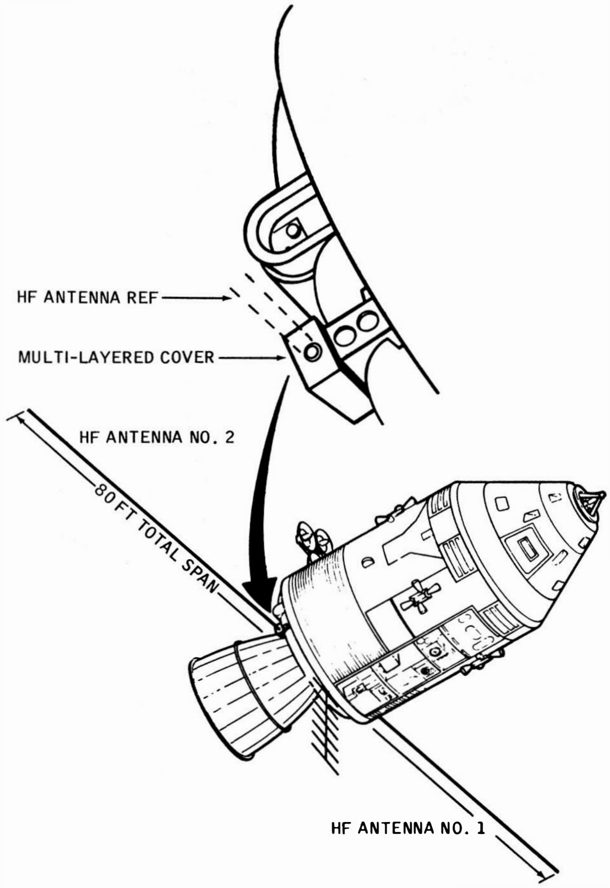

FIGURE 82.—Apollo Lunar Sounder Experiment. Two antennas are used, a dipole antenna with an 80 foot tip-to-tip length for use at 5 and 15 MHz and a Yagi for use at 150 MHz. During operation of the ALSE, the spacecraft orientation must be carefully controlled so that the Yagi points toward the ground track. NASA PHOTO S–72–49034.

retrieved by the CM pilot during an EVA in space and brought back to Earth for analysis. The job of building the optical recorder was not easy. In addition to the usual difficulties of building any equipment that must operate extremely reliably in the hostile environment of space, the equipment had to record very large quantities of data with high precision, very low noise, and high reliability. The external appearance of the optical recorder is seen in figure 83. The schematic diagram, showing how the recorder works, is shown in figure 84.

The antennas used in the ALSE are shown in figure 82. The short one is a Yagi. It is similar to the Yagi antennas that are so common on housetops and used for reception of television signals. The chief difference is that the ALSE Yagi is tuned for the frequency of 150 Megahertz. The other one, 80 feet tip to tip, is a dipole antenna, tuned to handle both 5 and 15 Megahertz signals. (Dipole antennas are discussed in the SEP section.)

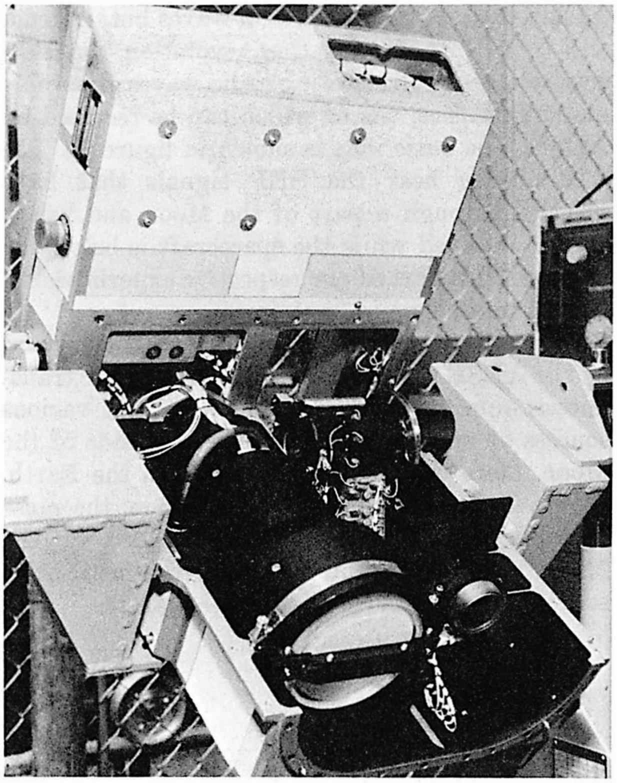

FIGURE 83.—ALSE optical recorder. The external appearance of the recorder is seen in this photo taken during a series of tests. The film in a cassette, not shown here, is removed by the CM pilot during an EVA in space and stowed in the CM for return to Earth. NASA PHOTO S–72–49482.

The ALSE will provide extremely valuable information obtained over a large area on the Moon with very good resolution. Data with which to "look" inside the Moon will be taken for a total time exceeding 10 hours. Any large changes in the electrical properties of the Moon—such as might be associated with a large deposit of iron (or other ores) would be seen easily. The thickness of the regolith will be measured over the total path around the Moon. Other layers, such as basalt flows, within the depth of 1½ km. will be detected and measured by ALSE. And of course, the presence of any water in the lunar subsurface (even less than 1 percent) would be seen easily.

One very exciting possibility for the team members of both ALSE and SEP is a combination experiment. During one revolution of the CSM, the

ALSE will not transmit radio waves but, instead, will listen only. During that revolution, the SEP transmitter will be sending radio waves at its normal frequencies, one of which can be received by ALSE. The basic idea is shown in figure 85. The ALSE *may* hear the SEP signals that have traveled through a part of the Moon and hence, will be received while the spacecraft is below the horizon. This part of our respective experiments is termed an occultation experiment.

One revolution around the Moon will be devoted by the ALSE to listening but with the SEP transmitter quiet. ALSE will listen to the various sources of noise in space. On the earthside of the Moon, there will likely be noise from the Earth. However on the backside of the Moon, the noise from Earth will probably be shielded by the Moon. We already know that electromagnetic noise sources exist in the Sun and other planets.

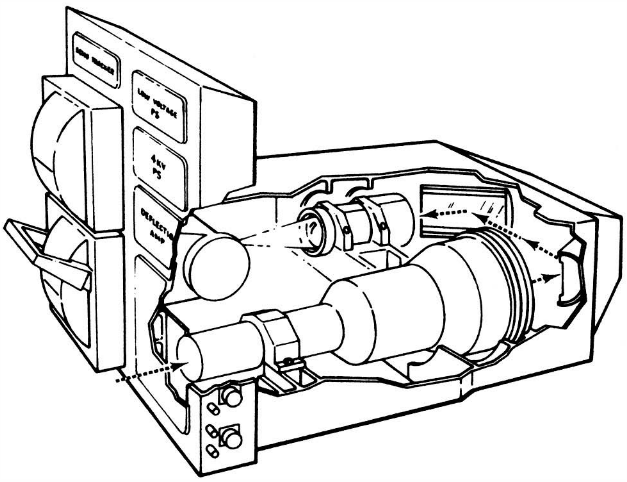

FIGURE 84.—Schematic diagram of the ALSE optical recorder. NASA PHOTO S–72–50317.

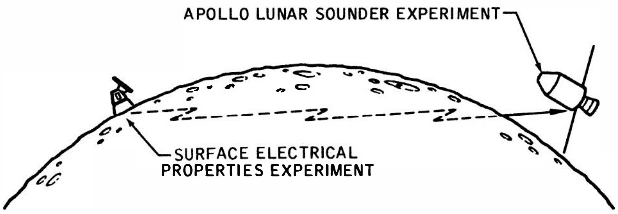

FIGURE 85.—Occultation experiment of SEP and ALSE. The surface electrical properties experiment will be used to transmit radiowaves. The Apollo lunar sounder experiment will listen. The radiowaves may propagate many kilometers through the Moon and be heard while the ALSE is below the lunar horizon. NASA PHOTO S–72–50316.

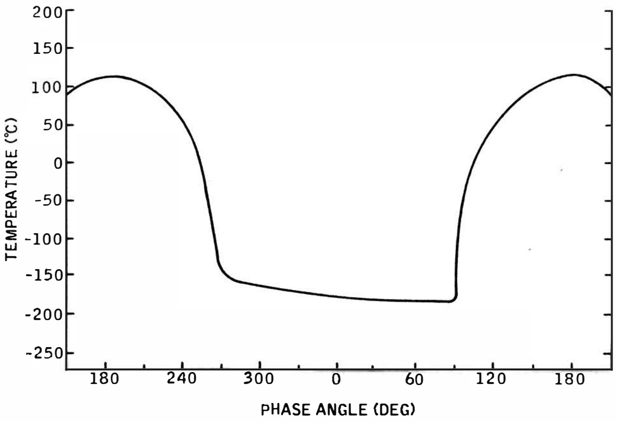

FIGURE 86A.—Temperature of the Moon. The average temperature of the Moon as a function of phase, or time, is shown here. The exact shape of the curve varies somewhat with geographical position on the Moon and is determined by the thermal properties at each position.

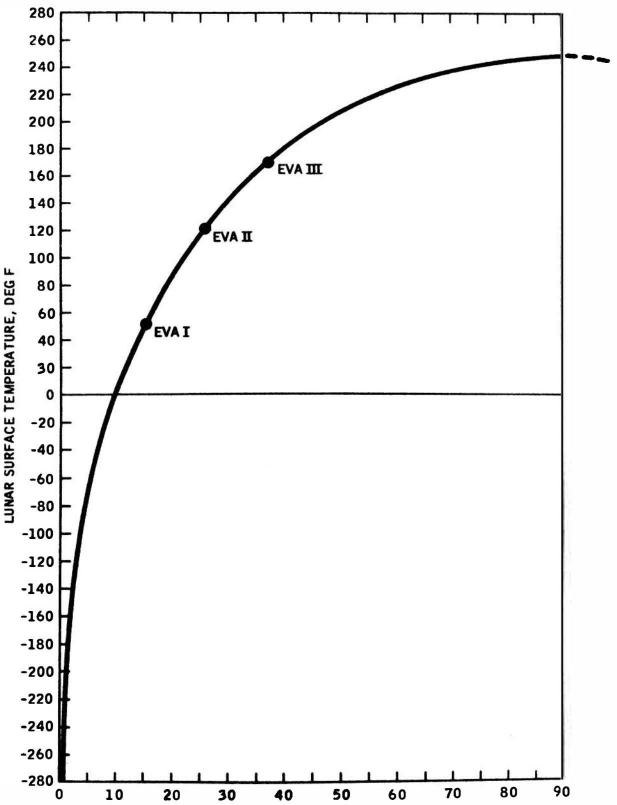

FIGURE 86B.—The temperature of the Taurus-Littrow site shown as a function of the Sun angle. Note that EVA 1 at +17° Sun angle should have +50° F, EVA 2 at +27° Sun angle should have +110° F, and EVA 3 at +37° Sun angle should have a temperature of +160° F.

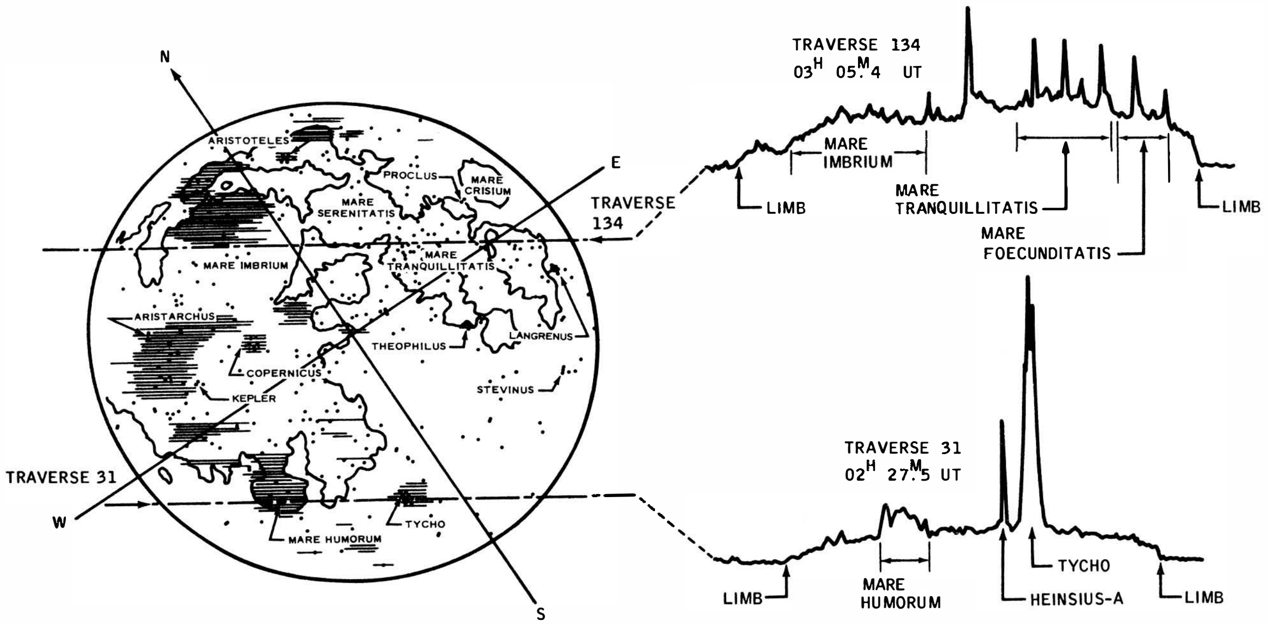

Figure 87.—Thermal Anomalies on the frontside of the Moon observed during an Eclipse. Saari and Shorthill used an automatically controlled telescope and high precision, fast-response circuits to measure the temperature of the Moon during an eclipse in 1966. Their resolution was about 15 km. Shown here is a map of the thermal anomalies (dots and lined regions on the map). Two selected scans are shown on the right side of the figure to indicate the sharp variation in temperature. Note especially the extreme thermal anomaly associated with the crater Tycho. FIGURE COURTESY OF RICHARD SHORTHILL.

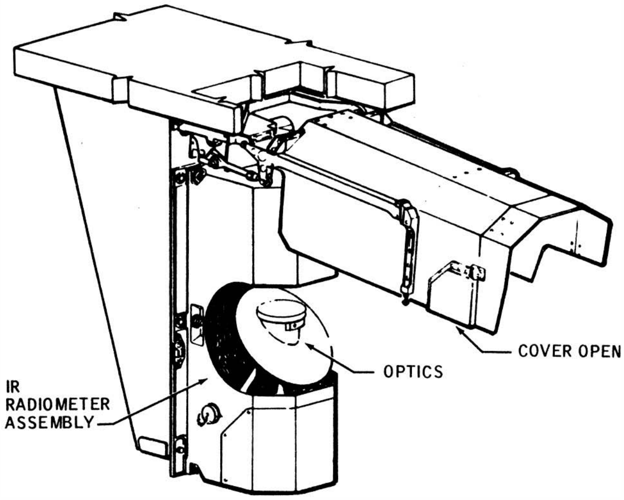

Figure 88.—External appearance of infrared scanning radiometer. This equipment is mounted in the SIM Bay.

Infrared Scanning Radiometer (ISR)

The exact temperature of the surface of the Moon has been of interest for many years. It was first measured in 1930 by Pettit and Nicholson. They used an electronic thermometer located at the focus of a telescope which was trained on the Moon. Data taken years later with the same technique but more refined equipment repeated their results but with higher precision and resolution. The temperatures actually measured on the surface of the Moon with thermometers onboard spacecraft have further confirmed the earth-based measurements. The temperature of the Moon is shown as a function of the phase of the Moon in figure 86. Notice that the coldest temperature is about − 200 °C., the hottest about +100 °C.

The shape of the temperature curve, when measured over a small area on the Moon rather than the entire Moon, changes somewhat. Indeed, the *exact* shape depends critically upon the thermal properties of the Moon's surface. Much can be learned about the Moon from measurements of its thermal properties. One way to measure the thermal properties of Moon rocks on the Moon would be to suddenly turn off the Sun's radiation and to measure the surface temperature of the Moon. Nature helps us with just such an experiment by providing eclipses of the Moon by the Earth. During such an eclipse in 1966, Jack Saari and Richard Shorthill of the Boeing Co. obtained temperature scans of a large portion of the frontside of the Moon. The resolution on the surface of the Moon of their telescope (when pointed at the center of the Moon) was an area about 15 km. square. Some of their results are indicated in figure 87. More than 1,000 thermal anomalies—spots on the Moon that showed a temperature significantly in excess of the surrounding region—were discovered. Many of the thermal anomalies, or hot spots as many people prefer to call them, correlated well with known geographical features. Others, however, showed no correlations with visible features.

The chief purposes of the Apollo 17 Infrared Scanning Radiometer (ISR) Experiment are to determine the temperature with high precision and high ground resolution along the ground track of several orbits of the Apollo 17 Mission and to correlate the derived thermal properties with geographical features. But you ask, "How can the temperature of the surface of the Moon be measured from a spacecraft that is 60 nautical miles from the surface?" In much the same way that the temperatures of the Moon were measured by Pettit and Nicholson in 1930 at a distance of some 240,000 miles. A sensitive thermometer is mounted at the focus of a telescope. The external appearance of this equipment is shown in figure 88. The schematic is shown in figure 89.

Let's trace the light path through the telescope. Light enters the telescope from a mirror that is attached to a motor. The mirror oscillates back and forth in such a way that the spot on the Moon's surface, as seen by the telescope, moves across the ground track. The light passes through the various mirrors, baffles, and lens of the telescope, which is termed a Cassegrain folded telescope, to a detector. The detector is a thermistor, a very small solid state device—similar in some ways to the solid state devices used in your home TV sets—which changes the radiant energy into an electrical signal. The electrical signal is related to the temperature of the spot on the surface of the Moon which is viewed by the telescope. This system must be accurately calibrated before it is flown to the Moon. But in addition, it is calibrated at two temperatures many times during the mis-

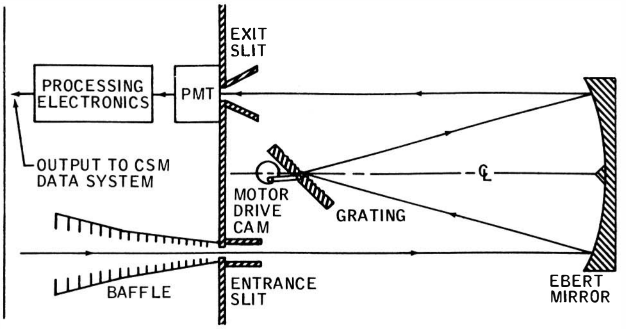

FIGURE 89.—Schematic of infrared scanning radiometer. A plane mirror rotates about the axis of the telescope to provide cross-track scanning.

