ON THE MOON WITH APOLLO 16

A Guidebook to the Descartes Region

APOLLO 16

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

April 1972

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ON THE MOON WITH APOLLO 16
A Guidebook to the Descartes Region

by
Gene Simmons

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PREFACE

The program to land man on the Moon and to return him safely to Earth, begun 10 years ago by President Kennedy, has shown science in the making to a world-wide audience. And we scientists have had a growing responsibility to tell that audience more about the scientific aspects of the lunar missions. 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 16 mission to the Moon so that others can share with me the excitement of the scientific exploration of the Descartes region of the Moon.

I have benefitted greatly from constructive comments on the Apollo 15 booklet by many people. Several hundred individuals sent me advance copy of their work and suggested ways to improve the Apollo 16 booklet. Especially helpful were the comments by Ed Roedder, Pembroke Hart, John Baum, J. W. DeWitt, Jr., Edward Anders, Nancy Anders (age 12) and George Anders (age 14).

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, Fred Hörz, and Mike Duke each provided several new photographs. The manuscript was improved greatly as a result of comments by Ruth and David Fitterman, Scott Baldridge, Amy and Mayme Strickland, James Head, George Esenwein, Terry Todd, Herb Wang, William Allen, Joe Allen, George Abbey, Doug Ward, Jack Sevier, Peter Mason, John Pomeroy, Don Bane, and Don Beattie. My former secretary Jean Ellis helped with many revisions. To all of these people, I express my thanks.

GENE SIMMONS
January 1972
Winchester, Massachusetts

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 begining 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 16. 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 set up 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, even I find that section is rather lengthy although complete, but 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.

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 mission, Apollo 15, are so exciting that I think you may wish to know what is being done on Apollo 16. 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 16 mission to the Moon's surface is expected to be launched from Cape Kennedy on 16 April 1972 and to land a few days later in the highlands region of the Moon, near the crater Descartes. 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. It will give the astronauts their first chance to collect rocks in the lunar highlands, believed by some scientists to be the oldest region on the Moon, and also to study and collect new volcanic rocks on the Moon. These rocks 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.

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. Some craters are very old (several billion years) but most 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 16 over those of earlier missions. Total duration of the mission has increased to a planned time of about $12\frac{1}{2}$ 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 73 hours. The amount of time spent by the astronauts on the lunar surface outside the LM, which has become known as Extravehicular Activity or EVA, has 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 second 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 16 mission is shown in Table 1. Scientific activities while the spacecraft is in orbit around the Earth consist mainly in photographing the Earth with film that is sensitive to ultraviolet (uv) radiation. The uv photography will be con-

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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.

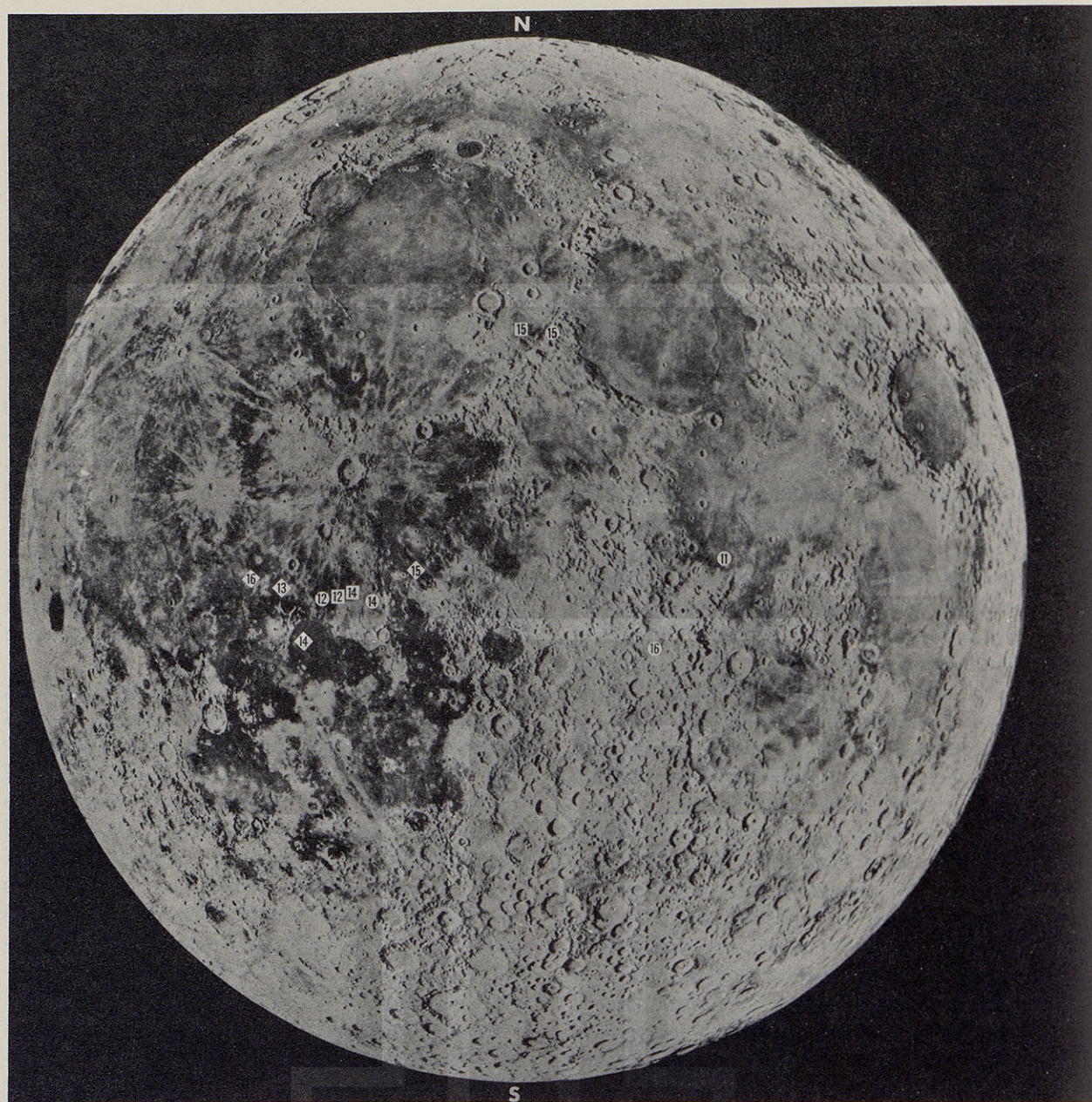FIGURE 1.—Front side of the Moon. This side always faces the Earth. Shown here are locations of the previous Apollo landings (circles) and of the impacts on the Moon of spent S–IVB stages (diamonds) and LM ascent stages (squares). The numbers in the symbols are the mission numbers. The sound waves created in the Moon by the impacts travel through the Moon; they are used to study the interior of the Moon. NASA PHOTO S–72–16338.

tinued during the journey to the Moon and pictures will be obtained at various distances from the Earth. Studies of these uv photos will help us interpret similar data for other planets. We currently have such photos of Mars and Venus. It is likely that most of the exploration of other planets during the next century will be done remotely by highly sophisticated robot space probes, carrying with them advanced computers that will be able to solve complicated problems. These will be necessary because of the great distances involved. Do you realize that the time needed for light to travel to Jupiter and back to Earth is about 1½ hours? This is the time needed to send and receive radio messages. A message to Pluto and back would take about 12 hours.

During the journey to the Moon and before the landing, one of the spent stages of the rockets that were 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 and 15 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.

Several of these orbital experiments will measure the approximate chemical composition of the Moon's surface materials. Others are intended to measure the variations of gravity and of the magnetic field around the Moon. A laser altimeter will be used to obtain precise elevations of features that
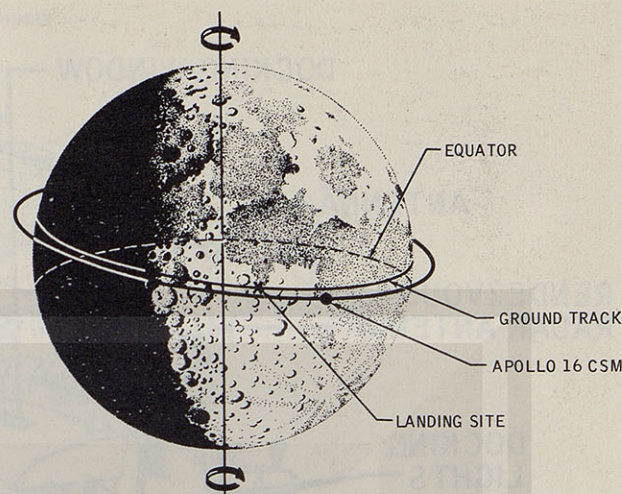

FIGURE 2.—Orbit and ground track of Apollo 16. Because the Moon rotates, the ground track is different for each revolution of the CSM.

lie on the Moon's surface beneath the orbiting CSM. An extensive set of photographs will be obtained. 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 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.

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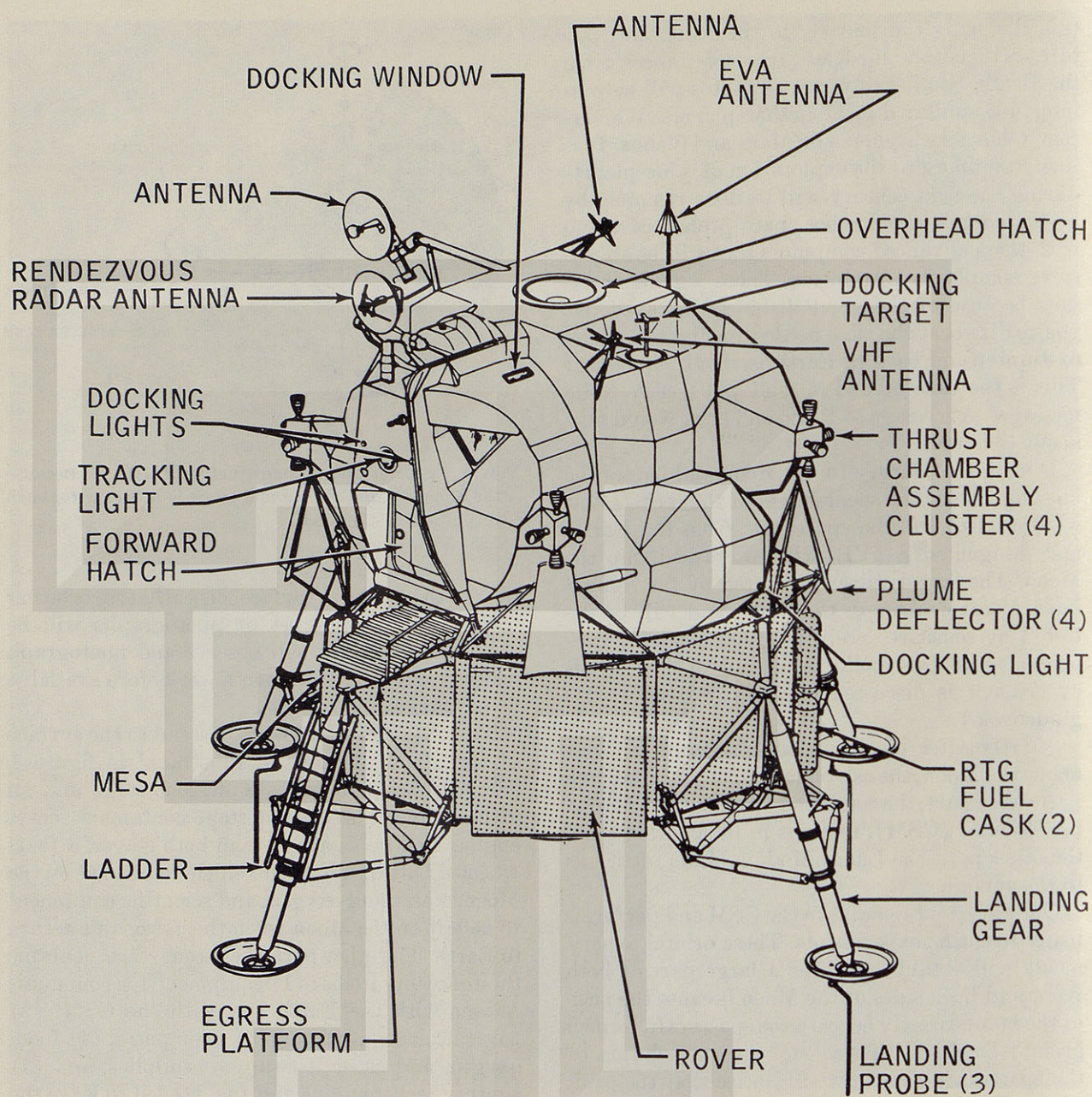
FIGURE 3.—The Lunar Module (LM). The shaded portion, the descent stage, remains on the Moon when the astronauts leave in the ascent stage to rendezvous with the CM and return to Earth. Scientific equipment is stored in the Mesa.
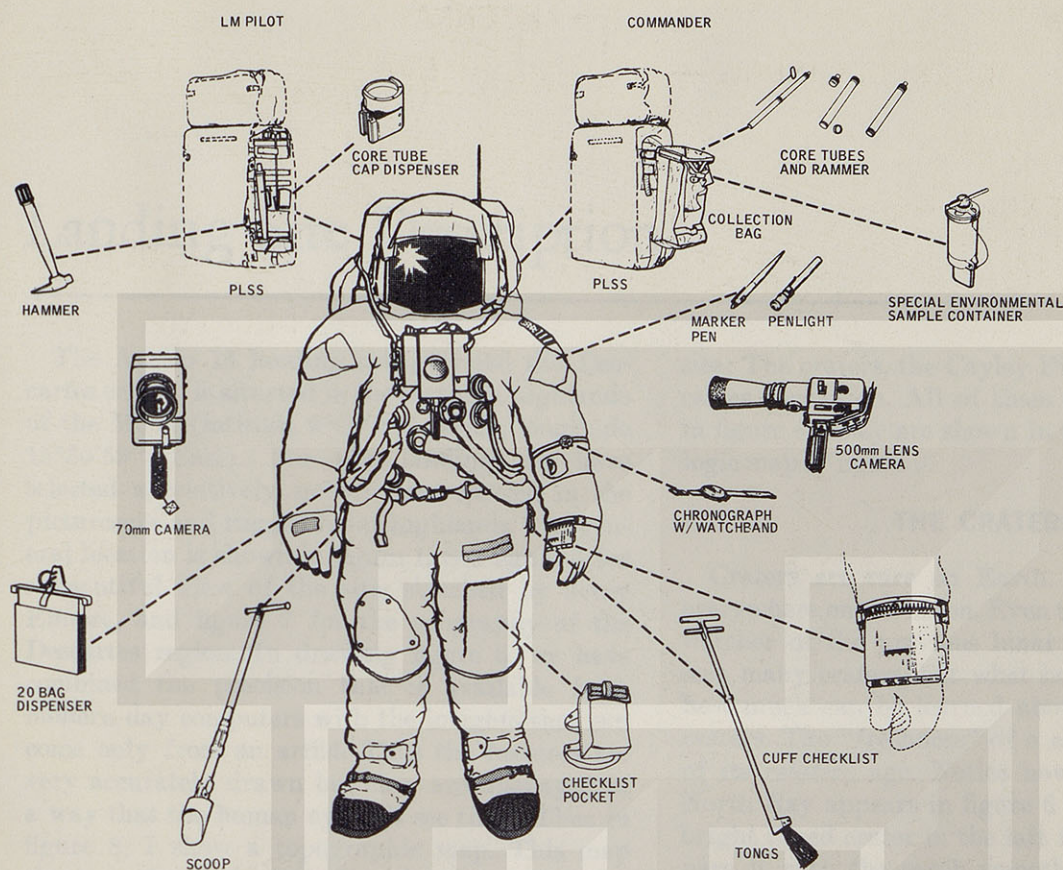
FIGURE 5.—Astronant suit and equipment. The suit prevents exposure of the astronaut to the Moon's vacuum. It incorporates many improvements over the suits used on early Apollo flights. Sketched also are several items of equipment.

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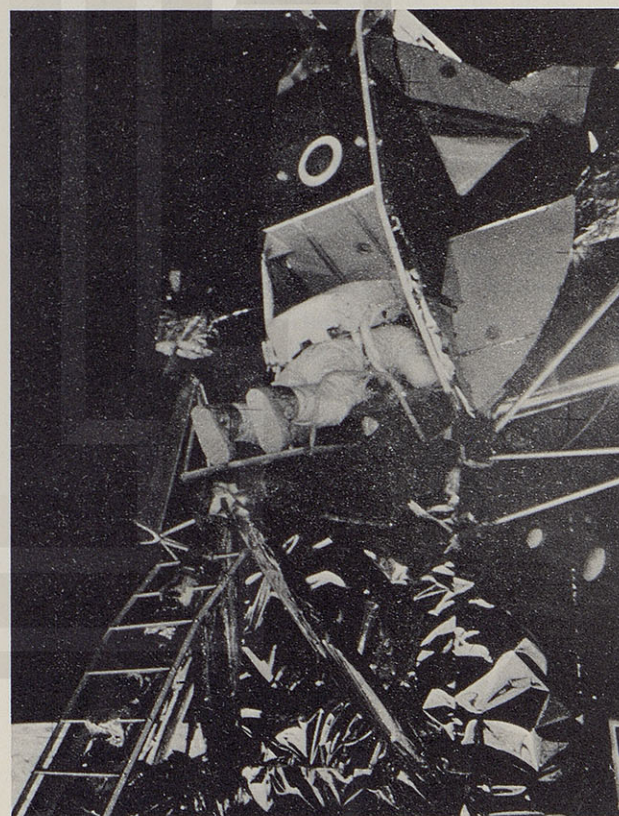
FIGURE 4.—Egress. Apollo 11 astronaut Aldrin is shown egressing from the LM. Note the ladder that leads down one leg from the platform. NASA PHOTO S-71-31090.

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Landing Site Description

The Apollo 16 landing area, termed the Descartes region, is situated in the southern highlands of the Moon (latitude 9°00'01" South, longitude 15°30'59" East). For this landing, we have selected a relatively smooth area nestled in the picturesque and rugged lunar highlands. The general location is shown in figure 1. See figure 6 for a beautiful view of the site, sketched by Jerry Elmore, and figure 7 for the geography of the Descartes region. 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 show a topographic map. This map shows in detail the elevation of each point on the landing site. It represents the basic data used to construct figure 6.

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 old 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 followed climbed part way up the initial slopes of the Apennine Mountains, a light area.

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 they indeed stand higher than the maria is now well established by measurements made on previous Apollo flights. On Apollo 16, we will visit the highlands and examine two different kinds of rock that together cover about 11½ percent of the front side of the Moon.

In the rest of this section, I will discuss the several geologic features present at the landing site: The craters, the Cayley Plains, and the Descartes formation. All of them are clearly visible in figure 6. They are shown in the simplified geologic map of figure 9.

THE 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. Notice how sharp the crater North Ray appears in figure 6 (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 10.