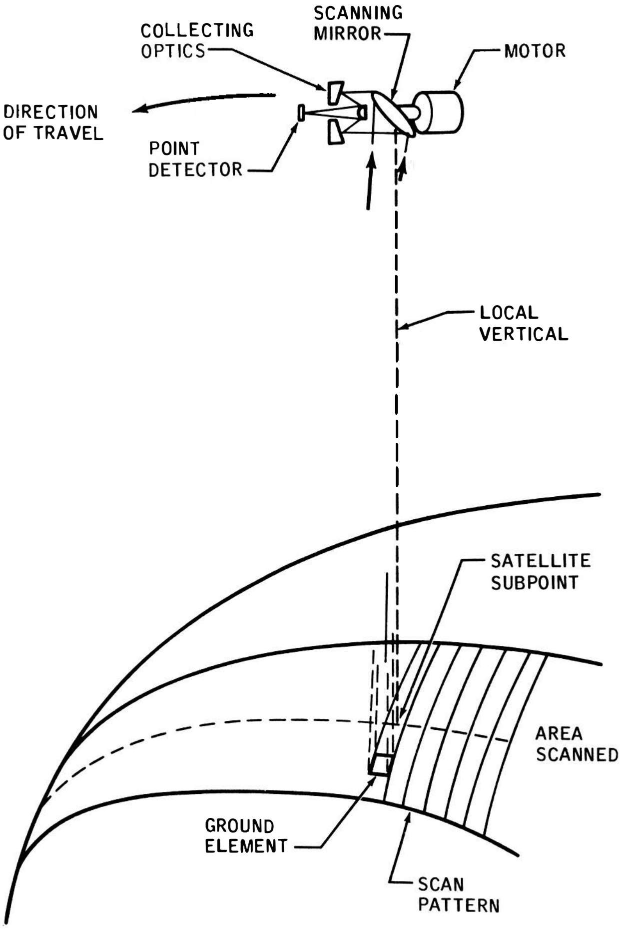

FIGURE 90.—Scanning relation for the IR scanning radiometer.

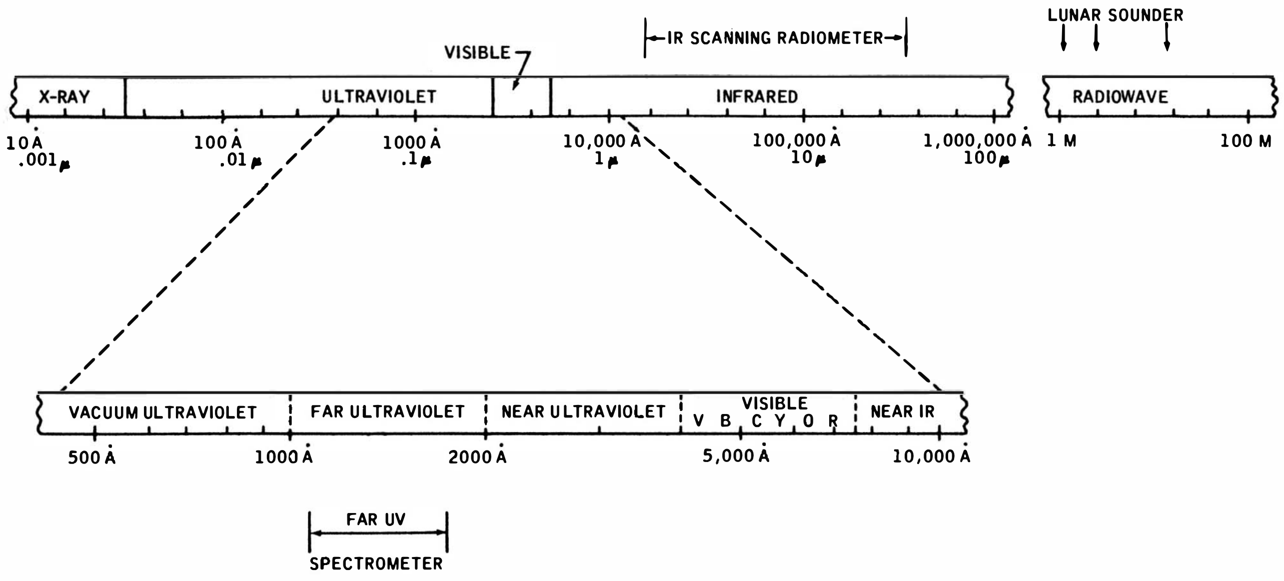

FIGURE 91.—A portion of the electromagnetic spectrum. Because the wavelength of the radiation changes so greatly over the spectrum, different units are most convenient for different portions of the spectrum. The Angstrom, Å, is 10^{-10} meters. The micron, μ, is 10^{-6} meters. The spectrum extends to still shorter, as well as longer, wavelengths. The FUS examines radiation over the spectrum from 1180 Å to 1680 Å. Shown also are the regions used by ISR and the Lunar Sounder.

sion. The mirror views briefly the inside of the equipment for one calibration temperature. It views deep space, which has a known effective temperature, for the second calibration point.

The relation of orbiting spacecraft to the area scanned by the ISR is shown in figure 90. Oscillation of the mirror causes the area "seen" on the Moon to move across the ground track of the spacecraft. The field of view of the telescope is such that the surface resolution is about 2 km. Temperatures can be recorded over the range of −213 °C. to +127 °C. The sensitivity is rather high, about 1 °C.

This experiment has many advantages over earth-based measurements. Most important are the greatly increased spatial resolution (2 km. versus 15 km.) and the ability to obtain data on the backside of the Moon.

Far Ultraviolet Spectrometer (FUS)

Electromagnetic waves vary greatly in wavelength, extending from wavelengths shorter than X-rays to those longer than the familiar 60-cycle household power. The wavelength of X-rays is measured in Angstroms, 10^{-8} cm. The wavelength of 60-cycle power is 5,000 km., one-eighth the circumference of the Earth. A portion of the electromagnetic spectrum is shown in figure 91, where you can see that the wavelength of the ultraviolet is shorter than the wavelength of visible light. Incidentally, the black light that has become popular in recent years occurs in the near ultraviolet region.

The primary objective of the Far UV Spectrometer (FUS) is to determine the lunar atmospheric composition and its density. Other important objectives are these: to determine lunar surface characteristics in the ultraviolet region and their geographical variation over the surface of the Moon—to measure the fluorescence of the Moon on its dark side—to measure the contributions to the lunar atmosphere by the LM's engines—to measure the ultraviolet radiation of our galaxy—and to measure the far UV component of zodiacal light.

From data taken previously on the surface of the Moon, from orbiting vehicles, and from the Earth, we know that the Moon's atmosphere is extremely tenuous (when compared with the Earth's atmosphere). The way that the Moon's atmosphere bends radiowaves, which in free space always travel in

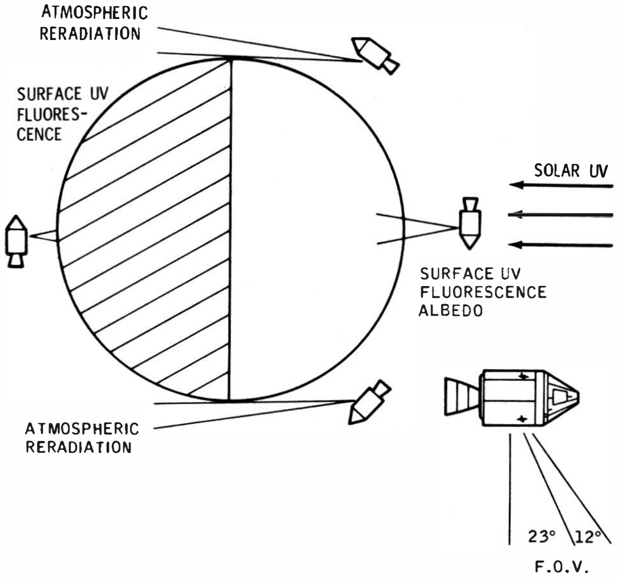

FIGURE 92.—Orientation of CSM during operation of Far UV Spectrometer. Near the terminator, the spacecraft is turned so that the field of view of the FUS is directed towards the Moon's dark side. This procedure minimizes the amount of direct radiation received from the Sun and maximizes that received from atmospheric reradiation. NASA PHOTO S–72–50285.

perfectly straight lines, indicated that the total pressure was less than 10^{-10} torr*. Actual measurements of the pressure by the cold cathode ionization gauge (a commonly used technique for measuring very low pressures in the laboratory) on Apollos 12, 14, and 15 showed that the total pressure was less than 10^{-11} torr. The CCIG equipment has also shown that there are sporadic increases in total pressure of 10 to 100 times the normal lunar atmospheric pressure and the large variations in pressure occur between lunar day and lunar night.

The Mass Spectrometers carried in the CSM on Apollos 15 and 16 showed clearly that a contamination cloud of gases surrounds the CSM in lunar orbit but does not accompany the CSM during its journey to and from the Moon. Furthermore, there is a large variation from day to night in lunar orbit. And finally, we have measured an upper limit for the abundance of neon-20, the major gaseous component in the Moon's thin atmosphere, at a height of 100 km. It is about 2,000 atoms per cubic cm. with a maximum density at the surface of the Moon of about 100,000 atoms per cubic cm. The maximum occurs at lunar night time.

You undoubtedly wonder how an instrument that measures electromagnetic radiation can determine composition. The principle is easy to understand and I think interesting. Let me explain it in some detail. An atom of any element can absorb energy of only certain wavelengths. In turn, the atom that has absorbed additional energy can release the energy by radiation only at the same wavelengths. This process is termed resonance reradiation. Thus an atom in the lunar atmosphere will receive energy from the Sun, absorb that energy, and then release the energy by reradiation. The reradiated energy—at its characteristic wavelength—is then detected and measured by the FUS equipment. So by measuring the wavelengths of the energy that is reradiated by the lunar atmosphere, we can determine which elements are present in the lunar atmosphere. The characteristic wavelengths of a few elements are:

Hydrogen	1216 Å
Carbon	1657 Å
Nitrogen	1200 Å
Oxygen	1304 Å
Krypton	1236 Å
Xenon	1470 Å

In this experiment, we wish obviously to minimize the amount of radiation that is received by the equipment directly from the Sun and to maximize the amount of energy that is received by reradiation from the lunar atmosphere. So on those orbits on which the FUS is operated, when the spacecraft is near the terminator (the separation between the sunlit and the dark regions of the Moon), it will turn so that the field of view of the FUS is looking directly away from the Sun as shown in figure 92.

While the spacecraft is on the dark side of the Moon, the FUS will measure fluorescence of the lunar surface as a function of geographic position. Those data will surely be interesting. But perhaps we will be fortunate enough to obtain UV data on one of the infrequent "transient events." In rare sightings, astronomers have reported seeing through Earth-based telescopes, short lived changes in the visible appearance of a few spots on the Moon. For example, such transient events

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*Torr is a unit of pressure commonly used for pressures less than atmospheric, i.e. vacuum. One torr is equal to the pressure exerted by a column of mercury that is 1 mm high and in the normal Earth's gravity field. From weather telecasts, you may know already that the Earth's atmospheric pressure is about 760 mm. Hg. (or equivalently 760 torr). The Moon's atmospheric pressure is therefore less than 10^{-13} times that of the Earth's atmopheric pressure!

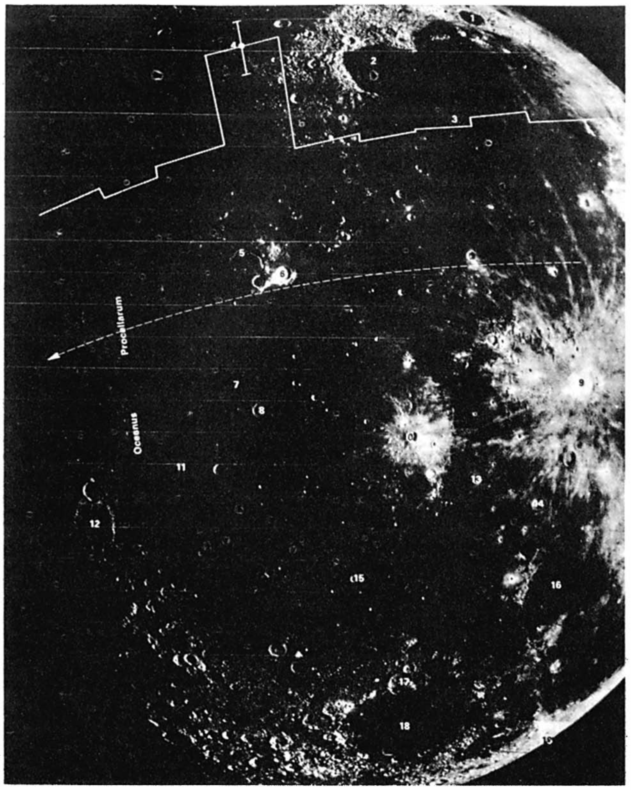

FIGURE 93.—Distribution of the count rate of Alpha particles from the decay of radon as a function of longitude. The solid line indicates the count rate, the dash line the ground track. The feature marked 6 on the figure is the crater, Aristarchus. COURTESY GORNSTEIN AND BJORKHOLM.

have been seen at the craters Aristarchus, Copernicus, and Kepler. These craters are all near the Apollo 17 ground track. So with luck, we just may obtain data with the FUS that will help us understand the cause of transient events.

Incidentally, the crater Aristarchus, shown in figure 80, is extremely interesting. It is one of the craters from which volcanic emissions—hot gases in this case and not liquid rock—have been observed. A Russian astronomer first measured about 15 years ago the spectra of the gases. Aristarchus also shows a significant thermal anomaly on the scans made by Saari and Shorthill. And even more recently one of the instruments carried in the Apollo 15 CSM, the Alpha-particle Spectrometer, detected the gas radon being emitted from the crater Aristarchus. In figure 93, reproduced from Gornstein and Bjorkholm, the correlation of the number of alpha particles from radon decay with the crater Aristarchus is unmistakable.

The FUS is carried in the SIM bay. Its location is shown in figure 73. Its sensitivity is very high. For example, it will detect reliably as few as 10 atoms of hydrogen per cubic cm. at the surface of the Moon, 100 for carbon, 200 for oxygen, 250 for xenon, and so on. The equipment is shown in an exploded view in figure 94 and in schematic form in figure 95. Let's trace the light path through the spectrometer, using figure 95. Radiation enters the spectrometer through the baffle which is really a telescope that limits the field of view to a few degrees. The webs in the baffle prevent scattered radiation from the surfaces of the baffle from entering the spectrometer. The radiation strikes the Ebert mirror and is reflected to the grating. An optical grating is a very flat surface on which many lines have been cut. The grating for the FUS is a mirror with 36,000 lines per cm. (about 90,000 lines per inch). The light is reflected from the grating back to the Ebert mirror where it is again reflected and finally travels through an

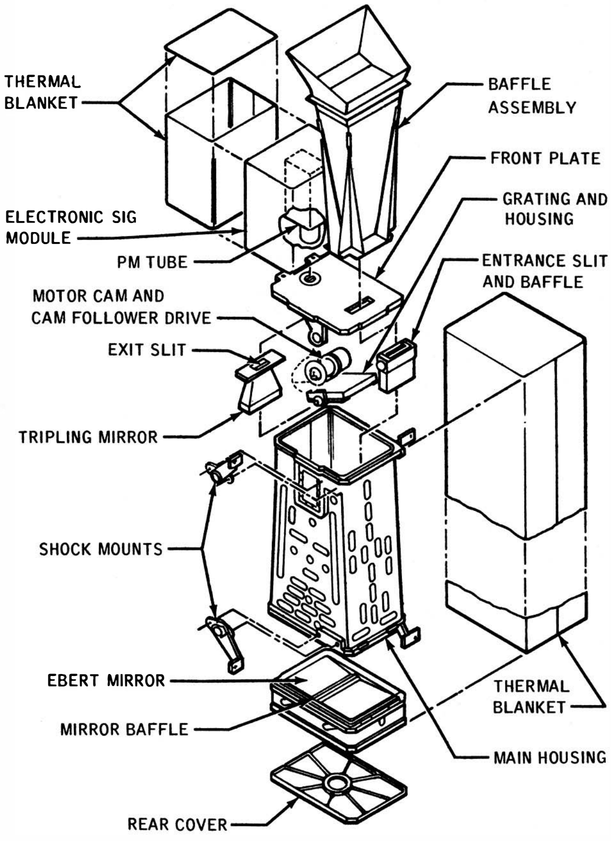

FIGURE 94.—Far ultra-violet spectrometer. Shown here is an exploded schematic view.

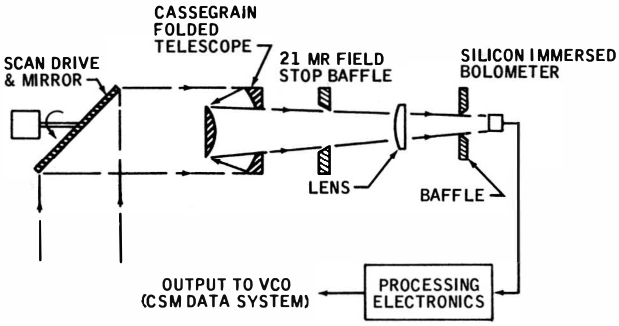

FIGURE 95.—Far ultra-violet spectrometer schematic. The individual components of the far UV spectrometer are shown here in schematic form. The path of the radiation through the equipment follows the line with arrows. See text for further discussion.

exit slit. It is then detected and measured by a light sensitive device termed a photomultiplier tube. The photomultiplier tube produces an electrical signal that is related to the intensity of the incident light. The electrical signal is processed through various electronic devices into a form that is suitable for transmission back to Earth.

A spectrometer measures the intensity of radiation as a function of the wavelength. In the FUS, the motor and drive cam cycle the grating through the wavelength range from 1180 A to 1680 A.

S–Band Transponder (SBT)

With the S-band transponder we measure very small *variations* in the Moon's gravity. I am sure that you know the Moon's gravity is only about one-sixth that of the Earth's. But did you know that the exact value changes significantly over the face of the Moon?

In order to see how the SBT works, think about the following situation. Suppose that the Moon is like a ball, perfectly round and homogeneous throughout. For a circular orbit around such an ideal Moon, there would be no variations in the velocity of the spacecraft. But suppose that we have at one spot buried just beneath the surface a very large chunk of material with very high density. Just for thinking purposes, let's suppose that this large chunk is 50 miles across and is twice as dense as the rest of the Moon. Consider figure 96. As the spacecraft approaches the dense chunk, at position 1, there is a gentle tug in the forward direction due to the gravitational attraction between the spacecraft and the dense chunk. That slight tug is enough to cause the CSM to speed up slightly. At position 2, all of the force is directed downward and there is no net increase, nor decrease in the horizontal velocity of the CSM. Finally in position 3, the spacecraft experiences a backwards pull on it and accordingly, the velocity decreases slightly. Now this change, even though it is very small, in the velocity of the orbiting CSM can be measured with extremely high precision.

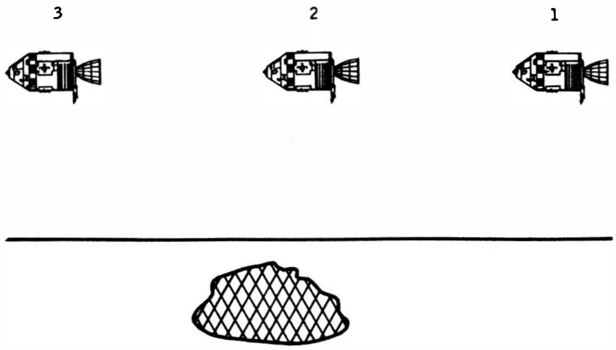

FIGURE 96.—Effect of density on spacecraft velocity. Suppose that a large chunk of material of high density is buried beneath the surface of the Moon. The spacecraft at position 1 will be pulled gently forward by it. At position 2, there will be only a net downward force and no horizontal force. At position 3, the high density material will pull gently backward on the spacecraft. Because of these forces the spacecraft speeds up slightly at 1 and slows slightly at 3. Of course these changes to the velocity of the spacecraft are really very small but can be easily measured with electrical means. See further discussion in text.