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 Moon were due to volcanoes. His hypothesis stood unchallenged for two centuries until someone suggested the impact hypothesis. As so often happens
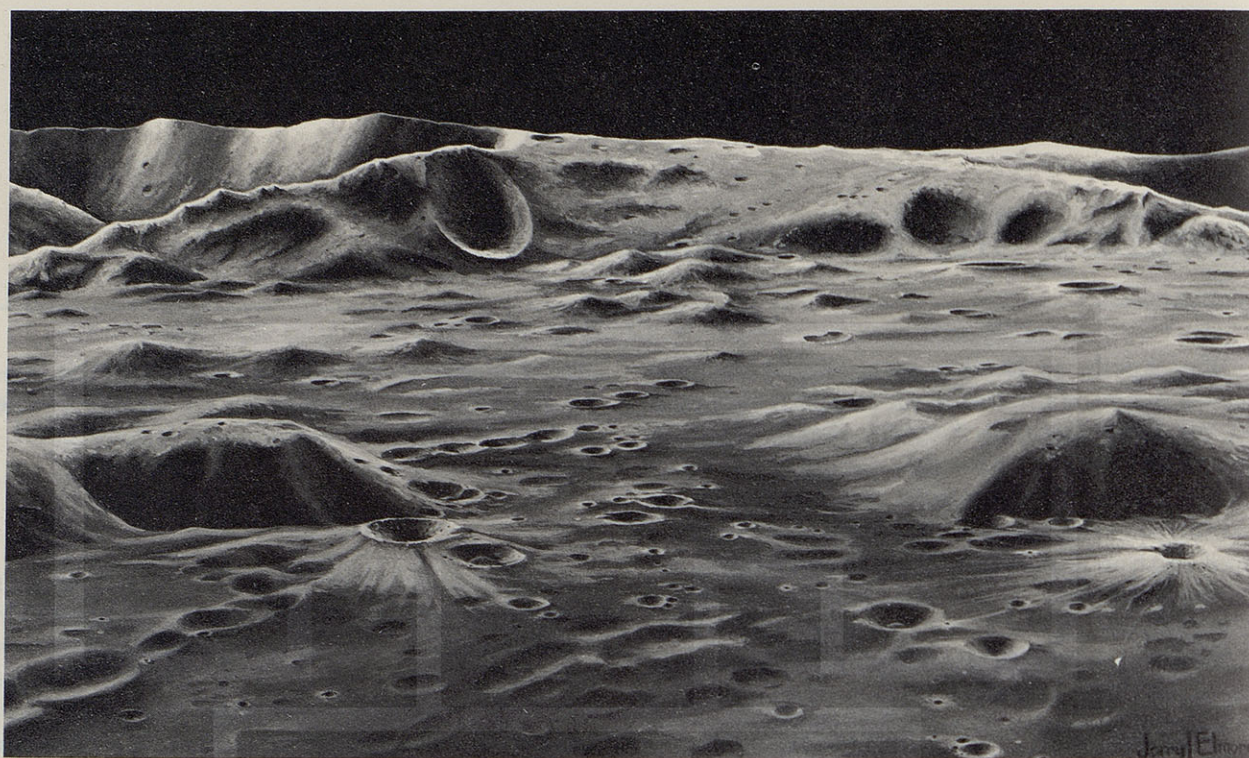
FIGURE 6.—The Descartes region, landing site of Apollo 16. We are looking due east and downward at an angle of about 10°. The bright rayed crater in the lower right hand corner is South Ray. The one slightly to the left of center and in the foreground is North Ray crater. The planned touchdown point for the LM is roughly midway between these two craters. The names of additional features are shown on figure 18. *Artwork by Jerry Elmore.* NASA PHOTO A–71–60976.

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. Consider South Ray (shown in figure 6). Note the rays. They are the white streaks that radiate from the crater. The material along any particular ray came from different depths in the Moon. By studying craters on Earth, we have learned that the position along a ray corresponds to a particular depth. We have even watched through slow motion photography the material exhumed from depth by a large explosion; we have traced it through the air and seen it land at a particular distance along the ray. Thus by sampling the rocks from a ray, 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 *shapes* of craters also yield information about the subsurface rocks. Note that North Ray and the unnamed crater about ½ mile southwest of it both have flat bottoms. Considerably smaller craters at the landing site, such as Flag, have cone-shaped bottoms. One interpretation of these features is that a relatively solid layer occurs at a depth of about 250 feet. Samples of this layer have been excavated by the impact that formed North Ray and will surely be identified in the rocks brought back to Earth. The layer is possibly a basalt flow similar in many ways to those known on Earth.

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, such as Stone and

Smoky (figure 6), can now be collected near the bottom of the mountains. 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 16 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.

THE CAYLEY PLAINS

Between the two bright rayed craters (North Ray and South Ray) lies a rather smooth surface, the Cayley Plains. It is on this smooth surface that the LM will land. The rocks beneath the plains make up the Cayley formation* which is the largest single rock unit* in the highlands of the

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* Geologists use the terms formation and rock unit interchangeably to mean a single body of rock than can be recognized as such. Thus on Earth, where we have more time, geologists very often trace the outline of a formation by physically following it over the surface. Formerly they walked or rode horses. Today they use jeeps and helicopters. On the Moon, we rely on photographs and telescopes. The abbreviation for formation is fm.

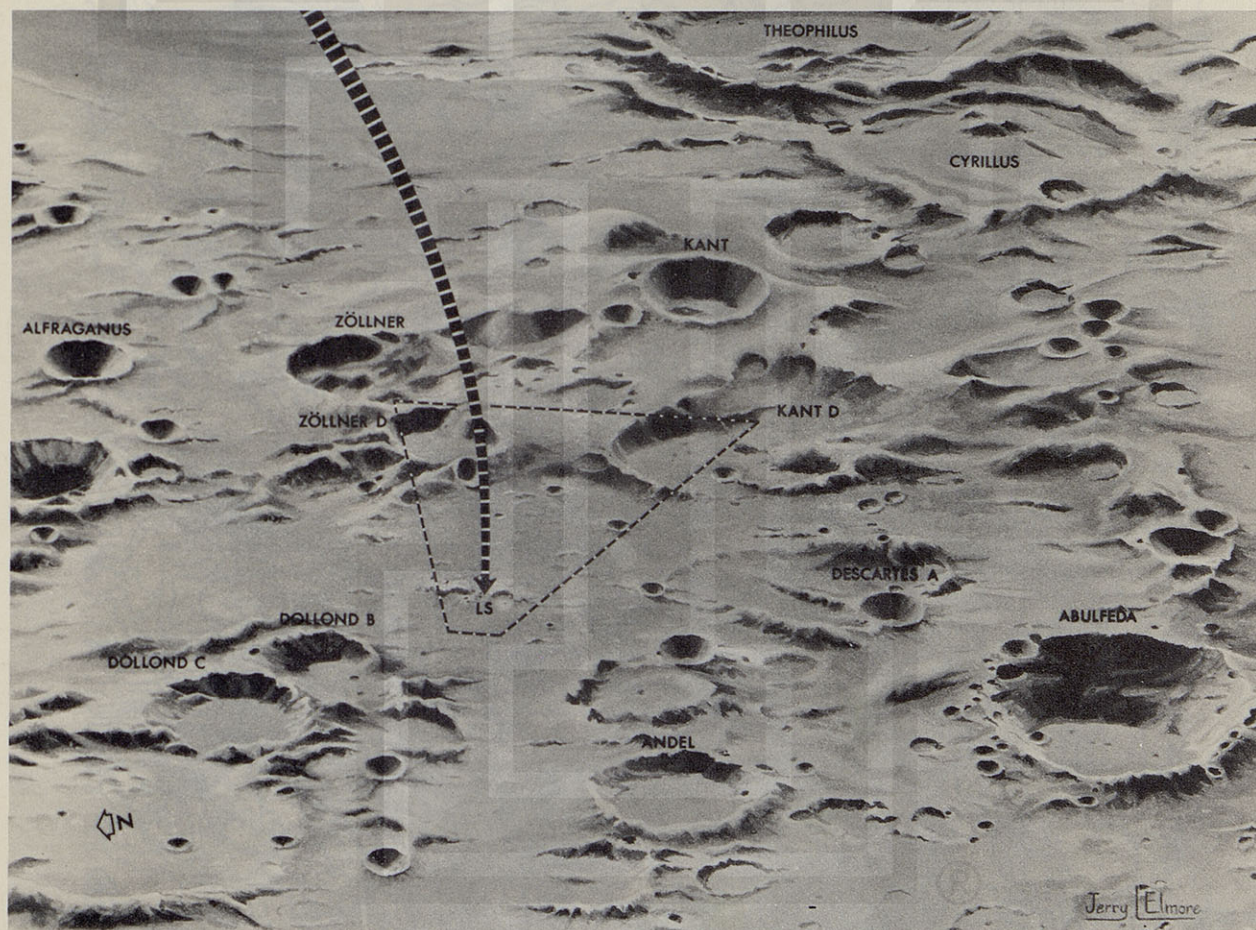FIGURE 7.—General geography of the Descartes region. The ruggedness of the lunar highlands is shown very well in this sketch of the region by artist Jerry Elmore. Note the flat bottoms of the large craters. We are looking due east. The trajectory of the descending LM is shown as the heavy dashed line. Location of area of Figure 6 is indicated by the light dashed line. NASA S-72-16853.

FIGURE 8
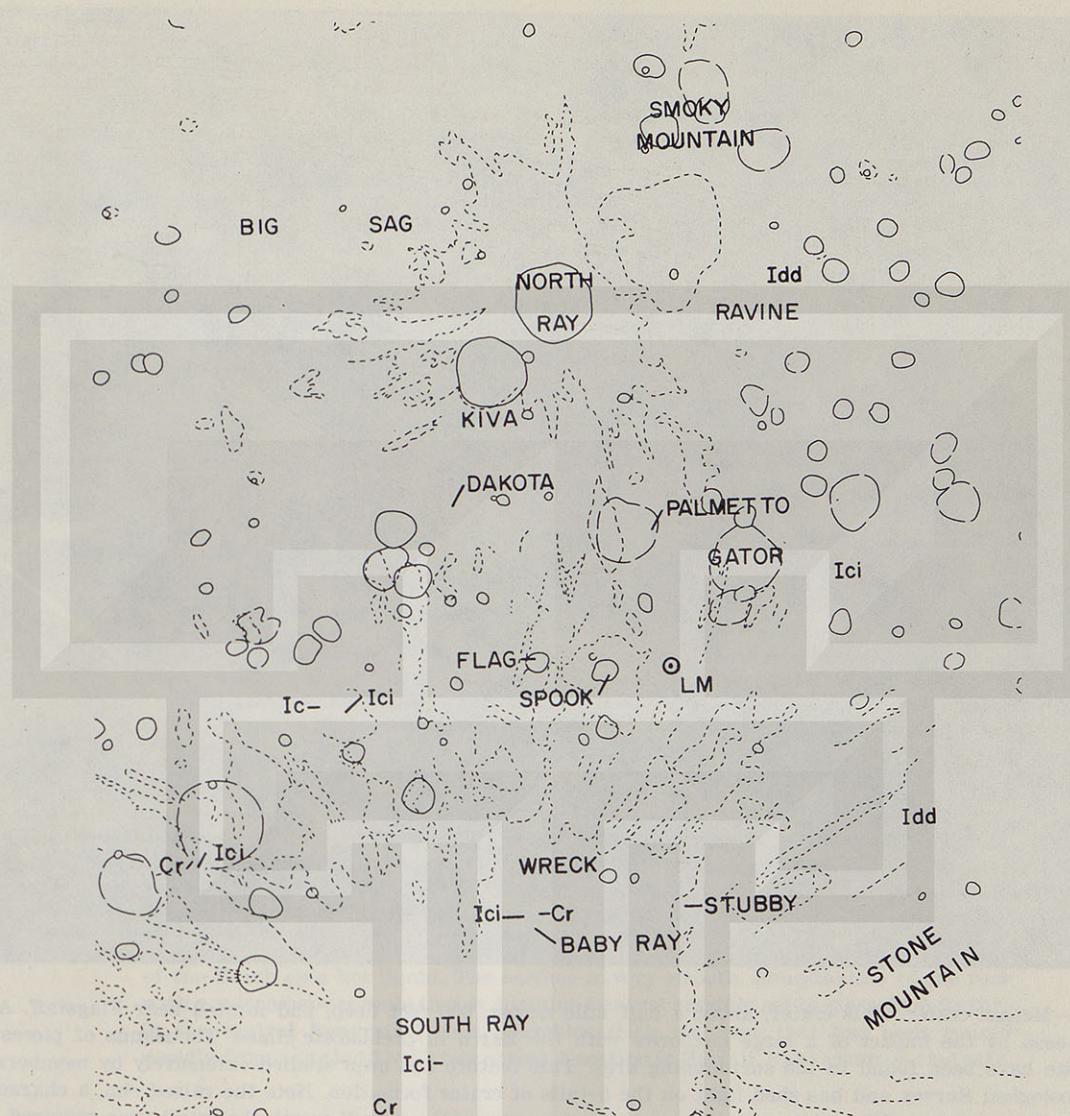vicin
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FIGURE 9.—Geologic sketch map of the Descartes region. The various symbols on this
map are used to indicate different features and different kinds of rocks that have
been discovered already through observations made of the Moon through Earth-based
telescopes and with spacecraft photography. Most of the area is covered with the
Cayley formation, shown on the map with the symbol Ic. The names of various
features, picked by the Apollo 16 crew, are also shown. The symbol Cr is used for
material from the rayed craters. The region of Stone Mountain is covered with
material that contains many furrows and is identified as the Descartes Formation
(Idd). It occurs in the vicinity of Smoky Mountain also. Note the extensive rays
of South Ray crater. Compare this map with the photo of the same area shown in
Figure 18. Map courtesy of U.S. Geological Survey.

FIGURE 8.—Topographic Map of the Descartes region. This map shows the elevations of the surface of the Moon in the
vicinity of the Apollo 16 landing site. The lines, called contours, connect points of equal elevation. Thus the line
that is labeled 8050 indicates that the elevation of all points on the Moon's surface corresponding to that line lies
at a relative height of 8050 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 is 10 meters (about 30 feet). NASA PHOTO S-72-16335.

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FIGURE 10.—Meteor crater. This crater, about a half mile across, 600 feet deep, and located near Flagstaff, Arizona, 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.

front side of the Moon. It covers about 7% of the front side. Samples from several levels within this unit can be collected by the astronauts. Some will be collected near the landing point, others along the traverses. Rocks exhumed by North Ray Crater (and other craters) from depths to about 600 feet can be sampled in the rays. Several layers are exposed in the east wall of North Ray Crater. They are probably the same layers that can be seen elsewhere in the landing site and form scarps (or cliffs) to the south and east of the crater. These layers may be layers of basalt. They may be something else. No one is now sure. The detailed sampling now planned for the Cayley fm should allow

us to obtain data with which to decipher this puzzle.

DESCARTES FORMATION

The Descartes fm consists of highland plateau material, the surface of which is composed of hills and valleys. To the non-geologist, this description may sound odd. But then, it's the easiest way of saying that the Descartes fm is the one that occurs on the highland plateau and that it forms hills and valleys. You see, we know that on Earth certain kinds of rocks have certain characteristics—some

FIGURE 11.—Basalt flow on Earth. This rock, now solidified, poured out on the surface of the Earth as a hot liquid. The surface is very smooth. Examination of the rock with a microscope reveals that it contains mineral crystals set in glass. The feature in the central foreground that resembles thick molasses that has been poured rapidly from a jar is 10 to 12 feet across. Location is Hawaii. NASA PHOTO S–72–16316.

occur mostly in valleys, some "hold up" ridges, others form very rough and majestic mountains, and so on. Because we have not yet seen a sample from the Descartes fm, we can best describe it in terms of those large scale characteristics that we *have* seen.

This unit covers about 4½% of the near-side of the Moon. Abundant samples of the Descartes fm should be available at the Apollo 16 landing site. The expected distribution of this material at the site is shown in Figure 9. This map was drawn on the bases of telescopic studies and photographs taken from orbit.

The Descartes formation is very likely composed of the igneous rock basalt. Terrestrial basalts are very common and are most likely known to you.

The rock that flows out of most volcanoes is lava. When it cools and becomes solid, then it is called basalt. A well-known example is that of the Hawaiian volcanoes. A striking illustration of a basalt flow in Hawaii is shown in figure 11. Basalt is very wide-spread throughout the western United States and most visitors to that area see solidified basalt flows. A rock that is chemically similar to basalt but slightly coarser grained is diabase. Many examples of diabase are known. Visitors to New York City often cross a prominent scarp (the steep hill) on the western side of the Hudson River. That scarp is the face of a gently dipping, flat, tabular body of diabase, known as the Palisades sill. The rock of the Palisades sill is similar in many ways to basalts.

Lunar Roving Vehicle

In the LM the astronauts will take with them to the surface a four-wheeled vehicle that can be used to transport themselves and equipment over the lunar surface. It is termed the Lunar Roving Vehicle (LRV) or Rover (figure 12). 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 13. A photograph of the folded Rover taken just before it was placed in the LM is shown in figure 14. The Rover deployment scheme is shown in figure 15. 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 16. In addition to the astronaut's oral descriptions, television pictures are telemetered back to Mission Control in Houston from the Rover. These pictures will be shown over the regular TV networks.
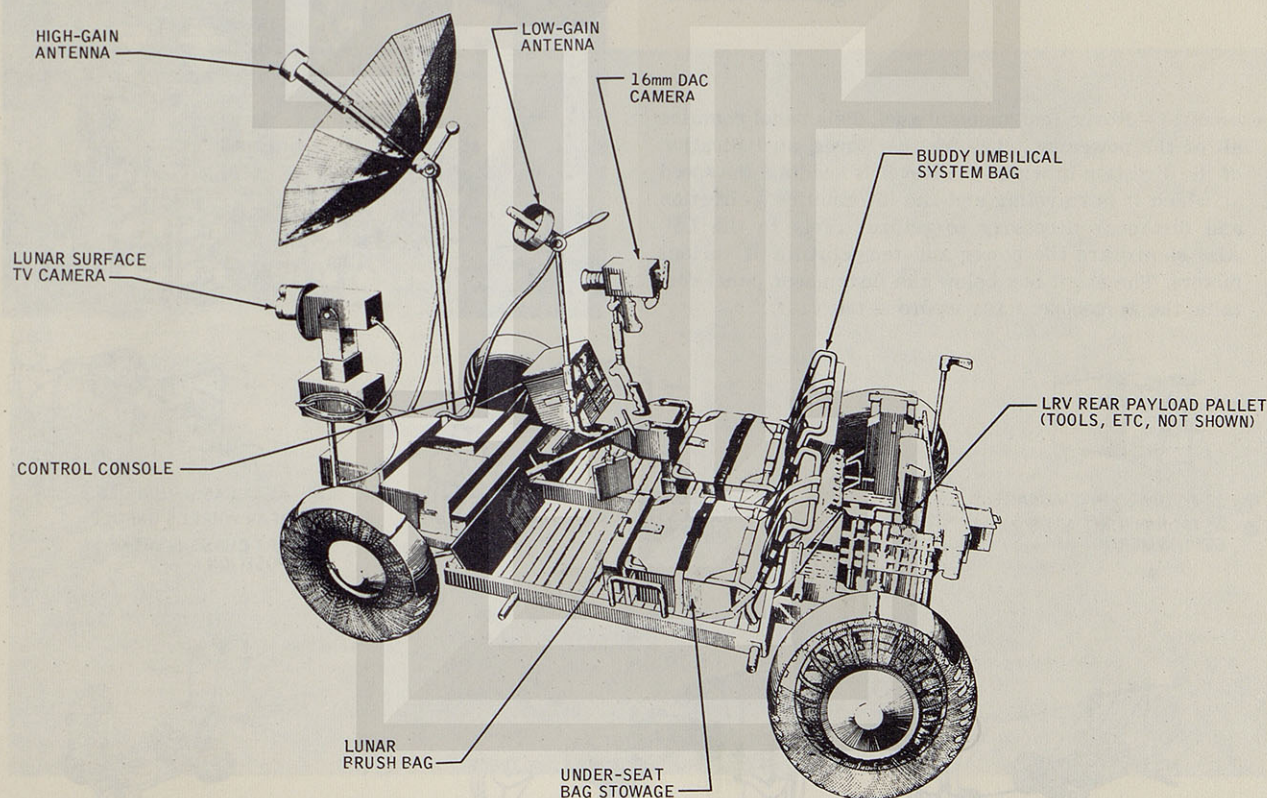