These high precision measurements of the changes in velocity are obtained in the following way. From Earth, a radio wave of very stable frequency * of 2115 MHz is transmitted to the orbiting spacecraft. When the radio wave is received by the spacecraft, the frequency is multiplied by the constant 240/221 (for electronic reasons) and then retransmitted to Earth. The frequency of the signal when it arrives back on Earth, though, is usually slightly different from the original fre-

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* The unit megahertz is one million cycles per second. I am sure that you are already familiar with the concept of frequency; exactly the same concept is used for AM radio (frequency of .54 to 1.6 MHz), FM radio (frequency 88 to 108 MHz), VHF television (frequency 54 to 216 MHz), UHF television and so on. The frequency that we use for the S-band transponder experiment is somewhat higher than any of those, but the concept is exactly the same.

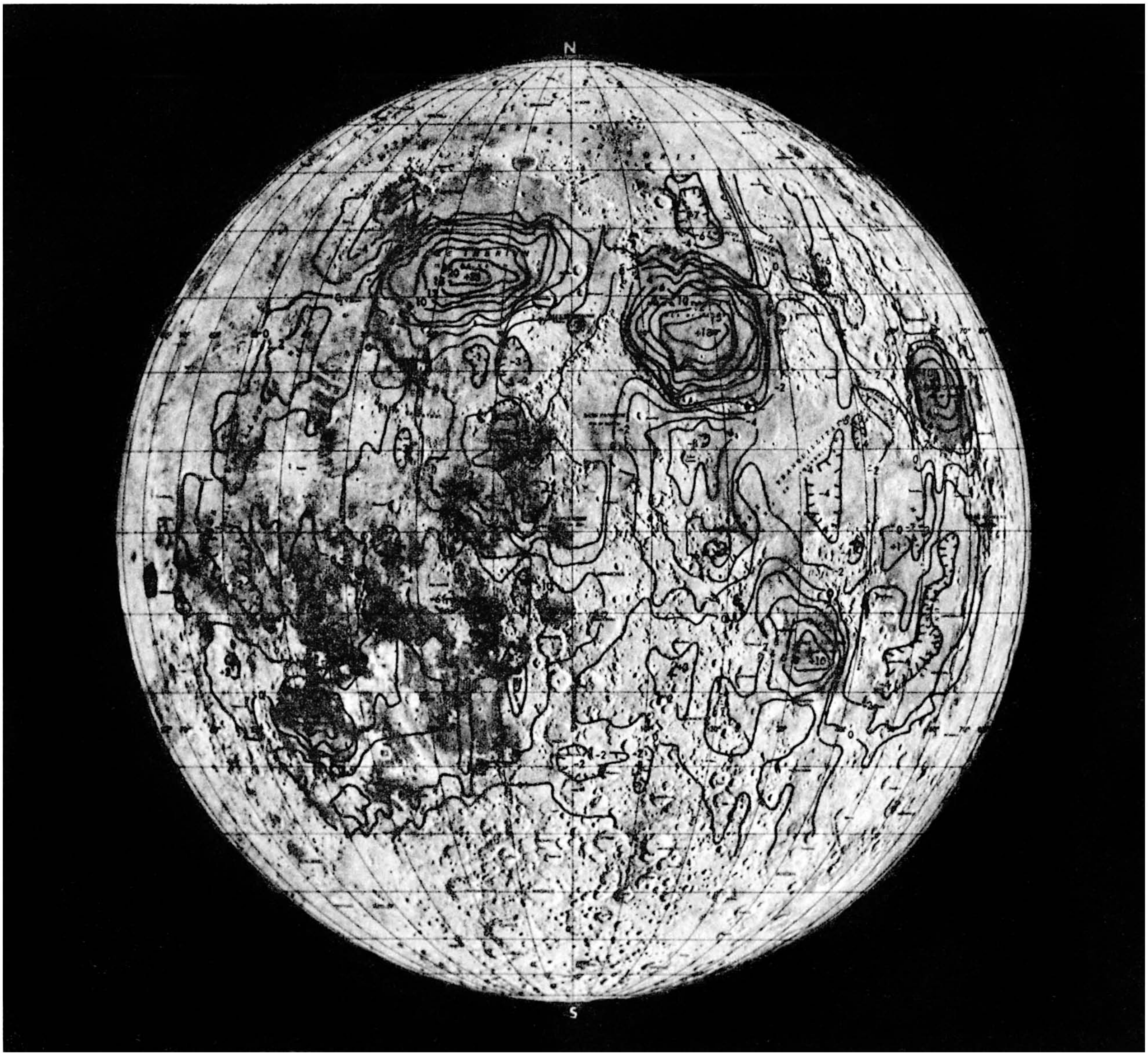

FIGURE 97.—Lunar gravity. These lines, called contour lines, show the departures from "normal" gravity on the front side of the Moon. The units are 10 milligals. The difference between adjacent lines, termed contour interval, is 20 milligals. To obtain total gravity, you must add the usual 1/6 of the Earth's gravitational field to these values. Muller and Sjogren, working at the Jet Propulsion Laboratory, first found these very large variations in the Moon's gravitational field by measuring the very small changes in the velocity of orbiting spacecraft. Notice the excellent correlation between the gravitational features and the surface features of the Moon. The discovery of these variations in the gravitational field surely ranks as one of the most important in Lunar Science. NASA PHOTO S–72–16340.

quency multiplied by 240/221. Let's see why. The radio waves sent by a moving source (the CSM) behave in exactly the same way as sound waves sent by a moving source. I am sure that most of us recall that a whistle on a train changes pitch considerably when the train passes us. The whistle is higher in pitch when the train is approaching than when it has already passed. The same phenomenon, termed Doppler shift, occurs when radio waves are transmitted from a moving source. In fact, the shifts that are observed are sometimes as large as several Hertz. We measure these shifts with a resolution of 0.01 Hertz. Thus we are able to measure very small changes in velocity of the spacecraft.

The basic data of the SBT experiment are the variations in velocity of the spacecraft along its path. From them, we deduce the changes in the Moon's gravitational field. This technique has been used on many of the spacecraft that have orbited the Moon. The earliest was done on the Lunar Orbiter series with the intriguing result shown in figure 97. Shown in that figure are the *variations* in gravity. The main part of the gravity field has been subtracted from these data and we are looking only at the *departures* from normal gravity. I personally think the discovery by Paul Muller and William Sjogren of the Jet Propulsion Laboratory of these variations of gravity over the face of the Moon ranks as one of the most important scientific discoveries about the Moon. On Apollo 17, the S-band transponder experiment will obtain data from both the orbiting CSM and the LM.

One big advantage of this experiment is that it allows us to "see" below the surface of the Moon. The differences in density of the rocks beneath the surface of the Moon produce the differences in the gravitational field which, in turn, affects the velocity of the spacecraft. Thus we have a tool with which to examine the distribution of the rocks beneath the surface of the Moon. It is a tool that we have found to be very effective in our exploration of the Earth's crust. We are especially anxious to see whether there are large variations in density beneath such topographic features of the Moon as the large craters.

Window Meteoroid Experiment (WME)

Many photographs and visual observations are taken *through* the Command Module windows. In order to prevent distortion of the photos and of the visual images by the windows, they are very carefully prepared of optical quality glass and the surfaces are polished to the same perfection as spectacle lenses. The outer surfaces of the windows are ideal detectors for micrometeroids. They are very carefully examined microscopically both before and after each mission. Particles as small as one-thousandth millimeter diameter (about 50 millionths of an inch) can be detected by the small pits produced on impact. A total of 10 possible meteoroid impacts have been found on the windows from previous missions—five on Apollo 7, one each on Apollo 8, 9, and 13, and two on Apollo 14.

The Crew

The prime crew consists of Gene Cernan, Commander, Harrison H. Schmitt (better known as Jack Schmitt), LM pilot, and Ron Evans, CM pilot. Cernan was pilot on the two-manned Gemini 9 Mission, backup pilot for Gemini 12, backup LM pilot for Apollo 7, and the LM pilot on Apollo 10 (in 1969). You may recall that Apollo 10 was the first really comprehensive lunar orbital flight test of the LM. On that mission, the LM separated from the CM in lunar orbit and descended to within 8 nautical miles of the lunar surface. Cernan has logged more than 264 hours in spaceflight. He was the backup commander for Apollo 14.

Jack Schmitt is the first geologist to visit the Moon and to study its rocks at first hand. The son of a mining geologist, he is eminently qualified. He has studied at the California Institute of Technology, University of Oslo in Norway, and Harvard University. He has logged more than 1200 hours in jet aircraft. He worked as a geologist in Norway, in southeastern Alaska, and in the U.S. Geological Survey's Astrogeology Branch at Flagstaff, Ariz. He served as backup LM pilot for Apollo 15.

Ron Evans has served as a member of the astronaut support crews for Apollo 7 and 9 and as backup CM pilot for Apollo 14. He has accumulated more than 3,500 hours in jet aircraft.

The Apollo 17 backup crew consists of John Young, Stu Roosa, and Charlie Duke. Each of them has flown to the Moon before—John Young and Charlie Duke visited the Moon's surface on Apollo 16, only a few months ago, and Roosa was

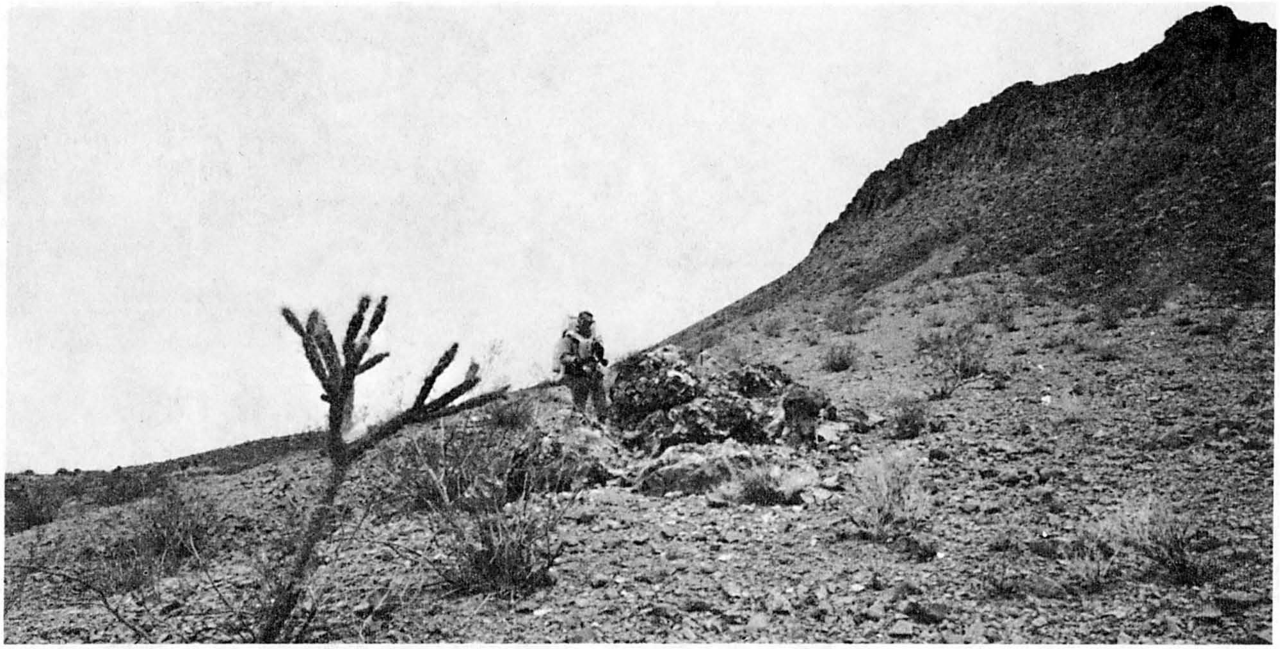

FIGURE 98.—Astronaut Gene Cernan studies geology. This photo was taken during training exercises near Boulder City, Nev. The American West is an excellent place to study geology because the vegetation is sparse and the rocks are very well exposed. NASA PHOTO S–72–30176.

the CM pilot on Apollo 14, 2 years ago. Several photographs of the prime and backup crews are shown in figures 98 through 107.

This crew, like previous ones, has undergone intensive training during the past few months and somewhat more casual training during the last few years. In addition to the many exercises needed to learn to fly their spacecraft proficiently, the astronauts have learned much about science, and in particular, about lunar science. After all, they will each spend many hours on the Moon or in orbit around the Moon performing scientific research.

The surface astronauts have had tutorial sessions with many of the nation's best scientists. They are able to set up experiments, such as those of ALSEP, but more importantly, they understand the scientific purposes behind the various experiments.

Most of the time on the lunar surface during Apollo 17 will be spent observing geologic features and collecting samples. Obviously anyone can pick up rocks with which to fill boxes and bags. Only a person highly trained in the geosciences, however, can properly select those few rocks, from many, that are likely to yield the greatest scientific return when examined in minute detail in the laboratory back on Earth. The Apollo 17 crew has spent many hours studying rocks under the guidance of geologists from the U.S. Geological Survey, several universities, and NASA's Manned Spacecraft Center.

FIGURE 99.—Astronauts Schmitt and Cernan. Notice that sampling tools, like the ones to be used on the Moon, are used during the practice exercises. Each astronaut carries a Hasselblad camera, sample bags, cuff checklists, and simulated backpacks. Schmitt carries a scoop and Cernan carries tongs. NASA PHOTO S-72-30170.

Figure 100.—Schmitt and Cernan ride the Explorer. The only model of the lunar Rover used for training is kept at the Kennedy Spacecraft Center. So the U.S. Geological Survey built an inexpensive version, nicknamed Explorer, for use on geological field trips. NASA PHOTO S–72–30173.

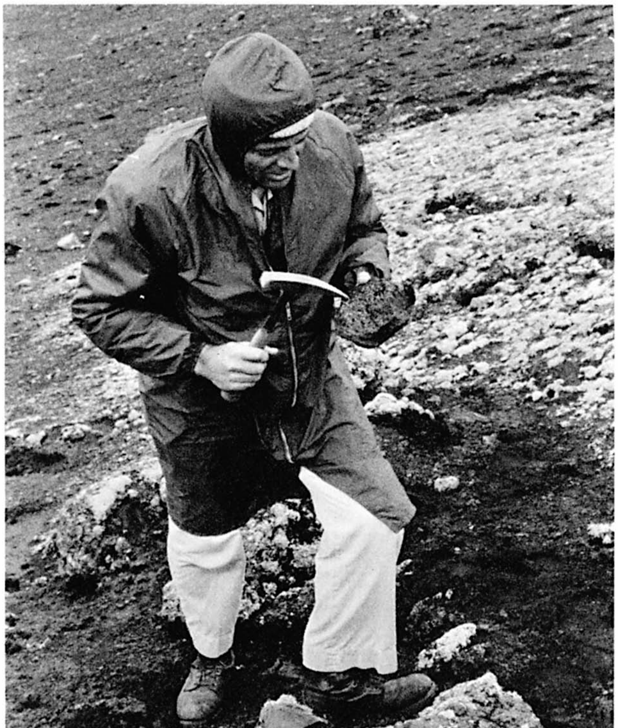

Figure 101.—Astronaut Ron Evans, Apollo 17 command module pilot. He is shown studying geology in Iceland about 5 years ago. Each astronaut has studied and practiced for many years for this particular mission. The observations of the Moon to be made by Evans from his vantage point in the CM will be greatly enhanced by his extensive knowledge of geology obtained over the years. NASA PHOTO S–67–38518.

Figure 102.—Astronaut Gene Cernan. This photo was obtained during the spring 1972 at a practice session intended to find any "bugs" in the various experiments. To save the cost of another astronaut suit, Cernan was practicing that day in the suit that had actually been worn on the Moon's surface by Dave Scott. NASA PHOTO S–72–35043.

Figure 103.—Astronaut Gene Cernan. During training exercises, the observations reported by the astronauts via radio are recorded on magnetic tape and later analyzed by members of the training group (at the Manned Spacecraft Center and U.S. Geological Survey) for accuracy. NASA PHOTO S–72–30182.

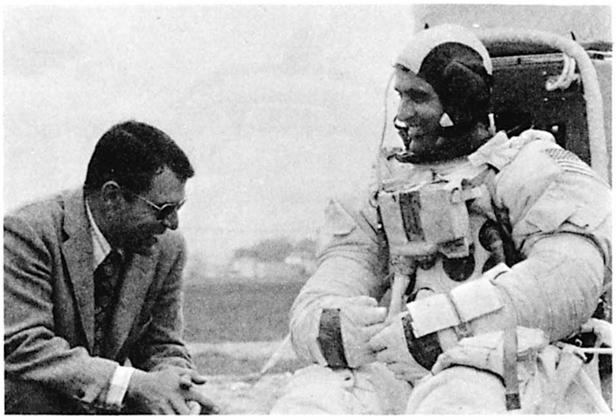

FIGURE 104.—Mission Scientist Bob Parker and Jack Schmitt. Parker, also an astronaut, helped solve many problems associated with the scientific equipment to be carried to the Moon, coordinated the crew's activities, and helped the mission in many other ways. He will be the Apollo 17 Capsule Communicator (Cap Com), the main voice communications link between Mission Control and the astronauts on the Moon. NASA PHOTO S–72–35046.

FIGURE 105.—Astronauts John Young and Charlie Duke. Even though they have already visited the Moon, they continue their geological training as part of the Apollo 17 backup crew. Notice the gnomon, the Hasselblad cameras, the lunar rock hammer and their excellent choice of hats. NASA PHOTO S–72–31181.

FIGURE 106.—Astronaut Stu Roosa. Even though the CM pilot will not examine rocks on the Moon's surface, an understanding of geology is absolutely essential. Roosa is shown here studying intensely a piece of basalt. This picture, taken in Iceland 5 years ago, indicates the long and continued effort of the crew to learn as much as possible about the science which they will be doing on the mission. The hand lens, probably 10X, allows him to see more clearly the individual crystals and to recognize them. NASA PHOTO S–67–38510.

FIGURE 107.—Astronauts Cernan and Schmitt discuss samples of rock collected on a training trip near Tonopah, Nev. NASA PHOTO S–72–48935.

What We've Learned About the Moon

INTRODUCTION

From the day that Galileo saw the Moon through the first telescope until July 20, 1969, when Aldrin and Armstrong walked on the Moon, man learned many things about the Moon. During those 300 years, he learned to weigh the Moon, to determine its size and shape, to measure the temperature of the surface, to estimate the electrical properties from radar waves bounced off the Moon, and to do many others without leaving the planet Earth. He even sent unmanned spacecraft to the Moon's surface and analyzed the chemical composition!

Man thus knew *many* facts about the Moon before Neil Armstrong and Buz Aldrin landed their spacecraft. Yet their historic landing opened the way for men to visit the Moon, to bring back actual material from the Moon itself, and to leave scientific instruments on the surface of the Moon to operate for several years. Just as Galileo's telescopic observations opened a new era in modern astronomy, Armstrong and Aldrin's voyage opened a new discipline in science—that of LUNAR SCIENCE.