FIGURE 12.—The Lunar Rover. Both astronauts sit in seats with safety belts. About 7 minutes are required to fully deploy Rover. The capacity of the Rover is about 1000 pounds. The vehicle travels about 10 miles per hour on level ground. The steps necessary to remove it from the LM and to ready it for use are shown in Figure 15.
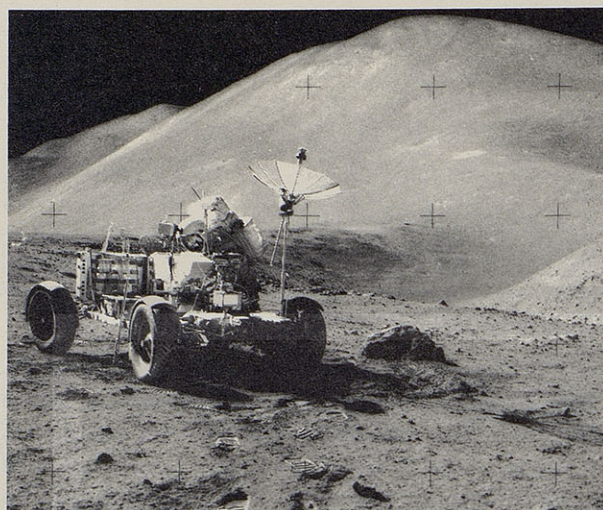
FIGURE 13.—The Apollo 15 Rover. Shown in the background is Mount Hadley delta, a 12,000 foot mountain. The valley on the right side of the photograph is about 1200 feet deep. On the Rover, note the high gain antenna and the television camera in the front and the tool carrier in the rear. The scale of the photograph varies greatly from the foreground to the horizon; it may be obtained from the footprints, the Rover, and the mountains in the distance. NASA PHOTO AS51–82–11121.
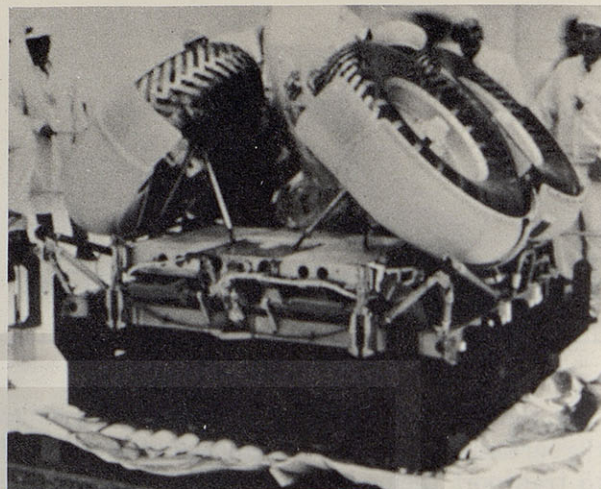
FIGURE 14.—Folded Rover. To save space in the LM, the Rover is carried to the Moon folded in this fashion. This photograph was taken at Cape Kennedy shortly before Rover was placed in the LM. NASA PHOTO 10S–KSC–371C–171/4.

FIGURE 16.—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. The small box below the instrument panel contains the gyroscope. NASA PHOTO S–72–16181.

- LRV STOWED IN QUADRANT
- ASTRONAUT INITIATES DEPLOYMENT

- ASTRONAUT LOWERS LRV FROM STORAGE BAY WITH FIRST REEL

- AFT CHASSIS UNFOLDS
- REAR WHEELS UNFOLD
- AFT CHASSIS LOCKS IN POSITION

- FORWARD CHASSIS UNFOLDS
- FRONT WHEELS UNFOLD

- FORWARD CHASSIS LOCKS IN POSITION. ASTRONAUT LOWERS LRV TO SURFACE WITH SECOND REEL.

- ASTRONAUT DISCONNECTS SSE
- ASTRONAUT UNFOLDS SEATS, FOOTRESTS

FIGURE 15.—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 3½ 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 16 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 has been built and was being stowed in the spacecraft at the time of writing.
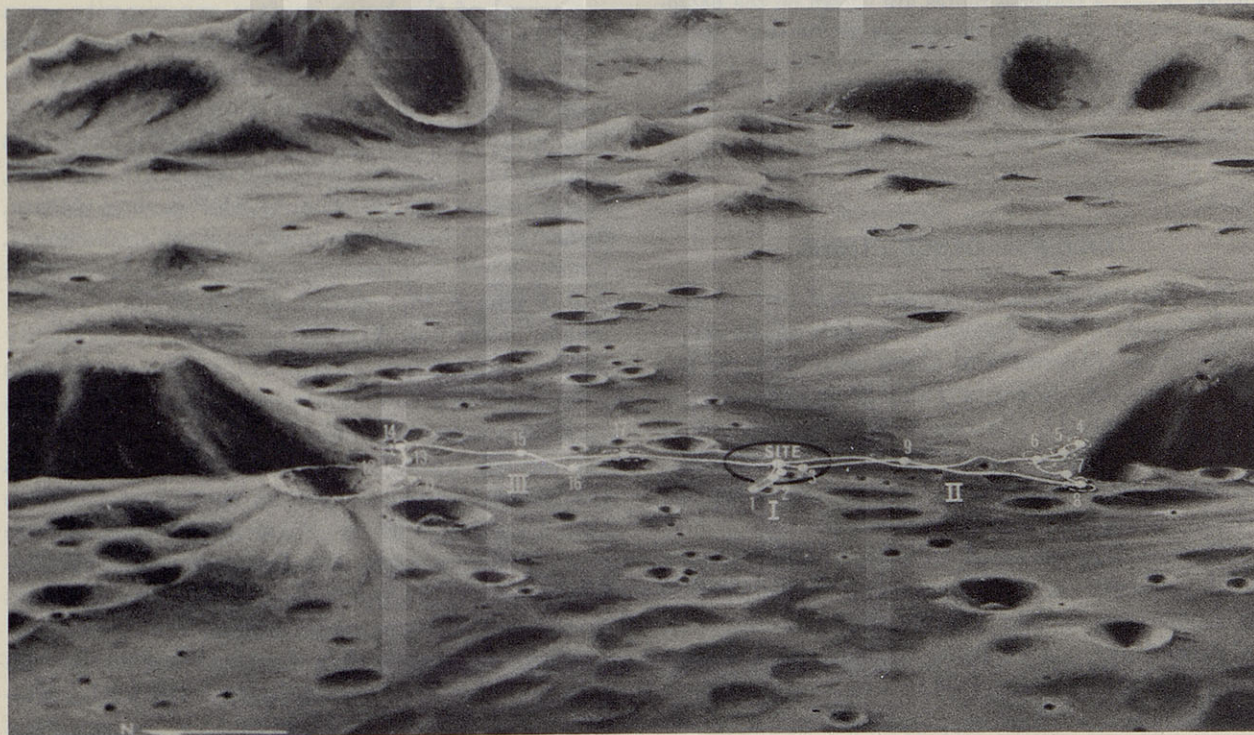

FIGURE 17.—The traverses planned for use with the Lunar Roving Vehicle. The Roman numerals indicate the three EVA's. The numbers are station stops. The station stops are keyed to the information given in Table 2. These same traverses are shown in figure 18, an overhead view of the landing site. *Drawn by Jerry Elmore.* NASA PHOTO S–72–16940.

DESCARTES LRV TRAVERSES

SMOKY MTN
NORTH RAY
SMOKY MTN
KIVA
RAVINE
PALMETTO
GATOR
FLAG
LANDING SITE
SPOOK
COVE
TRAP
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BABY RAY
STUBBY
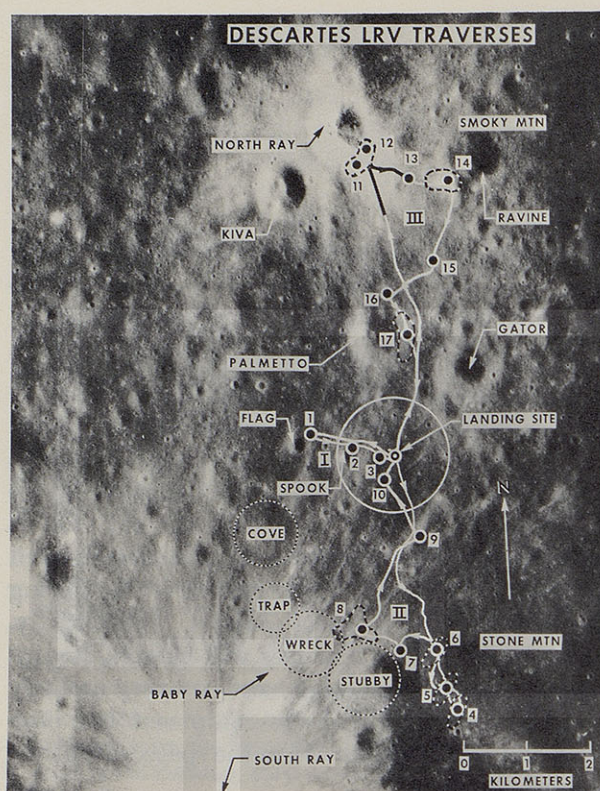STONE MTN
SOUTH RAY
N
0 1 2
KILOMETERS

FIGURE 18.—The traverse routes are shown on the *photograph* of the site. This photograph obtained on Apollo 14, has been used extensively in planning the surface activities. Shown also are the geographic names of various features that will be used by the astronauts during the mission. NASA PHOTO S-72-017-V.