This new science during its first 3½ years has been filled with surprises. Now surprises in science are good. They usually mean that we have discovered something that was not expected, a scientific bonus. In this section, I want to describe a few of the things we have learned about the Moon and to share with you some of the surprises.

I still vividly recall the intense excitement at the Lunar Receiving Laboratory in Houston more than 3 years ago when the Apollo 11 rock boxes were opened. The first samples of rocks and soil returned from the Moon! That was a moment some of us had worked toward for 5 to 10 years. But even so, most of us could hardly believe that we really had in our possession rocks from the Moon.

The study of those Apollo 11 samples is still being intensively explored today. The lunar samples are helping us unravel some of the most important questions in lunar science and astronomy. They include: 1. How old is the Moon? 2. Where and how did the Moon originate? 3. What history and geologic features do the Moon and Earth have in common, and what are the differences? 4. What can the Moon tell us about the rest of the solar system, and of the rest of the universe? 5. Is there any evidence of life on the Moon?

To help solve these questions, we have used highly advanced and very sensitive scientific equipment, sometimes on samples almost too small to be seen by the naked eye. Some of the equipment was designed and built specifically to work on the lunar material.

WHAT THE ROCKS TELL US

Rocks cannot literally speak. But they do contain interesting, often exciting, stories. And they do reveal their stories through the scientist's experienced eyes and sophisticated instruments. The shape, size, arrangement, and composition of the individual grains and crystals in a rock tell us about the history of the rock. Radioactive clocks tell us the age of the rock. Tiny tracks may even tell us the radiation history of the Sun during the last 100,000 years. And so on. In figures 108–110, I show the external appearance of three lunar rocks. In some aspects, their appearances resemble those of Earth rocks. The minerals are the same. The grain sizes are comparable. The shapes are familiar. And so on. But in other aspects, their appearances differ significantly. For example, the surface is pitted with tiny craters and the rocks are extraordinarily fresh.

But let me show you what we see when we study a rock with a microscope. Most rocks—lunar rocks as well as most Earth rocks—do not transmit light.

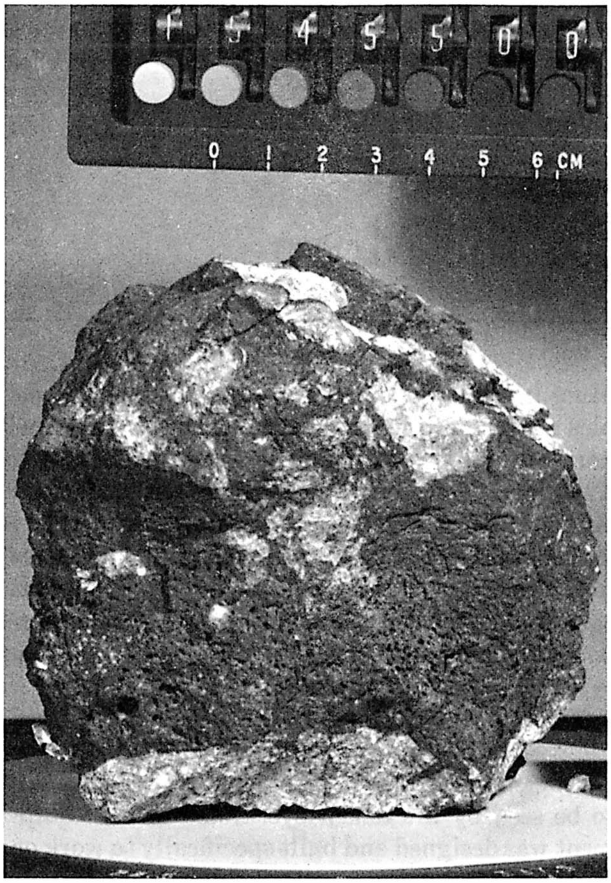

FIGURE 108.—The black and white rock. Sample 15455, collected on Apollo 15, is composed of two different kinds of rock and is termed a breccia. One kind shows as white, irregular spots within the second one. Note the gas holes or vugs in the dark rock. This sample weighs about ½ pound. Size of rock may be obtained with the scale shown in the figure. NASA PHOTO S–71–43889.

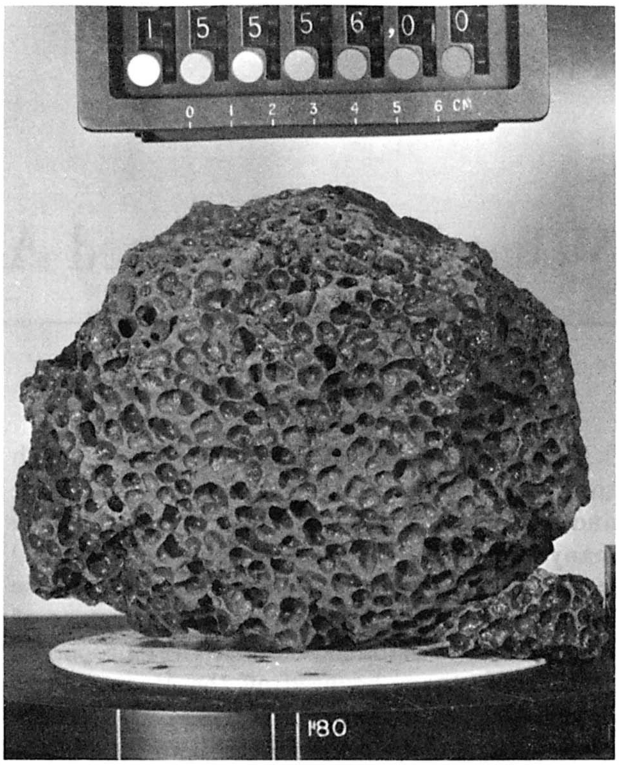

FIGURE 109.—Vesicular basalt. The holes, termed vesicles, were caused by gas in the rock when it was molten. This appearance is typical of many basalts on Earth that were near the top of lava flows. Some cavities are lined with glass. NASA PHOTO S–71–43328.

Yet when sliced very thin, about one-thousandth of an inch, the same rocks become transparent. Such slices are called thin sections. We study them with special microscopes.

In figure 111, we see the appearance of one kind of rock from the moon, an *igneous* rock. The term, igneous, means that the rock crystallized from a liquid, a fact that we infer from the minerals present, their arrangement and shape, and our experience of seeing similar rocks cool from the liquids erupted from volcanoes on Earth.

Note that many of the individual mineral grains transmit light but others (the completely black grains) do not transmit light. The black grains (termed opaque) are the mineral ilmenite, which is rich in titanium dioxide. On Earth, this mineral is

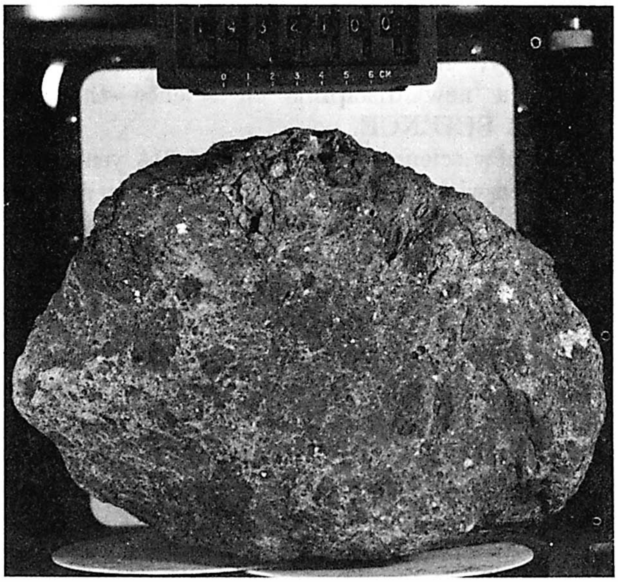

FIGURE 110.—Big Bertha. This sample, collected on Apollo 14, is one of the larger ones brought to Earth. NASA PHOTO S–71–56345.

FIGURE 111.—Apollo 11 Igneous Rock. This photo was obtained with a camera mounted on a microscope. The mineral grains can be seen clearly. The small black areas are due to the mineral ilmenite which is opaque to light. The large dark area on the right is due to a hole in the rock. NASA PHOTO S–69–47902.

commercially important—it is mined for the titanium dioxide which is used for many things, including the manufacture of white paint. One of the surprises discovered immediately when examining the Apollo 11 rocks was the relatively large amount of ilmenite. Many of the rocks found at Apollo 11 site contained more than 10% titanium dioxide, an unusually large amount when judged by Earth standards. (The rocks from other missions did not contain such large amounts, though.)

Another feature that is extremely common in lunar rocks, and also in terrestrial igneous rocks, is seen in the right hand side of figure 111, the round dark area. It is a hole in the rock, termed a vesicle and was caused by gas when the rock was still liquid. We see exactly this same feature in rocks that bubble up from the volcanoes on Hawaii. Thus we are certain of the explanation.

A photomicrograph (a photograph of a thin section taken through the microscope) of another lunar rock is shown in figure 112. You can probably see that there are three different kinds of minerals. One is completely dark, literally pops out of the figure towards you, and has rather straight sides and sharp angles. This mineral is spinel and, when sufficiently large and flawless, is a beautiful gemstone. The second mineral which you can probably distinguish, also stands out though not quite as sharply as the spinel, and also occurs as discrete grains. This mineral, olivine, also has sharp edges and angles and is probably better known as peridot, the birthstone for August. The third mineral, which transmits light very well and appears colorless in thin section, constitutes the rest of the rock, filling the space around the other two minerals. It is termed feldspar and is the pink mineral in granites—a terrestrial rock commonly used for tombstones. Almost surely you have held feldspar in your hand. The familiar household cleansing and scouring powders, such as Ajax, are mostly feldspar.

And finally, you can see in the left hand side of the figure a few dark spots that represent opaque grains, probably ilmenite; there may also be metallic iron with a small percentage of nickel.

From figure 112, let me illustrate two ways in which we "read" the history of a rock from the thin section. Because the grains of ilmenite, spinel, and olivine have their characteristic crystal shapes and are surrounded by the feldspar, we know that the feldspar crystallized last. Secondly, note the thin zone near the bottom in which the individual grains are all smaller than elsewhere. This zone indicates that the bottom part of the rock was broken loose from the top part and displaced slightly towards the left.

One of the major surprises—though in retrospect the "surprise" should have been expected—was the discovery in the Apollo 11 samples of large quantities of glass. Why should glass surprise us? After all, we are extremely familiar with glass. We use glass every day. So what should be surprising? Even though we are literally surrounded with glass every day, *all* of that glass is artificial. It was manufactured. On the Earth, the occurrence

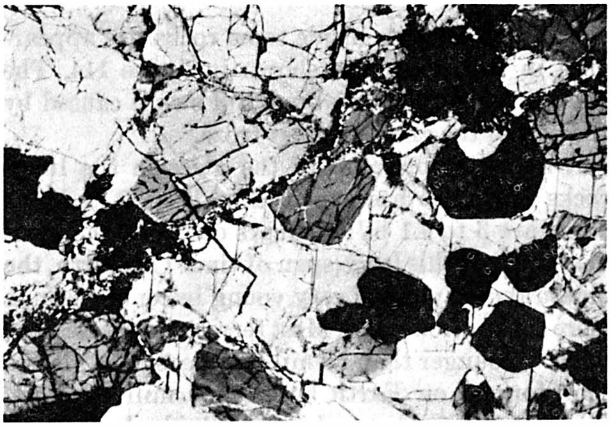

FIGURE 112.—Photomicrograph of Apollo 16 lunar igneous rock 67435. Note distinctness of the individual mineral grains. See text. NASA PHOTO S–72–42390.

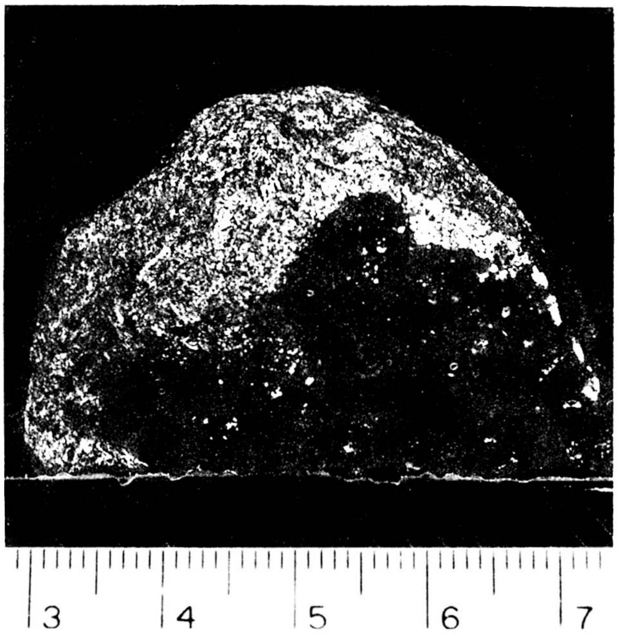

FIGURE 113.—Glass splash on lunar rock. The dark, bubbly looking material is glass that formed when a meteorite impacted the Moon. It was still hot when it hit this rock and so it stuck very securely to the rock. Sample 12017. NASA PHOTO S–70–44098.

of *natural* glass is exceedingly rare.* Most people have never seen natural glass! On the other hand, its occurrence on the Moon is extremely common. Indeed, glass is abundant in the material from each mission. It often sticks to the outside of rocks, as shown in figure 113. The glass was formed by the high pressure and temperature produced when a meteorite struck the Moon. It was splashed from the impact site, much as mud is thrown from the impact point when a pebble is dropped into a mud puddle.

Glass also occurs inside some rocks. Its appearance in thin section is shown in figure 114. The glass often forms very beautiful swirls caused by the flow of the glass before it froze.

Another surprise about the glass in the lunar rocks is that it has survived so long. The lunar rocks are 3 to 4.1 billion years old. Yet, the glass has survived this large span of time. On Earth, the oldest known glass is very young in comparison, a mere 200 million years. Most terrestrial glasses are, in fact, younger than 50 million years. The glasses that formed on Earth before 200 million years, have long since changed into individual minerals, a process called devitrification. In fact, all glasses devitrify with time. So why is the process so much more rapid on Earth than it is on the Moon? Because no water is present on the Moon. Water greatly increases the rate of devitrification. Thus a glass can persist on the Moon for 4 billion years in the complete absence of water. Yet the same glass on Earth in the presence of water would devitrify within a few tens of millions of years.

Water is indeed very rare on the Moon. The widespread abundance of ancient glasses is very strong evidence. But in addition, none of the minerals of the lunar rocks contains water. (Actually two or three occurrences of hydrous minerals have been reported but they are extremely rare.) The absence of water on the Moon surprised most lunar scientists. Of course, we had known that at present, because of the extremely thin—almost nonexistent—lunar atmosphere, there could be no free water on the surface of the Moon. Yet because some lunar features such as the beautiful valley at Hadley-Apennine, the Apollo 15 site, resemble features on the Earth that we know to have been formed by water, we had expected that perhaps in the past there had been significant quantities of water on, and inside, the Moon. But we now know that hypothesis to be completely false.

Incidentally, the absence of water on the Moon has great practical significance for mankind. I expect that man will soon live in permanent colonies

FIGURE 114.—Photomicrograph of lunar rock. This photo taken through a microscope shows the typical appearance of lunar glass. Most of the material in this field of view is glass. Note especially the swirls; they were caused by flow of the glass when it was still fluid. NASA PHOTO S–71–23092.

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*However, you may have seen obsidian, a black-to-brown volcanic glass.

on the Moon. Thus the absence of water means that supplies of water must be either carried with the colonists (as the present-day astronauts), or manufactured on the Moon. In a sense, this lack of water also has immediate benefits to Apollo 17 science. It is exactly this absence of water that causes the electrical properties to be such that my experiment, SEP, will be able to "see" deeply beneath the surface.

Another kind of lunar rock, also extremely common, is illustrated in figure 115. It is a breccia which is a rock that contains pieces of other rocks. On the Moon, breccias are formed under the intense pressure and temperature produced by meteorite impacts. Thus the rocks that existed before an impact, as well as the soils, are welded together under the high pressures and temperatures. In figure 115, the darkish material is glass that "cements" individual mineral grains as well as individual rock particles. The event that produced the glass was undoubtedly the last of several events. At least two other events are also recorded in this rock. Note that the large chunk of rock in the lower part of the figure contains other mineral grains, as well as pieces of other preexisting rocks. In addition, the darkish grain in the upper left hand part of the figure contains other grains. Thus a series of events occurred on the Moon that formed first, the small rock particle seen in about the upper third of the darkish rock fragment, second the darkish rock fragment, and third the dark glass that now encloses everything. Such is the complex history of this lunar rock.

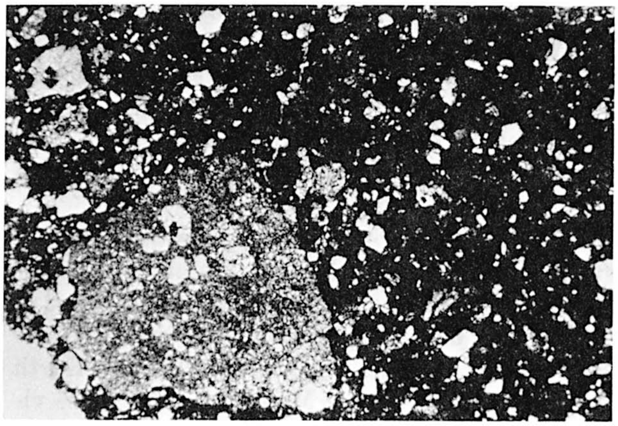

Figure 115.—Lunar Breccia. Fragments of several different rocks are apparent in this photomicrograph. See text. NASA PHOTO S–71–23092.

Figure 116.—Lunar Anorthosite. This photomicrograph shows that the rock is almost entirely feldspar; therefore, the rock is an anorthosite. Small amounts of other minerals may be seen here as small lightish grains enclosed within grains of feldspar. NASA PHOTO S–71–51778.

What about the minerals that we have seen in the Moon rocks? Most of them are similar to the ones with which we are familiar on Earth, though with some notable exceptions. The common minerals are feldspar (familiar to you from Ajax), olivine (in gem form, peridot), pyroxene (a mineral composed chiefly of iron, magnesium, calcium, silicon, and oxygen), and spinel. Quartz (silicon dioxide), an extremely common terrestrial mineral, is completely missing on the Moon. And finally, native iron is present, though in small quantities, in many of the lunar rocks. Even "rusty" iron has been seen in the preliminary examination of the Apollo 16 samples.

Still another kind of rock is shown in figure 116. It consists almost entirely of a single mineral, feldspar. The stripes across the grains, characteristic of feldspar, are caused by the individual sections having a special orientation with respect to the rest of the mineral grain. In this figure, you can see a very small amount of another mineral, olivine. The recognition that such rocks as this, termed anorthosites, probably form the highlands region of the Moon, is one of the most exciting chapters in Lunar Science. In the Apollo 11 material, very tiny fragments of anorthosite were discovered in the lunar soils. The hypothesis that such material might form the lunar highlands was suggested at that time. The evidence was certainly not very strong but the hypothesis was surely interesting. Furthermore, it "explained" the previous discovery by two scientists at the Jet Propul-

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Figures 111 through 116 inclusive are available on a full color poster. Order until December 31, 1973 from Box 2003, Kankakee, Ill. 60901.

sion Laboratory, William Sjogren and Paul Muller, that the rocks beneath the lunar highlands are less dense than the rocks beneath the lunar mare. Anorthosites were known to be less dense than basalts. The hypothesis was strengthened by finding additional anorthosites on each of the later missions. Indeed rather large samples of anorthosite were found on both the Apollo 15 and Apollo 16 Missions. And finally, an Apollo 15 *orbital* experiment, the X-ray fluorescence experiment (described in detail in the Apollo 16 guidebook) showed that the elements aluminum and silicon are in the proper ratio in the highlands for anorthosite.