TRAVERSE DESCRIPTIONS

The planned Rover traverses are shown in figures 17 and 18. 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 (January 15, 1972) and are not expected to change. However, extra stations may be added before, as well as during, the mission. These extra stations will be given a special designation to avoid confusing them with the existing stations.

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 to 3–3½ km from the LM. One walking EVA extends from the LM to the vicinity of Flag crater; another from the LM towards Stone Mountain; and a third towards Palmetto Crater.

LUNAR SURFACE SCIENTIFIC EXPERIMENTS AND HARDWARE

In addition to the observations made by the astronauts and the collection of samples of lunar material to be returned to Earth, several scientific experiments will be set out by the astronauts 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.

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 19. A photograph of the Apollo 14 ALSEP, which is similar but not identical to the Apollo 16 ALSEP, is shown in figure 20. The ALSEP central station, figure 21, although obviously 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 Earth. 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 Passive Seismic Experiment, the Active Seismic Experiment, the Lunar Surface Magnetometer, and the Heat Flow Experiment. I discuss briefly each of these experiments.

Electrical power for the experiments on the lunar surface is provided by the decay of radioactive plutonium in a device termed Radioisotope Thermoelectric Generator (RTG), shown in figure 22. A total of roughly 70 watts is delivered. Let me draw special attention to this power of 70 watts. It is truly incredible that all of the experi-

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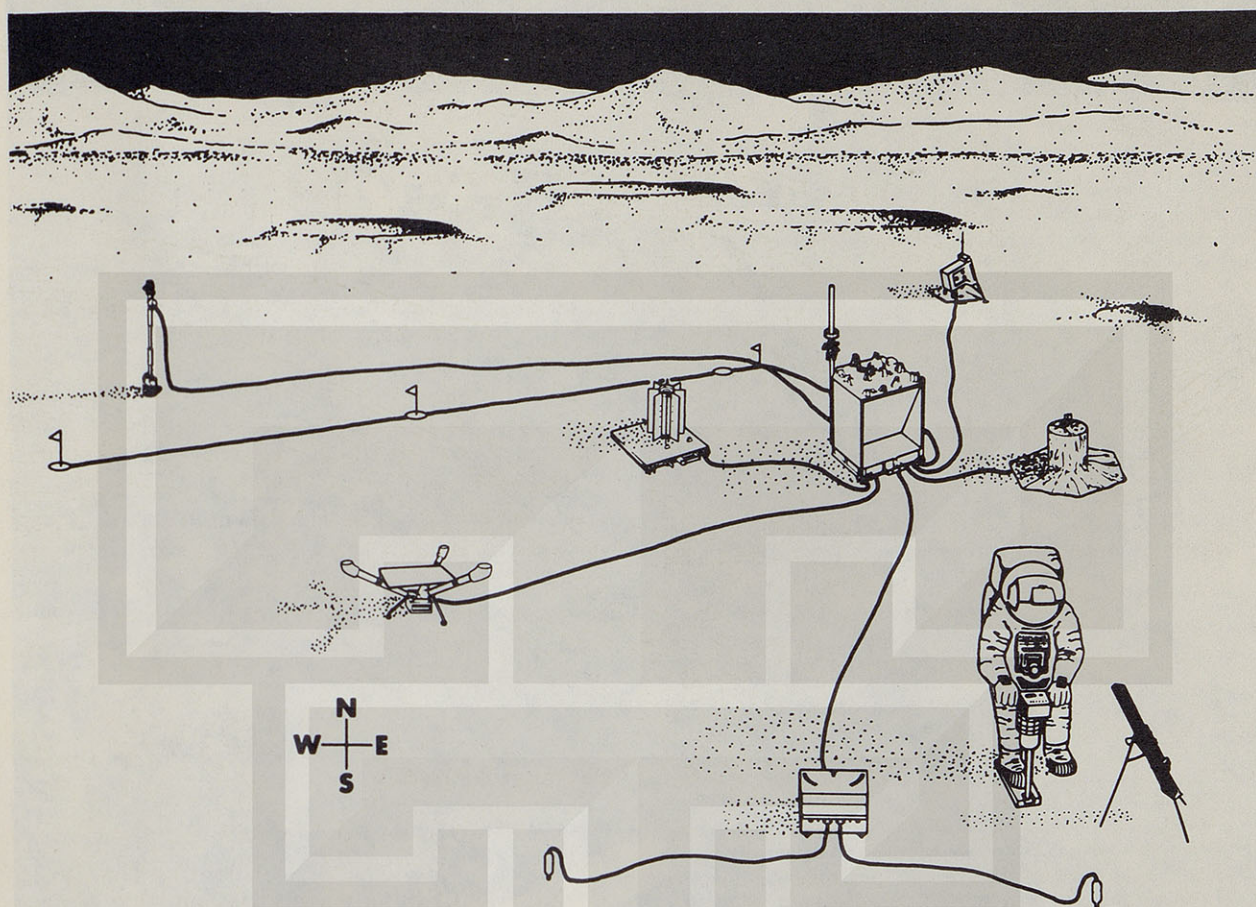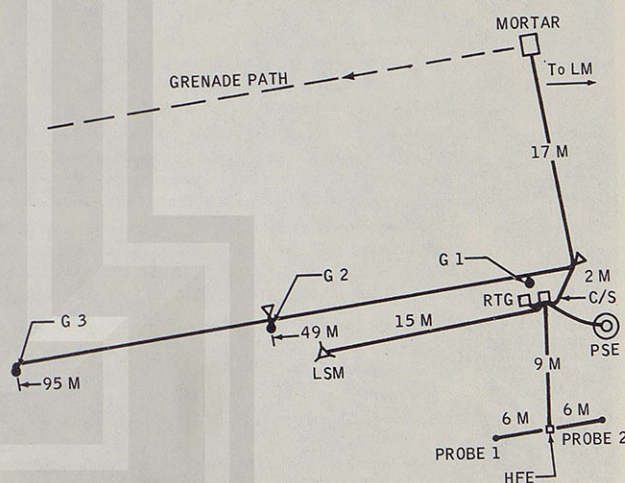ower of 70
f the experi-

FIGURE 19.—General layout of the ALSEP. (Above) 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 four experiments that are a part of the Apollo 16 ALSEP. This site is at least 300 feet west of the LH. North is towards top of figure. (Right) The correct distances (in meters) are shown on a map view of the site.

ments 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 20. The RTG is filed with nuclear fuel after the astronauts place it on the lunar surface. The fuel is caried to the Moon in a cask mounted on the side of the LM. The cask is sketched in figure 23 and can be seen in figure 3.

During EVA 1, the astronauts remove the ALSEP equipment from the LM, carry it to a site at least 300 feet from the LM, and place it on the lunar surface. In figure 24, we see astronaut Al Bean carrying the Apollo 12 ALSEP. The 16-ALSEP is carried in a similar way. In figure 25, a sketch of the ALSEP pallet, you can see the packing of the individual items of the ALSEP. A summary of these ALSEP operations is given in Table 3. A layout of the various ALSEP experiments on the Moon is shown in figure 19.
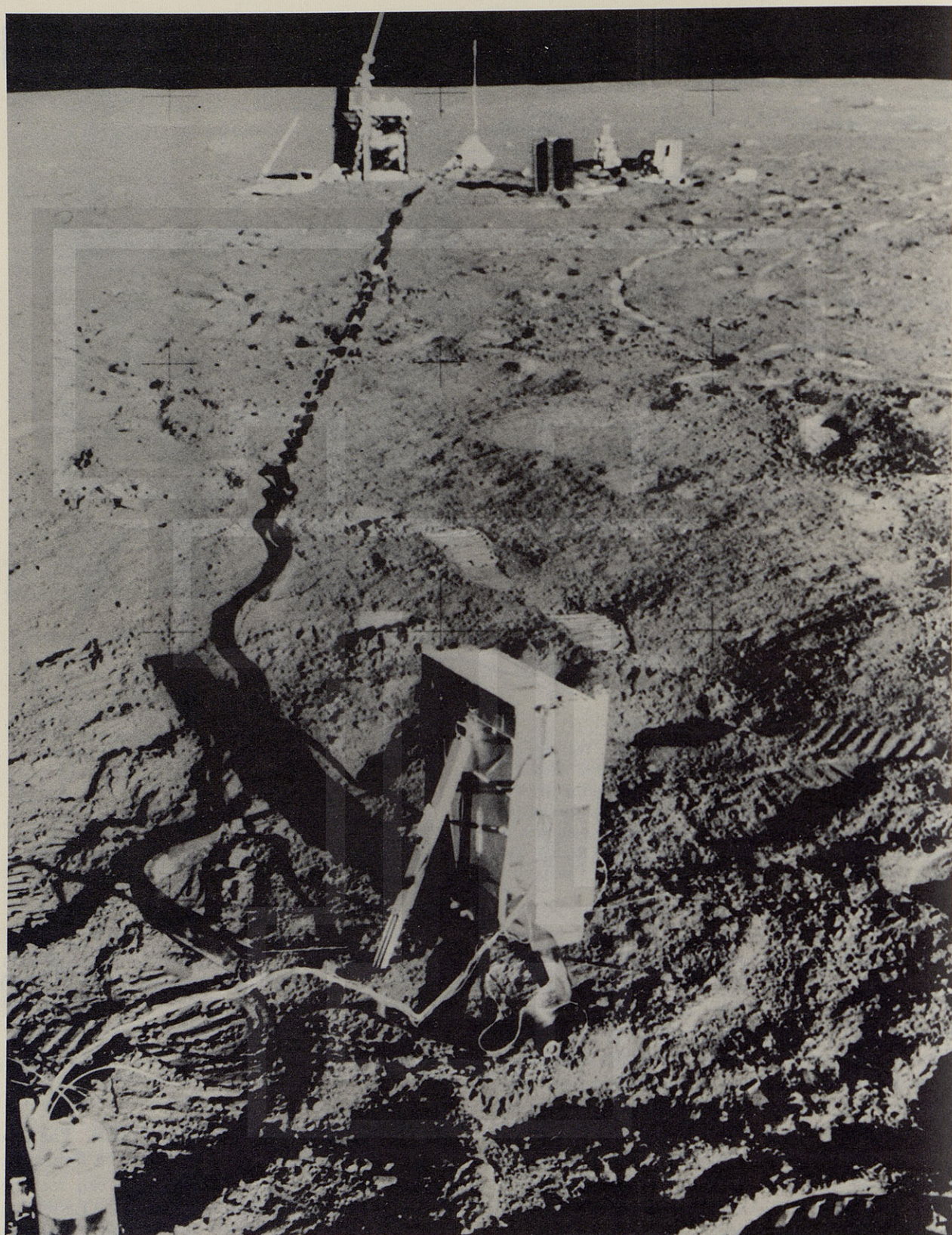
FIGURE 20.—Apollo 14 ALSEP. Note the changes in experiments between 14 and 16, NASA PHOTO A–71–31079.
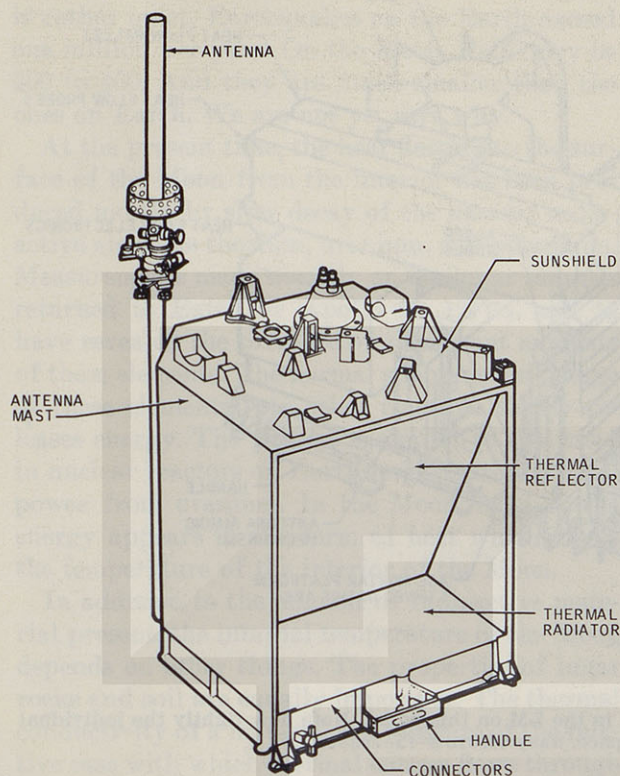
FIGURE 21.—The ALSEP central station. This equipment is connected electrically to each of the other ALSEP experiments. It is a maze of electronics that accepts the electrical signals from various experiments and converts them into a form suitable for transmission by radio back to Earth. The pole-like 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.
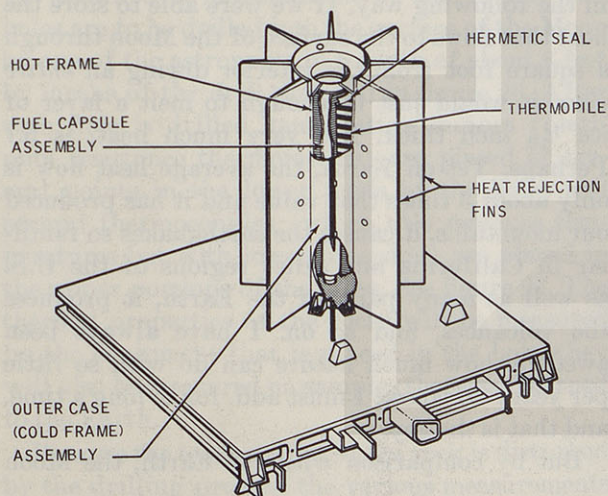
FIGURE 22.—Radioisotope Thermal Generator. This equipment provides all of the power used by the ALSEP. It furnishes continuously about 70 watts.
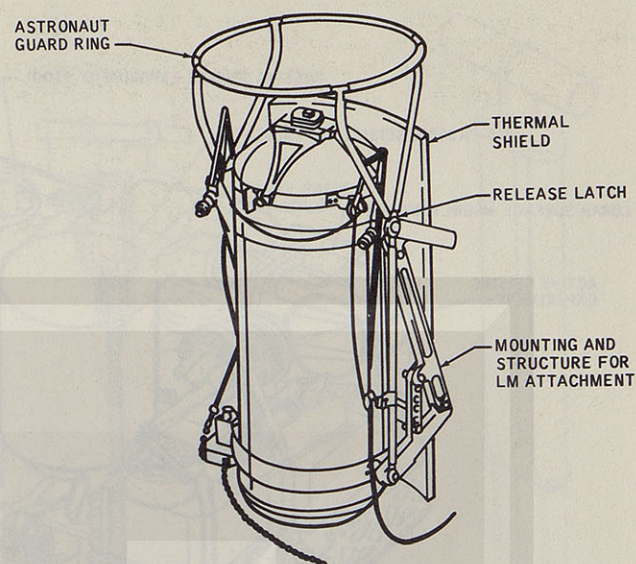
FIGURE 23.—Fuel Cask. The fuel, radioactive plutonium, for the RTG is carried to the Moon in this cask, which is mounted outside the LM.
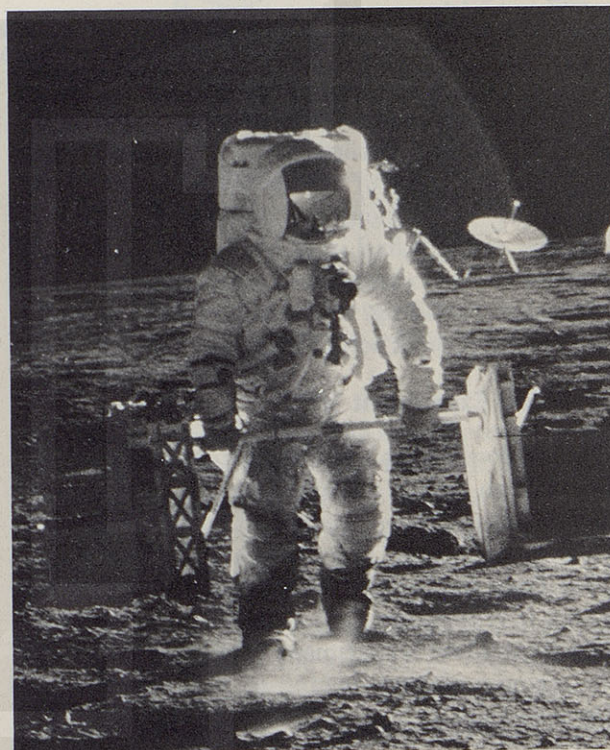
FIGURE 24.—Astronaut Al Bean carrying the ALSEP to its Apollo 12 location. There was no Rover on that mission and the ALSEP location was roughly 100 yards from the LM. The edge of the LM and the S-band antenna are shown in the background. The halo is caused by reflections in the camera lens systems; the halo was not present on the Moon. On Apollo 16 the same technique will be used to carry the ALSEP. NASA PHOTOGRAPH AS12–46–6807.
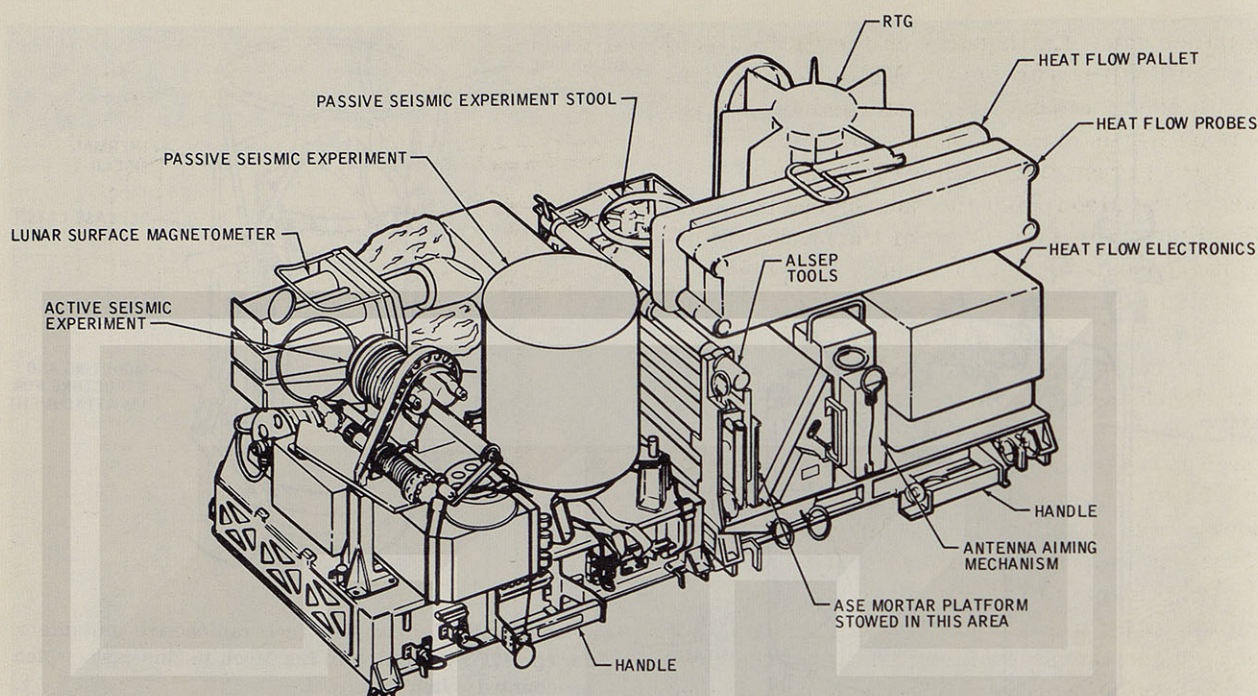
FIGURE 25.—ALSEP pallet, The ALSEP is carried to the Moon in the LM on this pallet. Note how tightly the individual items are packed in order to save space. NASA PHOTO S-72-16330.