Anorthosites are very special rocks. The observation that anorthosite consists almost entirely of a single mineral is very important. The chemical processes that lead from the ordinary igneous rocks—like basalt—to an anorthosite are very complex. An anorthosite is a "highly refined product." The processes are similar to the ones used on Earth in petroleum refineries to change crude oil to such diverse products as asphalt for roads, lubrication greases, motor oil, kerosene, jet fuel, automobile gasoline, aviation gasoline, and dozens of other products. Like aviation gasoline, the anorthosite is the final product of a series of very complex chemical processes.

All the lunar rocks are very, very old. Their ages range from 3 to 4 billion years. The oldest known terrestrial rock is about 3½ billion years old and rocks older than 2 billion years are extremely rare. How are such ages measured? By radioactive clocks. The rocks contain radioactive elements, such as uranium, that change slowly, and at a known rate, into other elements. From the ratio of daughter product to the parent radioactive element, measured with highly sensitive instruments, we can estimate the age

What about life on the Moon? We have found no chemical evidence that living things (except 10 very lively astronauts!) have ever been on the Moon. No fossils. No microorganisms. No traces of biologically formed chemicals. Nothing. Yet, there do appear to be extremely small amounts of amino acids and possibly other related organic compounds in some of the lunar soil. Recently, such molecules as formaldehyde, ammonia, and methyl alcohol have been detected as clouds in remote space. Such findings have led many to speculate that even though there is no evidence of life on the Moon, life, even intelligent life, must exist elsewhere in the universe. Undoubtedly, this question will remain a major one for future investigations.

Nearly 800 scientists in the United States and 17 foreign countries are studying the lunar samples today. Even though about 600 pounds of lunar samples have been brought to Earth so far, and we expect to get another 200 pounds from Apollo 17, we are still being very conservative in how much we use. Most of us who work on the samples actually receive a piece smaller than one-fourth inch on a side; a very few receive larger pieces. All material (except that which is used in a few experiments that consume the material) is returned to NASA when our work is fininshed. Less than 10 percent of the total samples have been used so far for analysis; the other 90 percent will be carefully preserved for scientific studies in future years, probably using new and more powerful analytical tools not yet known today. These samples will be a priceless scientific heritage as well as a special kind of enduring monument to the memory of the astronauts and to the many scientists, engineers, taxpayers, and others who made the Apollo missions possible. An inventory of lunar samples made in July 1972 is shown below. Small quantities have been given by the President to foreign heads of state and to the governors of each State.

WHAT THE LUNAR SURFACE EXPERIMENTS TELL US

The scientific experiments left on the Moon by the astronauts have sent data to Earth over microwave radio links for 3 years. It is hoped that they will continue to operate for several more years. A complete listing of these experiments is given in Table 4 of the Appendix. But let me discuss here only a few of those experiments that have helped us understand the interior of the Moon. They too have given us many surprises.

Very sensitive instruments, termed seismographs, measure extremely small vibrations of the Moon's surface. These instruments are similar to the familiar ones used by doctors to listen to your heartbeat. With them, we can listen back on Earth to the vibrations on the Moon. Some of those vibrations are caused by naturally occurring events, others by impacts on the Moon of parts of spacecraft, still others by meteorites. The spacecraft

Lunar Sample Inventory

	Apollo Missions				
	A–11	A–12	A–14 (grams)	A–15	A–16
Amount returned	21, 694	34, 369	42, 927	77, 380	95, 476
Used for Biotesting	702	538	589	158	[2] 72
Destructive Analysis	4, 225	2, 681	2, 823	3, 010	2, 933
On display	2, 113	1, 925	247	660	[2] 20
Processing loss at MSC	[1] 650	[1] 600	[1] 200	[1] 200	[2] 40
Available for future generation experiments	15, 218	29, 669	39, 315	74, 012	[2] 92, 431
Percent of returned sample used for scientific investigations and displays	25. 8	13. 4	7. 2	4. 7	3. 1

[1] Estimated.

[2] Preliminary figures, allocation, and sample processing still in progress at time of inventory.

impacts have been especially valuable to our study of the Moon's interior. We now believe that the Moon has a crust of rocks that differ greatly from the rocks deeper in the Moon. This crust is roughly 30 to 40 miles thick. Its existence implies that the early geological history of the Moon resembles that of the Earth which also developed a similar crust.

By comparison with the Earth, the Moon is extremely quiet. More than one million earthquakes occur on the Earth each year, yet only a few hundred seismic events—sometimes termed moonquakes—occur on the Moon.

The seismic properties of the lunar crust were greatly surprising. Very small signals from the impart of each spacecraft caused the Moon to ring like a bell for several hours. Such behavior of the Earth is not entirely unknown but occurs only with the largest of earthquakes. Similar signals on the Earth would have died completely after a few minutes. Perhaps this difference in behavior is caused by the absence of water in the Moon, the presence of a vacuum, and the lower temperature of the Moon's crust.

Another surprise, as well as some exciting implications, was provided by measurement of the Moon's magnetic field. Now the magnetic field of the Moon (and also the Earth) has two parts, one that changes with time and one that is steady and does not change rapidly with time.

The *steady* part of the Earth's magnetic field is about 50,000 gamma (the usual unit of magnetic field employed by Earth scientists). It causes compasses to point approximately north-south. The steady part of the lunar magnetic field, measured at the Apollo 12 site, was about 35 gamma, somewhat more than 1,000 times smaller than the Earth's field. Yet the 35 gamma field was several times larger than we had expected. Values measured at the Apollo 14 and 16 sites were even larger! The steady part of the lunar magnetic field is undoubtedly due to the presence of natural magnetism in lunar rocks. The natural magnetism was probably inherited early in the Moon's history (perhaps several billion years ago) when the magnetic field was many times larger than today. It is much too small at present to affect the usual compass.

The other part of the lunar magnetic field, that which varies with time, is influenced greatly by the electrical properties of the interior of the Moon. Therefore, a study of the variations with time of the magnetic field will reveal the electrical properties of the Moon as a function of depth. Because the electrical properties of rocks are influenced by the temperature, we hope to use such data to measure indirectly temperatures in the interior of the Moon.

Incidentally, there is now occurring an interesting debate in Lunar Science. One interpretation of the existing data is that deep inside, the Moon is relatively cool. It may be only 600 to 800° C. Such temperatures may seem high but in comparison with the Earth's temperature, which may be five times as high, they are relatively cool. This conclusion of low temperature is not certain but *if* substantiated by later work, will be most profound because it means that the lunar material is much lower in radioactivity than the Earth. Another interpretation is that some assumption

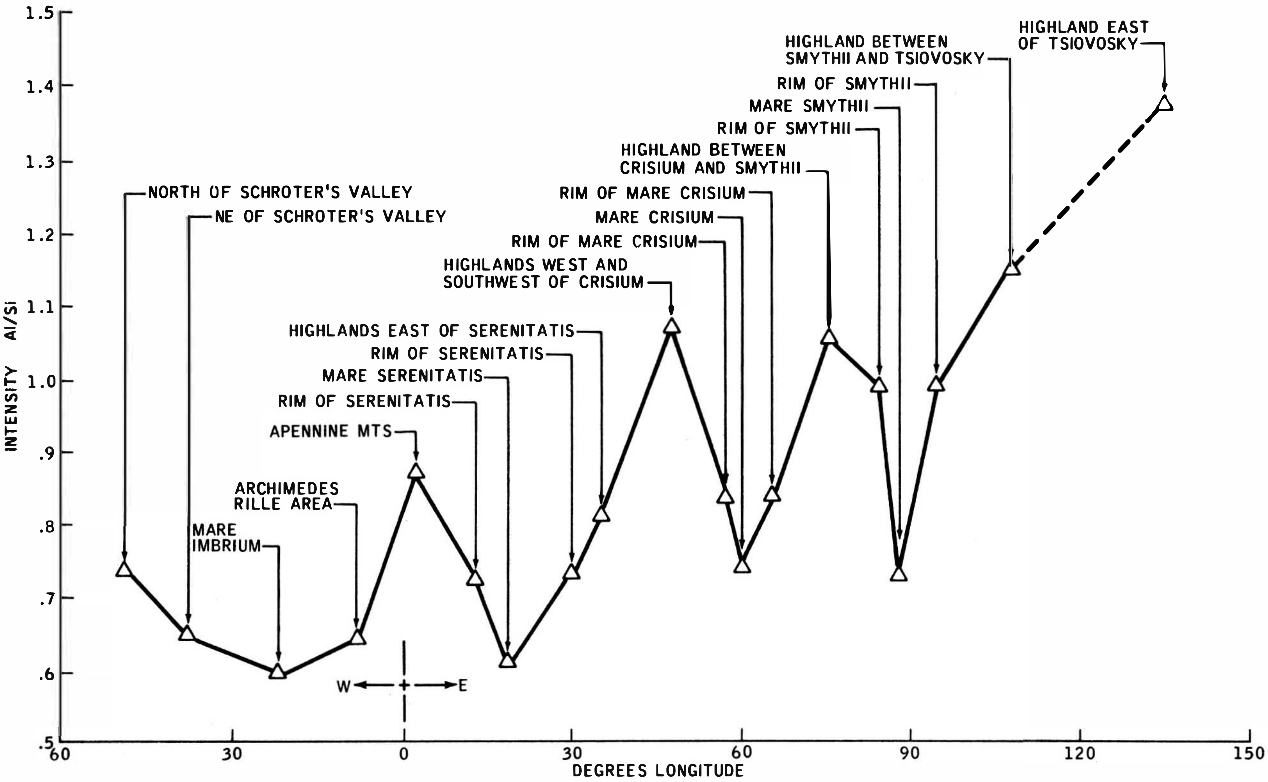

Figure 117.—Aluminum-silicon ratios measured along one track of Apollo 15. Note the excellent correlation between the intensity and different lunar regions. The maria have low ratios, the highlands have high values. These data support the idea that the lunar highlands consist mostly of anorthosite, an aluminum silicate rock. Similar data were obtained with identical equipment on Apollo 16. Data provided by Dr. I. Adler, the principal investigator of this experiment. NASA PHOTO S–72–16319.

in the data reduction method is incorrect and that the Moon is really hotter in the interior. It will be most interesting to watch the outcome of this debate which should be settled within a few years.

WHAT THE ORBITAL EXPERIMENTS TELL US

While the surface experiments tell us about the interior of the Moon, or about some phenomenon in the vicinity of the landing site, and the lunar rocks also tell us mainly about events that happened near the landing site, the orbital experiments give us information along a path completely around the Moon. So, in one sense, the orbital experiments allow us to extend the information collected at a very few landing spots on the Moon to much larger regions. For example, the chemical group of orbital experiments—the X-ray Fluorescence Experiment, the Alpha-particle Spectrometer, and the Gamma Ray Spectrometer have let us extend the chemical compositions obtained at the landing sites. Because of the orbital experiments, we are now quite confident that the highlands and maria *are* chemically different and that the highlands material is closely akin to anorthosite.

But not only do the orbital experiments let us extrapolate the site data, they also provide new information about the Moon that was not otherwise available. We have obtained very high quality photographs that will be used to provide a geodetic reference system for locations on the Moon that is comparable to the best yet developed for the Earth. But the current (preliminary) geologic analysis of a few of those photos has revealed the presence of several features on the Moon that had previously been suggested on the basis of less evidence. The photos of the Taurus-Littrow site have been interpreted by two geologists, Jim Head and Tom McGetchin, to indicate the presence at the Apollo 17 site of volcanic debris similar to that on Earth blown out of the volcanoes Stromboli and Etna. Head and McGetchin used slow motion photography of the eruptions of these two volcanoes, aerodynamic theory, and the effect of one-sixth gravity, to show the kind of deposits that these volcanoes would have built on the Moon. They then compared the predicted features with those shown on the lunar photos. Of course, their results will soon be tested by the Apollo 17 mission!

Recognition that materials bombarded with X-rays fluoresced allowed Dr. Isadore Adler to perform an orbital experiment to detect and measure fluorescent X-rays from the Moon. Under favorable conditions, his experiment can measure the amounts of lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, neon, sodium, magnesium, aluminum, and silicon. The most common of these elements in lunar rocks, as well as terrestrial, are magnesium, aluminum, and silicon.

Some preliminary results obtained from the Apollo 15 flight are shown in figure 117. The ratio of aluminum to silicon (usually denoted Al/Si) is plotted against longitude for one revolution. Shown also are the locations of various features of the Moon in relation to the data. Adler and his team observed that the ratios are generally low over mare regions and high over the Highlands. Such systematic variations are clearly related to the distribution of rock types over the surface of the Moon.

There were several other orbital experiments. Each experiment has told us many important and exciting things about the Moon. I have discussed the results of some of the experiments in the section on the orbital experiments of Apollo 17. But the whole story fills a book of its own—a book now in preparation that should be finished soon after the Apollo 17 Mission.

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NASA EDUCATIONAL PUBLICATIONS

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EP-70 Mission Report/Apollo 10.—The Apollo mission took two astronauts to within 50,000 feet of the lunar surface in a full dress rehearsal of the Apollo 11 lunar landing. This booklet describes that mission as the final test of all elements of the Apollo system. In full color. 12 pages. 35 cents.

EP-71 "In This Decade . . ." Mission to the Moon.—This "pre-launch" booklet outlines the complex steps leading to a manned lunar landing. The many and varied areas of research and development conducted by the National Aeronautics and Space Administration are illustrated. In color. 48 pages. $1.25.

EP-72 Log of Apollo 11.—The greatest voyage in the history of mankind, the journey of Apollo 11, is documented in this booklet. In color. 12 pages. 35 cents.

EP-73 The First Lunar Landing/As Told by the Astronauts.—The Apollo 11 postflight press conference is recorded in the astronauts' own words. They describe the history-making mission and answer reporters' questions. 24 pages. 75 cents.

EP-74 Apollo 12/A New Vista for Lunar Science.—The mission described as ". . . a thousand, maybe even a million times more important than Apollo 11," is shown as a significant addition to man's knowledge of the universe. 20 pages. 65 cents.

EP-76 Apollo 13. "Houston, We've Got a Problem."—Failure of one of Apollo 13's oxygen tanks made it necessary to continue flight in an emergency mode to and around the Moon, and back to splashdown in the Pacific Ocean. The story of this dramatic flight is told mainly in excerpts from the conversations between the astronauts and Mission Control. 25 pages. 75 cents.

EP-91 Apollo 14: Science at Fra Mauro.—Exploration of the upland Fra Mauro area of the Moon incorporated the most extensive scientific observations in manned lunar exploration up to that time. The story is presented in text, a traverse map and spectacular color photographs. The Fra Mauro area is believed to hold debris hurled out of the Moon's interior by the massive impact of an object from space. 48 pages, $1.25.

EP-94 Apollo 15 At Hadley Base.—The flight of Endeavour and Falcon to the Apennine Mountain area. The ability of the Apollo 15 astronauts to explore was significantly enhanced by the use of a Lunar Roving Vehicle. The story is presented in text and full color pictures. 32 pages. 75 cents.

EP-97 Apollo 16 at Descartes.—This publication covers the highlights of the mission and includes many detailed color photographs. 32 pages. 75 cents.

NASA PICTURE SETS

The picture sets described below are available, at prices quoted, from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

NASA Picture Set No. 1 Apollo—"In the Beginning . . ."—Seven 11" x 14" color lithographs that illustrate highlights from the Apollo 8, 9, and 10 missions. $1.25 per set.

NASA Picture Set No. 2 Men of Apollo.—Five 11" by 14" color lithographs that include portraits of the crews of Apollo 7, 8, 9, 10 and 11. $1 per set.

NASA Picture Set No. 3 Eyewitness to Space.—Twelve 16" x 20" color lithographs that reproduce the paintings of space program scenes by artists Mitchell Jamieson, Peter Hurd, James Wyeth, Lamar Dodd, George Weymouth, Nicholas Solovioff, Hugh Laidman, Fred Freeman, Billy Morrow Jackson, Paul Calle, and Frank McMahon. $2.75 per set.

NASA Picture Set No. 4 First Manned Lunar Landing.—Twelve 11" x 14" color lithographs depict the historic journey of Apollo 11, man's first visit to another celestial body. $1.75 per set.

NASA Picture Set No. 5 Man on the Moon.—One 16" x 20" color lithograph that best illustrates man's moment of success, the first step in his conquest of space. $1 per copy.

NASA Picture Set No. 6 Apollo 12—Pinpoint Landing on the Moon.—Eight 11" x 14" color lithographs and two 11" x 14" black and white lithographs illustrating man's return to the Moon. $1.50 per set.

NASA Picture Set No. 7 Apollo 15.—Nine 11" x 14" color lithographs illustrating the journey to the Moon of Endeavour and Falcon. $1.50 per set.

Acronyms and Abbreviations

ALSD	Apollo Lunar Surface Drill
ALHT	Apollo Lunar Hand Tools
ALHTC	Apollo Lunar Hand Tool Carrier
ALSE	Apollo Lunar Sounder Experiment
ALSEP	Apollo Lunar Surface Experiments Package
ALSRC	Apollo Lunar Sample Return Container (Rock Box)
AMU	Atomic Mass Unit
ASE	Active Seismic Experiment
BLSS	Buddy Secondary Life Support System
BW	Black and White
CAPCOM	Capsule Communicator, the single individual on Earth who talks directly with the crew
CCIG	Cold Cathode Ion Gauge
CM	Command Module
CSM	Command and Service Module
CDR	Commander
CRD	Cosmic Ray Detector
C/S	ALSEP Central Station
CSVC	Core Sample Vacuum Container
DAC	Data Acquisition Camera
DPS	Descent Propulsion System
DOI	Descent Orbit Insertion
DSEA	Data Storage Electronics Assembly
ETB	Equipment Transfer Bag
EVA	Extravehicular Activity
FMC	Forward Motion Compensation
FOV	Field of View
FUS	Far Ultraviolet Spectrometer
FWD	Forward
GASC	Gas Analysis Sample Container
GCTA	Ground-Commanded Television Assembly
GET	Ground Elapsed Time
GMT	Greenwich Mean Time
GLA	Grenade Launch Tube Assembly
GN_2	Gaseous Nitrogen
HBW	High-Speed Black and White
HCEX	High-Speed Color Exterior
HEC	Hasselblad Electric Camera
HEDC	Hasselblad Electric Data Camera
HFE	Heat Flow Experiment
IMC	Image Motion Compensation
IR	Infrared
ISR	Infrared Scanning Radiometer
JPL	Jet Propulsion Laboratory
KSC	Kennedy Space Center
LA	Laser Altimeter
LACE	Lunar Atmospheric Composition Experiment
LBW	Low Speed Black and White
LCRU	Lunar Communications Relay Unit
LDAC	Lunar Surface 16-mm Data Acquisition Camera
LDD	Lunar Dust Detector
LEAM	Lunar Ejecta and Meteorite Experiment
LESC	Lunar Environment Sample Container
LGE	Lunar Geology Experiment
LM	Lunar Module
LMP	Lunar Module Pilot
LMS	Lunar Mass Spectrometer
LNP	Lunar Neutron Probe Experiment
LOI	Lunar Orbit Insertion
LP	Long Period
LPM	Lunar Portable Magnetometer
LRL	Lunar Receiving Laboratory
LRRR	Laser Ranging RetroReflector (Pronounced LR-cubed.)
LRV	Lunar Roving Vehicle (ROVER)
LSAPT	Lunar Samples Analysis and Planning Team
LSG	Lunar Surface Gravimeter
LSM	Lunar Surface Magnetometer
LSPE	Lunar Surface Profiling Experiment
LSPET	Lunar Sample Preliminary Examination Team
LSUV	Lunar Surface UV Camera
LTG	Lunar Traverse Gravimeter Experiment
MC	Mapping Camera
MCC	Mission Control Center
MESA	Modularized Equipment Stowage Assembly (A storage area in the LM that contains science equipment.)
MIT	Massachusetts Institute of Technology
MPA	Mortar Package Assembly
MSC	Manned Spacecraft Center
MSFN	Manned Space Flight Network
NASA	National Aeronautics and Space Administration
NM	Nautical Mile
OPS	Oxygen Purge System
PC	Panoramic Camera
PET	Preliminary Examination Team
PI	Principal Investigator
PLSS	Portable Life Support System
PM	Portable Magnetometer (also LPM)
ppm	Parts per Million
PSCB	Padded Sample Collection Bag
PSE	Passive Seismic Experiment
PTE	Photographic Tasks and Equipment

RCS	Reaction Control System
REV	Revolution
RTG	Radioisotope Thermoelectric Generator
SC	Stellar Camera
S/C	Spacecraft
SCB	Sample Collection Bag
SEP	Surface Electrical Properties
SEQ	Scientific Equipment Bay
SESC	Surface Environment Sample Container
SEVA	Standup Extravehicular Activity (An Apollo 15 term, not planned for 17.)
SIDE	Suprathermal Ion Detector Experiment
SIM	Scientific Instrument Module
S–IVB	Saturn IVB (rocket stage)
SM	Service Module
SME	Soil Mechanics Experiment
SP	Short Period
SPS	Service Propulsion System
SRC	Sample Return Container (=ALSRC)
SSC	Surface Sampler Device
SWC	Solar Wind Composition Experiment
SWP	Science Working Panel
TEC	Transearth Coast
TEI	Transearth Injection
TV	Television
UHT	Universal Hand Tool
USGS	U.S. Geological Survey
V/h	Velocity-to-Height
VHBW	Very High Speed Black and White
VHF	Very High Frequency (The same term applies to VHF television.)
VSA	Vibrating String Accelerometer

Glossary

ALBEDO *al-beé-doh*	Relative brightness. It is the ratio of the amount of electromagnetic radiation reflected by a body to the amount of incident radiation.
ALPHA PARTICLE	A positive particle consisting of 2 protons and 2 neutrons. It is the nucleus of a helium atom.
ANGSTROM UNIT *ang'-strom*	A unit of length equal to 10^{-10} meters or 10^{-4} microns. It is approximately four-billionths of an inch. In solids, such as salt, iron, aluminum, the distance between atoms is usually a few Angstroms.
APERTURE *á-per-ture*	A small opening such as a camera shutter through which light rays pass to expose film when the shutter is open.
ATTENUATION *a-teń-u-eh-shun*	Decrease in intensity usually of such wave phenomena as light or sound.
BASALT *baá-salt*	A type of dark gray rock formed by solidification of molten material. The rocks of Hawaii are basalts.
BISTATIC RADAR *bi-sta-tic raý-dar*	The electrical properties of the Moon's surface can be measured by studying the characteristics of radio waves reflected from the Moon. If the radio transmitter and receiver are located at the same place, the term monostatic radar is used. If they are located at different places, then bistatic is used. In the study of the Moon with bistatic radar, the transmitter is aboard the CSM and the receiver is on the Earth.
BRECCIA *brech'-ya*	A coarse-grained rock composed of angular fragments of pre-existing rocks.
BOUNDARY LAYER	The interaction layer between the solar wind bow shock and the magnetopause.
BOW SHOCK	The shock wave produced by the interaction of the solar wind with the Earth's magnetosphere.
CARTOGRAPHY	The production and science of accurately scaled maps.
CASSETTE *kuh-set'*	Photographic film container. Also magnetic tape container.
CISLUNAR *sis-lune-ar*	Pertaining to the space between the Earth and Moon or the Moon's orbit.
COLLIMATOR *kol'-i-má-ter*	A device for producing beams of parallel rays of light or other electromagnetic radiation.
COLORIMETRIC	Pertaining to the measurement of the intensities of different colors as of lunar surface materials.
COSMIC RAYS *koś-mik*	Streams of very high energy nuclear particles, commonly protons, that bombard the Earth and Moon from all directions.
COSMOLOGY *kos-mol'-uh-gee*	Study of the character and origin of the universe.
CRATER *craý-ter*	A naturally occurring hole. On Earth, a very few craters are formed by meteorites striking the Earth; most are caused by volcanoes. On the Moon, most craters were caused by meteorites. Some lunar craters were apparently formed by volcanic processes. In the formation of lunar craters, large blocks of rock (perhaps as large as several hundred meters across) are thrown great distances from the crater. These large blocks in turn from craters also---such craters are termed secondary craters.
CROSS-SUN	A direction approximately 90 degrees to the direction to the Sun and related to lunar surface photography.
CROSSTRACK	Perpendicular to the instantaneous direction of a spacecraft's ground track.
CRYSTALLINE ROCKS	Rocks consisting wholly or chiefly of mineral crystals. Such rocks on the Moon are usually formed by cooling from a liquid melt.

DIELECTRIC *dyé-ee-lek-trik*	A material that is an electrical insulator. Most rocks are dielectrics.
DIURNAL *dye-er'-nal*	Recurring daily. Diurnal processes on Earth repeat themselves every 24 hours but on the Moon repeat every 28 Earth days. The length of a lunar day is 28 Earth days.
DOPPLER TRACKING *dopp'-lur*	A system for measuring the trajectory of spacecraft from Earth using continuous radio waves and the Doppler effect. An example of the Doppler effect is the change in pitch of a train's whistle and a car's horn on passing an observer. Because of this effect, the frequency of the radio waves received on Earth is changed slightly by the velocity of the spacecraft in exactly the same way that the pitch of a train's whistle is changed by the velocity of the train.
DOWN-SUN	In the direction that is directly away from the Sun and related to lunar surface photography.
EARTHSHINE	Illumination of the Moon's surface by sunlight reflected from the Earth. The intensity is many times smaller than that of the direct sunlight.
ECLIPTIC PLANE *ee-klip'-tik*	The plane defined by the Earth's orbit about the Sun.
EFFLUENT *eff-flu-ent*	Any liquid or gas discharged from a spacecraft such as waste water, urine, fuel cell purge products, etc.; also any material discharged from volcanoes.
EGRESS *eé-gress*	A verb meaning to exit or to leave. The popularization of this word has been attributed to the great showman, P. T. Barnum, who reportedly discovered that a sign marked exit had almost no effect on the large crowds that accumulated in his exhibit area but a sign marked "to egress" led the crowds outdoors. In space terminology it means simply to leave the spacecraft.
EJECTA *ee-jek'-tuh*	Lunar material thrown out (as resulting from meteoroid impact or volcanic action).
ELECTRON *ee-lek'-tron*	A small fundamental particle with a unit of negative electrical charge, a very small mass, and a very small diameter. Every atom contains one or more electrons. The *proton* is the corresponding elementary particle with a unit of positive charge and a mass of 1,837 times as great as the mass of the electron.
EXOSPHERE	The outermost portion of the Earth's or Moon's atmosphere from which gases can escape into outer space.
FIELD	A region in which each point has a definite value such as a magnetic field.
FIELD OF VIEW	The region "seen" by the camera lens and recorded on the film. The same phrase is applied to such other equipment as radar and radio antennas.
FILLET *fill'-it*	Debris (soil) piled against a rock; several scientists have suggested that the volume of the fillet may be directly proportional to the time the rock has been in its present position and to the rock size.
FLUORESCENCE *flur-eś-ence*	Emission of radiation at one wavelength in response to the absorption of energy at a different wavelength. Some lunar materials fluoresce. Most do not. The process is identical to that of the familiar fluorescent lamps.
FLUX	The rate of flow per unit area of some quantity such as the flux of cosmic rays or the flux of particles in the solar wind.
FRONT	The more or less linear outer slope of a mountain range that rises above a plain or plateau. In the United States, the Colorado Front Range is a good example.
GALACTIC *ga-lak'-tik*	Pertaining to a galaxy in the universe such as the Milky Way.
GAMMA	A measure of magnetic field strength; the Earth's magnetic field is about 50,000 gamma. The Moon's magnetic field is only a few gamma.
GAMMA-RAY	One of the rays emitted by radioactive substances. Gamma rays are highly penetrating and can traverse several centimeters of lead.
GARDENING	The overturning, reworking, and changing of the lunar surface due to such processes as meteoroid impact, volcanic action, aging and such.
GEGENSCHEIN *geg'-en-schine*	A faint light covering a 20-degree field-of-view projected on the celestial sphere about the Sun-Earth vector (as viewed from the dark side of the Earth).
GEOCHEMICAL GROUP	A group of three experiments especially designed to study the chemical composition of the lunar surface remotely from lunar orbit.
GEODESY *gee-odd'-eh-see*	Originally, the science of the *exact* size and shape of the Earth; recently broadened in meaning to include the Moon and other planets.
GEOPHONE	A small device implanted in the lunar surface during the deployment of the ASE to detect vibrations of the Moon from artificial and natural sources.

GEOPHYSICS *gee-oh-phýs-ics*	Physics of planetary bodies, such as the Earth and Moon, and the surrounding environment; the many branches include gravity, magnetism, heat flow, seismology, space physics, geodesy, meteorology, and sometimes geology.
GNOMON *know'-mon*	A rod mounted on a tripod in such a way that it is free to swing in any direction and indicates the local vertical; it gives Sun position and serves as size scale. Color and reflectance scales are provided on the rod and a colorimetric reference is mounted on one leg.
GRADIENT *graý-dee-unt*	The rate of change of something with distance. Mathematically, it is the space rate of change of a function. For example, the slope of a mountain is the gradient of the elevation.
IMBRIAN AGE	Two methods of measuring age on the Moon are used. One provides the absolute age, in years, and is based on radioactivity. The other gives only *relative* ages. A very old event on the Moon is that which produced the Imbrium basin. The age of other geologic features can be determined with respect to the Imbrium event.
INGRESS *iń-gress*	A verb meaning to enter. It is used in connection with entering the LM. See also "egress."
IN SITU *in-sit'e-u*	Literally, "in place", "in its original position". For example, taking photographs of a lunar surface rock sample "in situ" (as it lies on the surface).
LIMB	The outer edge of the apparent disk of a celestial body, as the Moon or Earth, or a portion of the edge.
LITHOLOGY	The character of a rock formation.
LUNATION	One complete passage of the Moon around its orbit.
MANTLE	An intermediate layer of the Moon between the outer layer and the central core.
MARE *maár-ray*	A large dark flat area on the lunar surface (Lunar Sea). May be seen with the unaided eye.
MARIA *maar'-ya*	Plural of mare.
MASCONS *mass-conz*	Large mass concentrations beneath the surface of the Moon. They were discovered only 3 years ago by changes induced by them in the precise orbits of spacecraft about the Moon.
MASS SPECTROMETER *mass spek-trom'-a-tur*	An instrument which distinguishes chemical species in terms of their different isotopic masses.
METEORITE *me-te-oh-rite*	A solid body that has arrived on the Earth or Moon from outer space. It can range in size from microscopic to many tons. Its composition ranges from that of silicate rocks to metallic iron-nickel. For a thorough discussion see *Meteorites* by Brian Mason, John Wiley and Sons, 1962.
METRIC PHOTOGRAPHY	Recording of surface topography by means of photography, together with an appropriate network of coordinates, to form the basis of accurate measurements and reference points for precise photographic mapping.
MICROSCOPIC	Of such a size as to be invisible to the unaided eye but readily visible through a microscope.
MINERALOGY	The science of minerals; deals with the study of their atomic structure and their general physical and chemical properties.
MONOPOLE *moń-oh-pole*	All known magnets have two poles, one south pole and one north pole. The existence of a single such pole, termed a monopole, has not yet been established but is believed by many physicists to exist on the basis of theoretical studies. Lunar samples have been carefully searched on Earth for the presence of monopoles.
MORPHOLOGY *mor-fol'-uh-ge*	The external shape of rocks in relation to the development of erosional forms or topographic features.
MOULTON POINT	A theoretical point along the Sun-Earth line located 940,000 statute miles from the Earth at which the sum of all gravitational forces is zero.
NADIR	That point on the Earth (or Moon) vertically below the observer.
NAUTICAL MILE	It is 6,280 feet—19 percent larger than a "regular" mile.
NEUTRON	An uncharged elementary particle that has a mass nearly equal to that of a proton and is present in all known atomic nuclei except hydrogen.
OCCULTATION *ah'-cull-taý-shun*	The disappearance of a body behind another body of larger apparent size. For example the occultation of the Sun by the Moon as viewed by an Earth observer to create a solar eclipse.
OZONE *oh'-zone*	Triatomic oxygen (O_3); found in significant quantities in the Earth's atmosphere.
P–10	A gas mixture consisting of 90 percent argon, 9.5 percent carbon dioxide, and 0.5 percent helium used to fill the X-ray detectors of the X-Ray Fluorescence Experiment.

PANORAMA	A series of photographs taken from a point to cover 360 degrees around that point.
PENUMBRA *pe-num'-bra*	The part of a shadow in which the light (or other rays such as the solar wind) is only partially masked, in contrast to the umbra in which light is completely masked, by the intervening object.
PETROGRAPHY	Systematic description of rocks based on observations in the field (e.g. on the Moon), on returned specimens, and on microscope work.
PHOTOMULTIPLIER TUBE	An electron tube that produces electrical signals in response to light. In the tube, the signal is amplified to produce a measureable output current from very small quantities of light.
PLASMA	A gas composed of ions, electrons, neutral atoms, and molecules. The interactions between particles is mainly electromagnetic. Although the individual particles are electrically positive or negative, the gas as a whole is neutral.
POSIGRADE	Lunar orbital motion in the direction of lunar rotation.
PRIMORDIAL *pry-mor'-dee-uhl*	Pertaining to the earliest, or original, lunar rocks that were created during the time between the initial and final formation stages of the Moon.
PROTON	The positively charged constituent of atomic nuclei.
RADON	Isotopes of a radioactive gaseous element with atomic number 86 and atomic masses of 220 and 222 formed by the radioactive decay of radium.
RAY	Bright material that extends radially from many craters on the Moon; believed to have been formed at the same time as the associated craters were formed by impacting objects from space; usually, but not always, arcs of great circles. They may be several hundred kilometers long.
REGOLITH *reg'-oh-lith*	The unconsolidated residual material that resides on the solid surface of the Moon (or Earth).
RETROGRADE	Lunar orbital motion opposite the direction of lunar rotation.
RILLE/RILL	A long, narrow valley on the Moon's surface.
RIM	Elevated region around craters and rilles.
SAMPLE	Small quantities of lunar soil or rocks that are sufficiently small to return them to Earth. On each mission several different kinds of samples are collected. Contingency sample consists of 1 to 2 pounds of rocks and soil collected very early in the surface operations so that at least some material will have been returned to Earth in the event that the surface activities are halted abruptly and the mission aborted. Documented sample is one that is collected with a full set of photographs to allow positive identification of the sample when returned to Earth with the sample in situ together with a complete verbal description by the astronaut. Comprehensive sample is a documented sample collected over an area of a few yards square.
S-BAND	A range of frequencies used in radar and communications that extends from 1.55 to 5.2 kilomegahertz.
SCARP	A line of cliffs produced by faulting or erosion.
SEISMIC *sizé-mik*	Related to mechanical vibration within the Earth or Moon resulting from, for example, impact of meteoroids on the surface.
SHOCKED ROCKS	Rocks which have been formed by or subjected to the extremes of temperature and pressure from impacts.
SOLAR WIND	Streams of particles (mostly hydrogen and helium) emanating from and flowing approximately radially outward from the Sun.
SPATIAL	Pertaining to the location of points in three-dimensional space; contrasted with temporal (pertaining to time) locations.
SPECTROMETER	An instrument which separates radiation into energy bands (or, in a mass spectrometer, particles into mass groups) and indicates the relative intensities in each band or group.
SPUR	A ridge of lesser elevation that extends laterally from a mountain or mountain range.
STELLAR	Of or pertaining to stars.
STEREO	A type of photography in which photographs taken of the same area from different angles are combined to produce visible features in three-dimensional relief.
SUPPLEMENTARY SAMPLE STOP	A stop added to a traverse after the stations are numbered. Mission planning continues through launch and the supplementary sample stops are inserted between normal traverse stations.
SUPRATHERMAL *soup'-rah-therm'-al*	Having energies greater than thermal energy.
SUBSATELLITE	A small unmanned satellite, deployed from the spacecraft while it is in orbit, designed to obtain various types of solar wind, lunar magnetic, and S-band tracking data over an extended period of time.

TALUS *tail-us*	Rock debris accumulated at the base of a cliff by erosion of material from higher elevation.
TEMPORAL	Referring to the passage or measurement of time.
TERMINATOR *term'-ugh-nay-tor*	The line separating the illuminated and the darkened areas of a body such as the Earth or Moon which is not self-luminous.
TERRA *terr'-ugh*	Those portions of the lunar surface other than the maria; the lighter areas of the Moon. They are visible to the unaided eye.
TIDAL	Referring to the very small movement of the surface of the Moon or the Earth due to the gravitational attraction of other planetary bodies. Similar to the oceanic tides, the solid parts of the Earth's crust rise and fall twice daily about three feet. Lunar tides are somewhat larger. The tides of solid bodies are not felt by people but are easily observed with instruments.
TIMELINE	A detailed schedule of astronaut or mission activities indicating the activity and time at which it occurs within the mission.
TOPOGRAPHIC *Top'-oh-grá-fick*	Pertaining to the accurate graphical description, usually on maps or charts, of the physical features of an area on the Earth or Moon.
TRANSEARTH	During transit from the Moon to the Earth.
TRANSIENT	A short lived event that does not repeat at regular intervals, often occurring in a system when first turned-on and before reaching operating equilibrium. For example, the initial current surge that occurs when an electrical system is energized.
TRANSLUNAR	During transit from the Earth to the Moon.
TRANSPONDER *Trans-pón-der*	A combined receiver and transmitter whose function is to transmit signals automatically when triggered by a suitable signal. Those used in space are sensitive to radio signals.
UMBRA *um-bruh*	The dark central portion of the shadow of a large body such as the Earth or Moon. Compare penumbra.
UP-SUN	Into the direction of the Sun and related to lunar surface photography.
URANIUM *your-raiń-nee-um*	One of the heavy metallic elements that are radioactive.
VECTOR	A quantity that requires both magnitude and direction for its specification, as velocity, magnetic force field and gravitational acceleration vectors.
WAVELENGTH	The distance between peaks (or minima) of waves such as ocean waves or electromagnetic waves.
X-RAY	Electromagnetic radiation of non-nuclear origin within the wavelength interval of 0.1 to 100 Angstroms (between gamma-ray and ultra-violet radiation). X-rays are used in medicine to examine teeth, lungs, bones, and other parts of the human body; they also occur naturally.
ZODIACAL LIGHT *zo-dié-uh-cal*	A faint glow extending around the entire zodiac but showing most prominently in the neighborhood of the Sun. (It may be seen in the west after twilight and in the east before dawn as a diffuse glow. The glow may be sunlight reflected from a great number of particles of meteoritic size in or near the ecliptic in the planetoid belt).

Tables

Table 1.—*Timeline of Apollo 17 Mission Events*

Event	Time from liftoff hours and minutes	Day	Eastern Standard Time
Launch	0:00	12/6	9:53 p.m.
Trans Lunar Injection	3:21	12/7	1:14 a.m.
Lunar Orbit Insertion	88:56	12/10	2:49 p.m.
Descent Orbit Insertion	93:13	12/10	7:06 p.m.
Spacecraft Separation	110:28	12/11	12:21 p.m.
Lunar Landing	113:02	12/11	2:55 p.m.
EVA 1	116:40	12/11	6:33 p.m.
EVA 2	139:10	12/12	5:03 p.m.
EVA 3	162:40	12/13	4:33 p.m.
Lunar Liftoff	188:03	12/14	5:56 p.m.
Spacecraft Docking	190:05	12/14	7:58 p.m.
Trans Earth Injection	236:40	12/16	6:33 p.m.
Trans Earth EVA	257:30	12/17	3:23 p.m.
Splashdown (Pacific Ocean)	304:41	12/19	2:34 p.m.

Table 2.—*LRV Exploration Traverses*

(The entries in this table are brief. They are explained in the text and in the glossary. The table should be considered a general guide only; not every item is mandatory at each stop. The times are especially likely to change during the mission. The reader may wish to mark the actual times for himself on the table.)

EVA 1. Refer to figure 118 for traverse route and station location.

Station/activity	Segment distance (km)	Travel time (min)	Total travel distance (km)	Arrive station EVA time (hr:min)	Stop time (min)	Depart station EVA time (hr:min)
LM			0.00	0:00	107	1:47
Ride	0.10	1				
ALSEP			0.10	1:48	136	4:04
Ride	1.25	10				
LSP–1 lb			1.35	4:14	3	4:17
Ride	1.15	9				
Station 1			2.50	4:27	66	5:33
LSP–3 lb (at station 1)						
Ride	1.70	14				
LSP–½ lb			4.20	5:47	3	5:50
Ride	.60	5				
SEP			4.80	5:54	25	6:19
Ride	.10	1				
LM			4.90	6:20	40	7:00
Totals		40			380	7:00

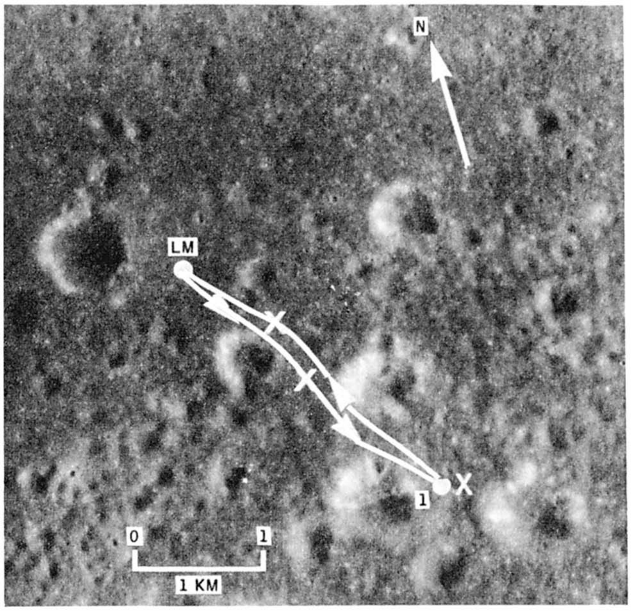

Figure 118.—EVA 1 LRV Traverse. Symbols: diamond—LRV sample location, X—LSPE charge location, circle—science station stop. NASA PHOTO S–72–50298.

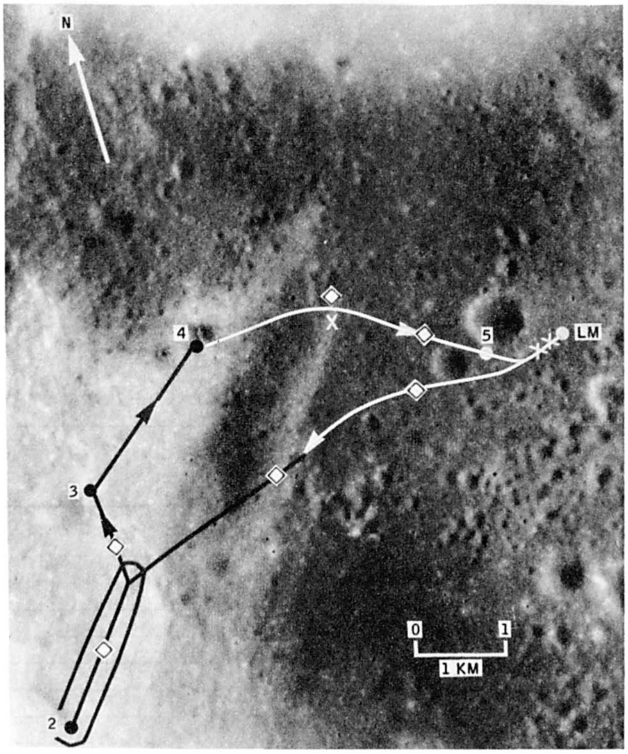

Figure 119.—EVA 2 LRV Traverse, symbols are same as those used in figure 118. NASA PHOTO S–72–50282.

TABLE 2.—*LRV Exploration Traverses*—Continued

EVA 1 — **STATION 1** — **STATION TIME—66 min.**

Investigate SUBFLOOR material exposed in crater rim; study historical sequence and mode of emplacement of multiple DARK MANTLE units—at 650m. mantled crater in plains area.

Initial overhead Pan Geophysics TV Pan	Observation of DARK MANTLE along linear boundary separating two possible mantle units. Observation of bright crater rim deposits.	SUBFLOOR material—sampling in crater rim.	DARK MANTLE—investigate and sample lighter and darker DARK MANTLE units.	Final overhead Pan.
	Observations 70mm. photos. Structural or depositional relationships.	Documented sampling Boulders. Rocks and soil. Rake sampling.	Rake sampling Documented sampling (both sides of contact). Double core near edge of DARKER MANTLE unit.	
0:05	0:05	0:26	0:26	0:04

TABLE 2.—*LRV Exploration Traverses*—Continued

EVA 2. Refer to figure 119 for traverse route and station locations.

Station/activity	Segment distance (km)	Travel time (min)	Total travel distance (km)	Arrive station EVA time (hr:min)	Stop time (min)	Depart station EVA time (hr:min)
LM			0. 00	0:00	52	1:52
Ride	0. 25	2				
LSP–⅛ lb			0. 25	0:54	3	0:57
Ride	1. 55	13				
LRV Sample			1. 30	1:10	2	1:12
Ride	1. 70	14				
LRV Sample			3. 50	1:26	2	1:28
Ride	3. 65	30				
Station 2			7. 15	1:58	51	2:49
Ride	1. 03	8				
LRV Sample			8. 18	2:57	2	2:59
Ride	1. 03	8				
LRV Sample			9. 21	3:08	2	3:10
Ride	1. 04	9				
Station 3			10. 25	3:18	45	4:03
Ride	0. 67	6				
LRV Sample			10. 92	4:09	2	4:11
Ride	1. 33	11				
Station 4			12. 25	4:22	41	5:03
Ride	1. 35	11				
Photo			13. 60	5:14	5	5:19
LRV Sample						
LSP–6 lb						
Ride	0. 90	7				
LRV Sample			14. 50	5:26	2	5:28
Ride	0. 90	7				
Station 5			15. 40	5:36	30	6:06
Ride	0. 55	5				
LSP–¼ lb			15. 95	6:10	3	6:13
Ride	0. 35	3				
LM			16. 30	6:16	44	7:00
Totals		134			286	7:00

TABLE 2.—*LRV Exploration Traverses*—Continued

EVA 2 STATION 2 STATION TIME—51 min

Study MASSIF and LIGHT MANTLE and their relationships—at base of SOUTH MASSIF and proximal end of LIGHT MANTLE.

Initial overhead Pan. Geophysics. TV Pan.	Observations of MASSIF, trench, blocks, and LIGHT MANTLE.	MASSIF—investigate and sample base of SOUTH MASSIF.	LIGHT MANTLE—investigate and sample furrowed area at proximal end of mantle.	Final overhead Pan.
	Observations 70mm. photos. Uplands. Blocks and trench. LIGHT MANTLE.	Documented samples. Boulders. Rocks and soil. Rake sample. Polarimetry.	Rake sample. Documented samples of rocks and soil. Single core.	
0:05	0:05	0:21	0:16	0:04

EVA 2 STATION 3 STATION TIME—45 min

Study scarp and LIGHT MANTLE and their relationships—small bright craters near base of scarp.

Initial overhead Pan. Geophysics. TV Pan.	Observations of scarp and LIGHT MANTLE—origin of scarp, age relationships with mantle.	LIGHT MANTLE—sampling at intermediate point—small craters.	Scarp—investigate relations between scarp and LIGHT MANTLE and sample materials of scarp face.	Final overhead Pan.
	Observations 70mm. photos. Scarp.	Documented sampling. Rake sampling. Radial sampling of small bright crater.	Exploratory trench. Documented sampling 70mm. photos.	
0:05	0:05	0:13	0:18	0:04

EVA 2 STATION 4 STATION TIME—41 min

Study dark halo crater, LIGHT MANTLE, and historical sequence in light and dark materials—at edge of 110m. dark halo crater near distal edge of LIGHT MANTLE.

Initial overhead Pan. Geophysics. TV Pan.	Observations of LIGHT MANTLE, dark ejecta, contact relations, crater interior.	LIGHT MANTLE—sample distal part at small bright craters.	Dark Halo Crater—investigate and sample to determine origin (internal or external) history.	Final overhead Pan.
	Observations 70mm. photos. Crater interior. Scarp.	Documented sampling. Radial sampling of small crater. Rake sample.	Radial sampling. Double core near edge of dark ejecta.	
0:05	0:05	0:11	0:16	0:04

Table 2.—*LRV Exploration Traverses*—Continued

EVA 2 **STATION 5** **STATION TIME—30 min.**

Study relations between SUBFLOOR and DARK MANTLE—on rim of low-rimmed 700m. mantled crater in plains area.

Initial overhead Pan	Observations of crater rim materials (SUBFLOOR), blocks, and DARK MANTLE.	SUBFLOOR—sampling of crater rim materials and boulders near rim crest for comparison with other SUBFLOOR samples.	DARK MANTLE—sampling lateral variation; any possible source of DARK MANTLE.	Final overhead Pan.
Geophysics TV Pan	Observations 70mm. photos. Crater wall	Documented sampling Rake sampling Compare with SUBFLOOR material from earlier station.	Double core in undisturbed DARK MANTLE material.	
0:05	0:05	0:05	0:11	0:04

EVA 3. Refer to figure 120 for traverse route and station locations.

Station/activity	Segment distance (km)	Travel time (min)	Total travel distance (km)	Arrive station EVA time (hr:min)	Stop time (min)	Depart station EVA time (hr:min)
LM			0. 00	0:00	45	0:45
Ride	1. 55	13				
LRV Sample			1. 55	0:58	2	1:00
Ride	1. 55	13				
Station 6			3. 10	1:12	47	15:9
Ride	1. 25	10				
Station 7			4. 35	2:10	47	2:57
Ride	1. 65	14				
Station 8			6. 00	3:10	47	3:57
Ride	1. 85	15				
Station 9			7. 85	4:13	30	4:43
Ride	. 70	6				
LRV Sample			8. 55	4:48	2	4:50
Ride	. 70	6				
Station 10B			9. 25	4:56	47	5:43
Ride	1. 75	14				
LSP-¼ lb			11. 00	5:57	3	6:00
Ride	0. 10	1				
LSP-⅛ lb			11. 1	6:01	3	6:04
Ride	0. 05	0				
LM			11. 15	6:05	55	7:00
Totals		92			328	7:00

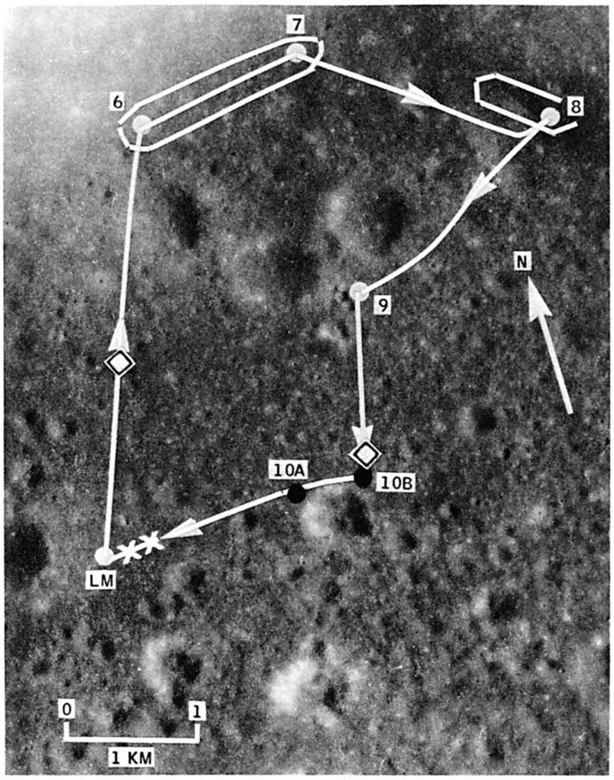

FIGURE 120.—EVA 3 LRV Traverse. Station 10A or 10B are alternate locations. One will be selected during the mission. Symbols are same as those used in figure 118. NASA PHOTO S–72–50299.

TABLE 2.—*LRV Exploration Traverses*—Continued

EVA 3 **STATION 6 and 7** **STATION TIME—88 min**

Study Northern MASSIF and sample widest possible variety of rock types—near the base of the MASSIF.

Initial overhead Pan	Observations of base of MASSIF, mantling materials, boulders.	MISSIF material—sample at base of MASSIF; study relation to DARK MANTLE.	MASSIF material—investigate and sample widest possible variety of boulders near base of MASSIF; investigate relations of boulders to DARK MANTLE.	Final overhead Pan.
Geophysics TV Pan				
	Observations 70mm. photos. Boulders.	Documented sampling Rake sampling. Polarimetry North MASSIF SCULPTURED HILLS.	Documented sampling of variety of boulders. Photo-documentation of boulder fabrics.	
0:10	0:10	0:20	0:40	0:08

TABLE 2.—*LRV Exploration Traverses*—Continued

EVA 3 **STATION 8** **STATION TIME—44 min.**

Characterize SCULPTURED HILL unit and study its relationships to DARK MANTLE—near base of SCULPTURED HILLS

Initial overhead Pan. Geophysics TV Pan	Observations of SCULPTURED HILL unit and DARK MANTLE.	SCULPTURED HILLS materials—sample at base of SCULPTURED HILL for comparison with other highland units.	DARK MANTLE—sample for lateral variation.	Final overhead Pan.
	Observation	Rake sampling Documented sampling of rocks and soil.	Documented sampling	
0:05	0:05	0:20	0:10	0:04

EVA 3 **STATION 9** **STATION TIME—29 min.**

Study historical sequence and origin (?) of DARK MANTLE—at fresh 80m. crater.

Initial overhead Pan Geophysics TV Pan	Observations of dark crater and its ejecta.	DARK MANTLE—investigate crater and sample its ejecta blanket to study internal stratigraphy and/or origin; lateral variation.	Final overhead Pan.
	Observation 70mm. photos Crater interior	Radial sampling Rake sampling (?) Documented sampling	
0:05	0:05	0:15	0:04

EVA 3 **STATION 10A*** **STATION TIME—47 min**

Study relationships between DARK MANTLE and SUBFLOOR—on rim of 500m. blocky-rimmed mantled crater.

Initial overhead Pan Geophysics TV Pan	Observations of DARK MANTLE/SUBFLOOR relations in crater interior.	SUBFLOOR material—investigative and sample on rim of crater.	DARK MANTLE—investigative and sample.	Final overhead Pan.
	Observations 70mm. photos crater wall blocks.	Documented sampling of rocks and soil.	Double core near contact with SUBFLOOR material. Documented sampling of rocks and soil.	
0:05	0:05	0:17	0:14	0:04

*10A and 10B are *alternate* locations for Station 10. One of the two will be selected during the mission depending upon the sampling objectives to be emphasized.

TABLE 2.—*LRV Exploration Traverses*—Continued

EVA 3 — **STATION 10B*** — **STATION TIME—47 min**

Study relationships between DARK MANTLE and large blocks—on rim of 500m. blocky-rimmed mantled crater

Initial overhead Pan	Observations of DARK MANTLE/SUBFLOOR relations in crater interior and of DARK MANTLE/block relations near rim.	SUBFLOOR material—investigate and sample large blocks near crater rim.	DARK MANTLE—investigate and sample.	Final overhead Pan.
Geophysics				
TV Pan				
	Observations 70mm. photos crater wall blocks.	Documented sampling of block materials.	Double core near contact with SUBFLOOR material. Documented sampling of rocks and soil.	
0:05	0:05	0:17	0:14	0:04

*10A and 10B are *alternate* locations for Station 10. One of the two will be selected during the mission depending upon the sampling objectives to be emphasized.

TABLE 3.—*ALSEP Timeline*

Time after start of EVA in hour/min	Activity	
	Commander	LM pilot
1:15	Remove experiment pallett	Inspect LM.
1:20	Remove experiment pallett	Remove ALSEP.
1:30	Prepare for ALSEP travel	Fuel RTG.
1:40	Travel to ALSEP site	Travel to ALSEP site.
1:50	Deploy HFE	Place ALSEP packages and connect electrical cables.
1:55	Deploy HFE	Deploy LSP.
2:00	Deploy HFE	Remove LSP.
2:05	HFE drill hole for probe 1	Deploy LMS.
2:10	HFE drill hole for probe 1	Level, align, deploy C/S.
2:20	HFE emplace probe 1	Deploy antenna.
2:25	HFE drill hole for probe 2	Deploy LEAM.
2:30	HFE drill hole for prove 2	Deploy LSP antenna.
2:40	HFE emplace probe 2	Deploy LSP Geophone.
2:50	Drill deep core	Deploy LSP Geophone.
3:00	Drill deep core	ALSEP photos.
3:10	Recover deep core and emplace neutron flux.	ALSEP photos.
3:20	Initial settings for LRV navigational system	Stow sampler. Return core to LM. Get SEP.
3:30	SEP site traverse and layout	Prepare for SEP Transmitter deploy.
3:40	SEP Deploy Transmitter	SEP Deploy Transmitter.
3:50	Begin traverse activities	Begin traverse activities.

TABLE 4.—*Apollo Science Experiments*

The science experiments carried on each Apollo mission are more numerous and also more complex than those carried on each preceding Apollo mission. None of the Apollo 11 experiments is operating today (October 1972). About half of the Apollo 12 experiments still operate and all of the Apollo 14, 15, and 16 experiments are operating. We expect that many of the experiments will continue to send data to the Earth for several years.

Experiment		Mission and landing site						
		A-11 Sea of Tranquility	A-12 Ocean of storms	A-13 Mission aborted	A-14 Fra Mauro	A-15 Hadley-Apennine	A-16 Descartes	A-17 Taurus-Littrow
Number	*Orbital experiments*							
S—158	Multi-Spectral Photography		X					
S—176	Cm Window Meteoroid				X	X	X	X
S—177	UV Photography—Earth and Moon					X	X	
S—178	Gegenschein from Lunar Orbit			X	X	X		
S—160	Gamma-Ray Spectrometer					X	X	
S—161	X-Ray Fluorescence					X	X	
S—162	Alpha Particle Spectrometer					X	X	
S—164	S-Band Transponder (CSM/LM)			X	X	X	X	X
S—164	S-Band Transponder (Subsatellite)					X	X	
S—165	Mass Spectrometer					X	X	
S—169	Far UV Spectrometer							X
S—170	Bistatic Radar			X	X	X	X	
S—171	IR Scanning Radiometer							X
S—173	Particle Shadows/Boundary Layer (Subsatellite).					X	X	
S—174	Magnetometer (Subsatellite)					X	X	
S—209	Lunar Sounder							X
	Surface experiments							
S—031	Passive Seismic	X	X	X	X	X	X	
S—033	Active Seismic				X		X	
S—034	Lunar Surface Magnetometer		X			X	X	
S—035	Solar Wind Spectrometer		X			X		
S—036	Suprathermal Ion Detector		X		X	X		
S—037	Heat Flow			X		X	X	X
S—038	Charged Particle Lunar Env.			X	X			
S—058	Cold Cathode Ion Gauge		X		X	X		
S—059	Lunar Field Geology	X	X	X	X	X	X	X
S—078	Laser Ranging Retro-Reflector	X			X	X		
S—080	Solar Wind Composition	X	X	X	X	X	X	
S—151	Cosmic-Ray Detection (Helmets)	X						
S—152	Cosmic Ray Detector (Sheets)						X	
S—184	Lunar Surface Closeup Photography		X	X				
S—198	Portable Magnetometer				X		X	
S—199	Lunar Gravity Traverse							X
S—200	Soil Mechanics				X	X	X	X
S—201	Far UV Camera/Spectroscope						X	
S—202	Lunar Ejecta and Meteorites							X
S—203	Lunar Siesmic Profiling							X
S—204	Surface Electrical Properties							X
S—205	Lunar Atmospheric Composition							X
S—207	Lunar Surface Gravimeter							X
M—515	Lunar Dust Detector		X	X	X	X		
S—229	Lunar Neutron Probe							X

TABLE 5.—*Apollo Science Principal Investigators and Instrument Contractors*

Listed here are the principal investigators for all the scientific experiments that will have been done in the Apollo program when it ends in 1973. The principal investigator is the individual directly responsible for the scientific interpretation of the data obtained on each experiment. In most cases, he has the help of a team of experts in his field of science. Seldom before in the study of the science of either the Moon or the Earth has so much talent been brought to bear on the interpretation of an individual experiment.

Also listed are the instrument contractors. Only the prime contractors are shown. Many subcontractors from widely different geographic areas also contributed significantly toward the success of the new scientific discipline LUNAR SCIENCE.

There are also 189 principal investigators in the United States and 15 foreign countries who are carrying out researches on lunar samples. Because of the length of this list, their names could not be given here.

LUNAR SURFACE EXPERIMENTS

Experiment	Principal investigator	Instrument contractor
Lunar Passive Seismology	Dr. G. V. Latham University of Texas, Galveston, Tex.	Bendix, Aerospace Division, Ann Arbor, Mich.
Lunar Active Seismology	Dr. R. L. Kovach Department of Geophysics, Stanford University, Stanford, Calif. 94305	Bendix.
Lunar Tri-Axis Magnetometer	Dr. Palmer Dyal, Code N204–4 Ames Research Center, Moffett Field, Calif. 94034	Philco-Ford.
Solar Wind Spectrometer	Dr. C. W. Snyder Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif. 91103	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif.
Suprathermal Ion Detector	Dr. J. W. Freeman Department of Space Science, Rice University, Houston, Tex. 77001	Time Zero Corp.
Lumar Heat Flow (with drill)	Dr. M. E. Langseth Lamont-Doherty Geological Observatory, Columbia University, Palisades, N. Y. 10964	Columbia University, Arthur D. Little, Cambridge, Mass., Martin-Marietta, Denver, Colo.
Cold Cathode Ionization Gauge	Dr. F. S. Johnson University of Texas at Dallas, Post Office Box 30365, Dallas, Tex. 75230	The Norton Co. Time Zero Corp.
Lunar Geology Investigation Apollo 11 and 12.	Dr. E. M. Shoemaker California Institute of Technology, Pasadena, Calif. 91109	
Lunar Geology Investigation Apollo 14 and 15.	Dr. G. A. Swann U.S. Geological Survey, Flagstaff, Ariz. 86001	
Lunar Geology Investigation Apollo 16 and 17.	Dr. W. R. Muehlberger Geology Department, University of Texas, Austin, Tex. 78712.	
Laser Ranging Retro-Reflector	Dr. J. E. Faller Wesleyan University, Middletown, Conn. 06457.	Bendix.
Solar Wind Composition	Dr. J. Geiss University of Berne, Berne, Switzerland.	University of Berne, Berne, Switzerland
Cosmic Ray Detector (sheets)	Dr. R.L. Fleischer General Physics Lab, G.E. R. & D. Center, Schenectady, N.Y. 12301	General Electric, R. & D. Center, Schenectady, N.Y.

TABLE 5.—*Apollo Science Principal Investigators and Instrument Contractors*—Continued

LUNAR SURFACE EXPERIMENTS

Experiment	Principal investigator	Instrument contractor
Portable Magnetometer	Dr. Palmer Dyal, Code N204-4 Ames Research Center, Moffett Field, Calif. 94034	Ames Research Center (in-house)
Lunar Traverse Gravimeter	Dr. M. Talwani Lamont-Doherty Geological Observatory, Columbia University, Palisades, N.Y. 10946	Massachusetts Institute of Technology—Draper Laboratory
Lunar Seismic Profiling	Dr. R. L. Kovach Department of Geophysics, Stanford University, Stanford, Calif. 94305	Bendix
Surface Electrical Properties	Dr. Gene Simmons Massachusetts Institute of Technology, Building 54–314, Cambridge, Mass. 02139	Massachusetts Institute of Technology, Center for Space Research, Cambridge, Mass., and Raytheon, Sudbury, Mass.
Lunar Atmospheric Composition	Dr. J. H. Hoffman Atmospheric & Space Sciences, University of Texas at Dallas, Post Office Box 30365, Dallas, Tex. 75230	Bendix and University of Texas at Dallas, Division of Atmospheric and Space Sciences, Post Office Box 30365, Dallas, Tex. 75230
Lunar Surface Gravimeter	Dr. Joseph Weber Department of Physics and Astronomy, University of Maryland, College Park, Md. 20742	Bendix. LaCoste and Romberg, Austin, Tex.
Lunar Dust Detector	Mr. J. R. Bates, Code TD5 Manned Spacecraft Center, Houston, Tex. 77058	
Lunar Neutron Probe	Dr. D. S. Burnett Division of Geology and Planetary Sciences, California Institute of Technology, Pasadena, Calif. 91109	California Institute of Technology, Pasadena, Calif. 91109, Manned Spacecraft Center, Houston, Tex. 77058
Soil Mechanics	Dr. James K. Mitchell Department of Civil Engineering, University of California, Berkeley, Calif. 94720	
Far UV Camera/Spectroscope	Dr. G. Carruthers, Code 7124.3 U.S. Naval Research Laboratory, Washington, D.C. 20390	U.S. Naval Research Laboratory, Washington, D.C.
Gamma-Ray Spectrometer	Dr. J. R. Arnold Chemistry Department, University of California-San Diego, La Jolla, Calif. 92037	Jet Propulsion Laboratory
X-Ray Fluorescence	Dr. Isidore Adler Theoretical Studies Br., Code 641, Goddard Space Flight Center, Greenbelt, Md. 20771	American Science and Engineering, Inc., 11 Carleton St., Cambridge, Mass. 02142

TABLE 5.—*Apollo Science Principal Investigators and Instrument Contractors*—Continued

LUNAR SURFACE EXPERIMENTS

Experiment	Principal investigator	Instrument contractor
Alpha Particle Spectrometer	Dr. Paul Gorenstein American Science and Engineering, Inc., 11 Carleton St., Cambridge, Mass. 02142	American Science and Engineering, Inc.
S-Band Transponder (subsatellite) S-Band Transponder (CSM/LM)	Mr. W. L. Sjogren Mail Code 156–251, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif. 91103	TRW Systems Group, One Space Park, Redondo Beach, Calif. 98278 (None for CSM/LM S-Band.)
Mass Spectrometer	Dr. J. H. Hoffman Atmospheric & Space Sciences, University of Texas at Dallas, Post Office Box 30365, Dallas, Tex. 75230	University of Texas at Dallas, Division of Atmospheric and Space Sciences, Post Office Box 30365, Dallas, Tex. 75230
Far UV Spectrometer	Mr. W. E. Fastie The Johns Hopkins University, Baltimore, Md. 21218	Applied Physics Laboratory, 8621 Georgia Ave., Silver Spring, Md. 20910
Bistatic Radar	Mr. H. T. Howard Stanford Electronics Laboratory, Stanford University, Stanford, Calif. 94305	
IR Scanning Radiometer	Dr. Frank J. Low Lunar and Planetary Laboratory, The University of Arizona, Tucson, Ariz. 85721	Barnes Engineering Co., Defense and Space Contracts Division, 44 Commerce Road, Stamford, Conn.
Particle Shadows/Boundary Layer (Subsatellite).	Dr. Kinsey A. Anderson Space Science Laboratory, University of California, Berkeley, Calif. 94726.	Analog Technology, 3410 East Foothill Boulevard, Pasadena, Calif. 91907. Subcontractor to TRW Systems Group.
Magnetometer (Subsatellite)	Dr. Paul J. Coleman, Jr Department of Planetary & Space Science, UCLA, Los Angeles, Calif. 90024.	Time Zero Corp., 3530 Torrance Boulevard, Torrance, Calif. 90503. Subcontractor to TRW Systems Group.
Lunar Sounder	Dr. Stanley H. Ward Department of Geological and Geophysical Sciences, Room 30 Mines Building, University of Utah, Salt Lake City, Utah. Mr. Walter E. Brown, Jr Mail Code 183–701, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif, 91103	
SM Orbital Photographic Tasks 24-Inch Panoramic Camera.	CSM "Photo Team"* Mr. F. J. Doyle, Chairman Topographic Division, U.S. Geological Survey, 1340 Old Chainbridge Road, McLean, Va. 22101.	Itek Corp., 10 Maguire Road, Lexington, Mass. 02173.
SM Orbital Photographic Tasks, 3-Inch Mapping Camera, 3-Inch Stellar Camera.	CSM "Photo Team"* Mr. F. J. Doyle, chairman.	Fairchild Camera and Instrument Corp., 300 Robbins Lane, Syosset, Long Island, N.Y. 11791

TABLE 5.—*Apollo Science Principal Investigators and Instrument Contractors*—Continued

LUNAR SURFACE EXPERIMENTS

Experiment	Principal investigator	Instrument contractor
SM Orbital Photographic Tasks, Laser Altimeter.	CSM "Photo Team"* Mr. F. J. Doyle, chairman	RCA Aerospace Systems Division, Post Office Box 588, Burlington, Mass. 01801
CM Visual Observations	Dr. Farouk El Baz Code MAS, NASA Headquarters, Washington, D.C. 20546	
Apollo Window Meteoroid	Mr. B. G. Cour-Palais/ TN61. NASA Manned Spacecraft Center, Houston, Tex. 77058	
UV Photography Earth and Moon Uses CM electric Hasselblad camera with specified lens and filters.	Dr. Tobias C. Owen Department of Earth and Space Sciences, The State University of New York, Stony Brook, N.Y. 11790	
Gegenschein from Lunar Orbit Uses CM 35-mm. Nikon camera.	Mr. Lawrence Dunkelman, Code 613. 3. Goddard Space Flight Center, Greenbelt, Md. 20771	
CM Photographic Tasks Uses standard CM facility camera.	CSM "Photo Team" * Mr. F. J. Doyle, chairman.	

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*The cameras flown in the Command and Service Modules are considered to be facility equipment, and have no principal investigator *per se*. The Photographic Team, headed by Mr. F. J. Doyle, fills the principal investigator role in preflight development and flight planning activities. There are many investigators who do scientific analysis of the facility data from the cameras and laser, and these data will continue to be available for study in the future by more scientists. As in the case of scientists who perform analysis on lunar samples, they are too numerous to list here.

Table 6.—*Scientific Equipment Suppliers*

The companies that built scientific equipment for the Apollo program, including 11 through 17, are shown here. Clearly, I could not list every company that produced a small screw; there would be too many. So I have chosen to list those companies, or governmental agencies, that contributed significantly to the design, building, etc., of hardware.

Company	Address	Responsibility
Motorola, Inc., Govt. Elec. Div	Scottsdale, Ariz	Command Receiver, ALSEP Control Data System
U.S. Geological Survey	Flagstaff, Ariz	Lunar Geology Investigation
Murdock Engineering	Los Angeles, Calif	Penetrometer
Ames Research Center	Moffett Field, Calif	Lunar Portable Magnetometer and Lunar Surface Magnetometer
Analog Technology Corporation	Pasadena, Calif	Particle Shadows/Boundary Layer (Subsatellite), Particles Experiment Subsystem, and Gamma Ray Spectrometer
California Institute of Technology	Pasadena, Calif	Neutron Flux Gradient Experiment
Electro-Optical Systems, Inc	Pasadena, Calif	Design and fabrication of electronics and packaging, ALSEP Solar Wind Spectrometer
Jet Propulsion Laboratory	Pasadena, Calif	Gamma Ray Spectrometer, and Medium Energy Solar Wind
North American Rockwell	Downey, Calif	Lunar Sounder
Philco	Palo Alto, Calif	Lunar Tri-Axis Magnetometer
Space Ordnance Systems, Inc	Saugus, Calif	Grenade Launcher, Subsystem of ASE
Stanford Electronic Laboratory, Stanford University	Standord, Calif	Bistatic Radar
Time Zero Corporation	Torrance, Calif	Magnetometer (Subsatellite), Suprathermal Ion Detector, and Electronics Subsystem of LEAM
TRW Systems Group	Redondo Beach, Calif	S-Band Transponder (Subsatellite and CSM/LM), and SS Particle Boundary Layer
University of California at Berkeley	Berkeley, Calif	Cosmic Ray PI Support
Velonex, Inc	Santa Clara, Calif	High Voltage Power Supply, Lunar Surface Ultraviolet Camera/Spectrograph
Martin Marietta Corporation	Denver, Colo	Apollo Lunar Surface Drill (ALSD)
Barnes Engineering Co	Stamford, Conn	IR Scanning Radiometer
Chicago-Latrobe Co	Chicago, Ill	Core stems, core and bore bits, Apollo Lunar Surface Drill
Applied Physics Laboratory	Silver Spring, Md	FAR UV Spectrometer
Black and Decker Manufacturing Co	Towson, Md	Powerhead, Apollo Lunar Surface Drill
Westinghouse Electric Corp	Baltimore, Md	CM Color TV Camera
American Science & Engineering, Inc	Cambridge, Mass	Alpha Particle Spectrometer, and X-Ray Fluorescence
ITEK Corp	Lexington, Mass	24-Inch Panoramic Camera
Arthur D. Little, Inc	Cambridge, Mass	Heat Flow Probes, Surface Electrical Properties, Boron Filament/Glass Epoxy-bore stems, Apollo Lunar Surface Drill, and LSG Thermal Subsystem
Littleton Research & Engineering Corp	Littleton, Mass	Assist in structural verification of hardware
Massachusetts Institute of Technology—Draper Laboratory	Cambridge, Mass	Lunar Traverse Gravimeter
Massachusetts Institute of Technology—Center for Space Research Geophysics	Cambridge, Mass	Surface Electrical Properties
RCA Aerospace Systems Division	Burlington, Mass	Laser Altimeter
David Clark Co	Worcester, Mass	Communication Carriers (Com-caps)
Raytheon Co	Sudbury, Mass	Surface Electrical Properties
Bendix Corp	Ann Arbor, Mich	ALSEP
Rosemont Engineering Co	Minneapolis, Minn	Platinum Sensors
Eagle-Picher Ind., Electric Division	Joplin, Mo	Battery housing and attachment design
Washington University at St. Louis	St. Louis, Mo	Cosmic Ray PI Support and Equipment Construction
The Singer Co., Kearfott Division	Little Falls, N.J	Pendulous Vertical Sensors

TABLE 6.—*Scientific Equipment Suppliers—Continued*

Company	Address	Responsibility
Paillard	Sinden, N.J	Hasselblad Cameras and Equipment
RCA—Astro Electronics Div	Princeton, N.J	Ground Commanded Color TV
RCA—Government Systems	Camden, N.J	EVA Communications Systems and Lunar Communications Relay Unit (LCRU)
Atomic Energy Commission	Albuquerque, N. Mex	Radioisotope Thermoelectric Generator (RTG)
Bulova Watch Co., Inc., Systems & Instrument Division	Valley Stream, N.Y	LSP Timers
Fairchild Camera and Instrument Corp	Syosset, Long Island, N.Y	3-Inch Mapping Camera
General Electric R. & D. Center	Schenectady, N.Y	Cosmic Ray Detector (Sheets)
Norton Research Corp	Merrick, N.Y	Cold Cathode Gauge
Yardney Electric Corp	New York, N.Y	Silver Zinc Battery Apollo Lunar Surface Drill
Maurer	Long Island, N.Y	16 mm Camera System
Research Foundation of NY	Albany, N.Y	PI Support for UV Photography
Naval Research Laboratory	Washington, D.C	FAR UV Camera/Spectroscope
Hershaw Chemical Co	Solon, Ohio	Inorganic scintillator assembly—Gamma Ray spectrometer
General Electric	Valley Forge, Pa	Equipment design and construction Cosmic Ray Detector (sheets)
Radio Corporation of America	Lancaster, Pa	Photomultiplier tubes—Gamma Ray Spectrometer
Three-B Optical Co	Gibsonia, Pa	Schmidt optics for Lunar Surface Ultraviolet Camera
Union Carbide Corp	Oak Ridge, Tenn	Sample Return Containers (SRC's)
LaCoste & Romberg	Austin, Tex	Sensor for LSG
Manned Spacecraft Center	Houston, Tex	Lunar Dust Detector, Cold Cathode Ionization Gauge, and Soil Mechanics
Rice University	Houston, Tex	Suprathermal Ion Detector
Teledyne Industries Goetech Division	Garland, Tex	Seismic Detection Subsystem of ASE
University of Texas at Dallas	Dallas, Tex	Mass Spectrometer and Atmospheric Composition
University of Berne	Berne, Switzerland	Solar Wind Composition.

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