A list of *all* science experiments of the 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 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 the Moon is warm. It may be hot. 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 Descartes site.

A similar measurement is now in progress 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 has been re-

designed. It should now drill the Apollo 16 holes to full depth in 15 minutes, perhaps less. I am sure that many viewers will want to watch particularly this aspect of our mission.

But let me continue with the main story of heat flow. It will be at least several months before we have obtained our best estimate of the amount of heat flow at the Apollo 15 site. The preliminary value is 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 3 times that value and it has produced our mountains, it causes the earthquakes so familiar in California and other regions of the U.S. 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

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

is 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 radioactive elements thorium, uranium, and potassium. Measurements made directly on the lunar samples returned to Earth by Apollo 11, 12, 14, and 15 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.

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 HFE has been designed to measure the rate of heat loss from the interior of the Moon. To obtain this measurement at the 16-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 26. After each hole is drilled, temperature sensors (platinum resistance thermometers) are placed at several points in the lower parts of the holes and several thermocouples (which also measure temperatures but with lower precision) are placed in the upper portions of the holes. See figure 27. 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
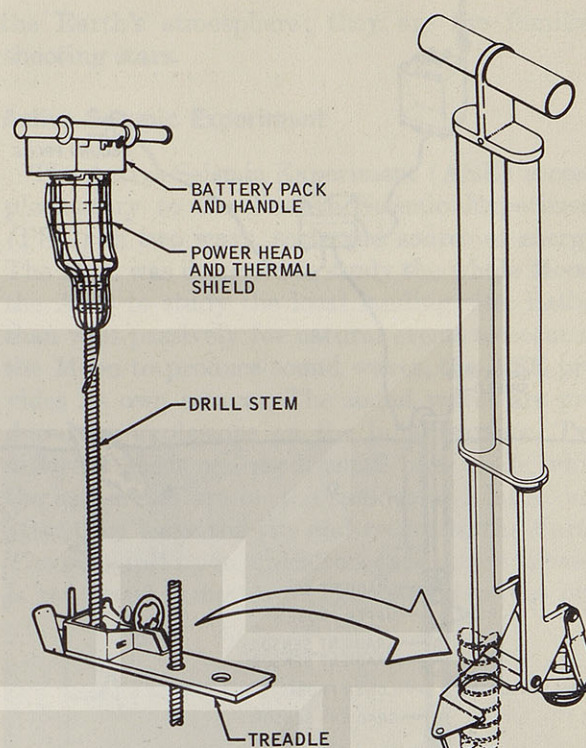
FIGURE 26.—Lunar Surface Drill. This drill will be used to drill holes on the Moon to a depth of about 10 feet. It is electrically powered and operates from batteries. The treadle is used to steady the drill stem and to deflect cuttings from striking the astronaut. Two holes are used for the heat flow experiment and a third one is used to obtain samples for study back on Earth. The tool sketched on the right is used to extract the core from the hole and operates somewhat like an automobile bumper jack. A rack, used for holding the drill stem, is sketched in figure 19.

temperatures measured in the experiment will approach the undisturbed temperatures of the Moon.

The great importance of the HFE is due to the limits that it allows us to set. The heat now reaching the surface of the Moon has been produced by radioactive decay. Knowledge of the amount of heat flowing from the interior of the Moon will be used to set limits on the amount of radioactivity *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. And 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.

FIGURE 28.—Passive Seismometer. The instrument is covered with a blanket of superinsulation to protect it from the extreme variations of temperature on the Moon (−400° to +200°F). The principle of operation is shown in figure 29. The level, used on the Moon in exactly the same way as on the Earth, indicates whether the instrument is level. The Sun compass indicates direction.
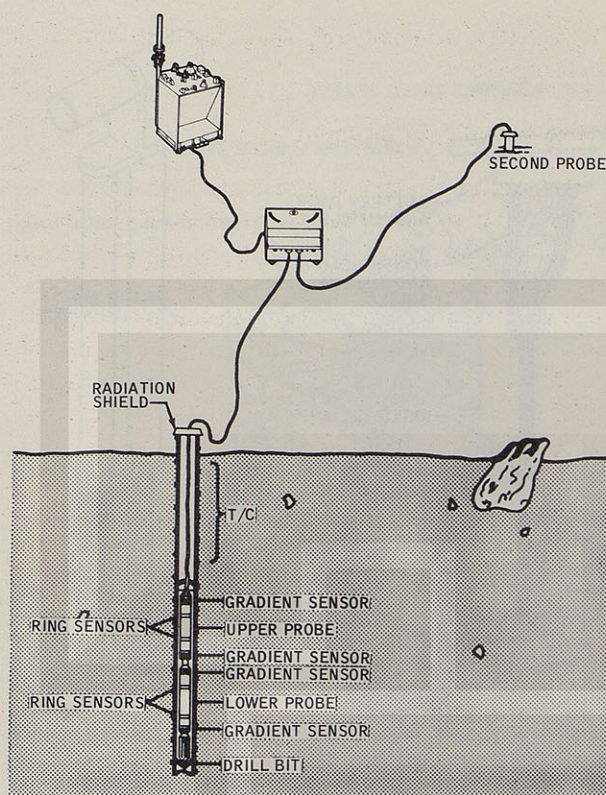
FIGURE 27.—Heat Flow Experiment. Probes are placed in two holes drilled in the lunar surface with the drill shown in figure 26. One hole is shown in the figure as a section to show the various parts. The gradient is the difference of temperature at two points divided by the distance between the points. 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.

FIGURE 29.—Principle of operation of passive seismometer. See text for details.

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 16 measurements confirm this surprising result.

Passive Seismic Experiment (PSE)

The Passive Seismic Experiment (PSE) is used to measure extremely small vibrations of the Moon's surface. It is similar to instruments used on the Earth to study the vibrations caused by earthquakes and by man-made explosions. The PSE equipment is shown schematically in figure 28. The principle of operation is indicated in figure 29. As the instrument is shaken, the inertia of

the mass causes the boom to move relative to the case. This relative motion is detected electrically by the capacitor and the electrical signal is sent by radio to the Earth.

These instruments are really just very fancy electronic stethoscopes and are similar in some ways to the familiar ones used by doctors to listen to your heartbeat. With them, we can listen back on Earth to the vibrations of the Moon. Some of these vibrations are caused by naturally occurring events, others by impacts on the Moon of parts of the spacecraft, still others by meteorites.

Typical seismic signals for the Moon are seen in

PASSIVE SEISMIC EXPERIMENT
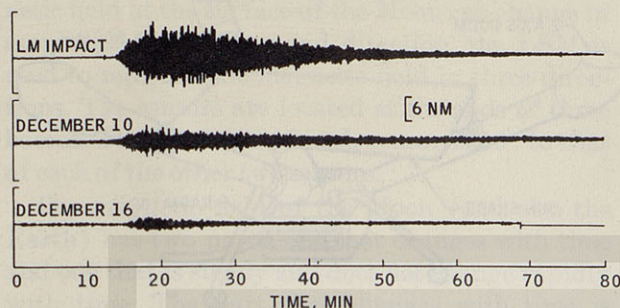
FIGURE 30.—Typical seismic signals for the Moon. These events were sensed at the Apollo 12 seismometer. To produce the largest signals shown here, the Moon's surface moved about 2 ten-thousandths of an inch.

figure 30. Such signals are detected at the Apollo 12, 14, and 15 sites at the rate of about one per day. There is usually increased activity when the Moon is farthest from the Earth and also when it is nearest the Earth, though we don't yet know why!

The spacecraft impacts have been very valuable to our understanding of the Moon's interior. Their locations are shown in figure 1. Two more are planned for this mission. The S–IVB will hit the Moon near 2°18′ South latitude, 31°42′ West longitude before the astronauts land. The LM ascent stage will hit the Moon after they leave. The sound waves produced by these impacts travel through the Moon and are detected by the seismometers. Signals like the ones shown in the top of figure 30 are sent to the Earth.

A very recent study of the results of previous spacecraft impacts has revealed the existence of a lunar crust that may be roughly 40 miles thick. It is now believed by some of us that the Moon may be shrouded with material that differs greatly from the material in the interior of the Moon. Perhaps the additional data that will be obtained from the Apollo 16 impacts will strengthen the hypothesis of a lunar crust.

The data from the PSE, in conjunction with similar data from Apollo 12, 14, and 15 sites, are especially valuable in understanding the natural events that occur on the Moon. They will be used to study the nature of the interior of the Moon, to determine the location of moonquakes and to detect the number and size of meteorites that strike the lunar surface. The Moon is still being bombarded by small objects; most of them are microscopic in size. The Earth is also being bombarded but most small objects completely disintegrate in the Earth's atmosphere; they are the familiar shooting stars.

Active Seismic Experiment

The Active Seismic Experiment (ASE) is complementary to the Passive Seismic Experiment (PSE) in two ways, scale and source of energy. The PSE was designed to study the whole Moon; the ASE to study the local landing site. Rather than wait passively for natural events to occur on the Moon to produce sound waves, the ASE provides its own sources. The sound waves are produced by explosions on the lunar surface. Two different kinds are used, small ones made while the astronauts are on the surface and large ones after they leave the site and return to the Earth. The principle upon which this experiment is based is indicated in figure 31. The sound waves pro-
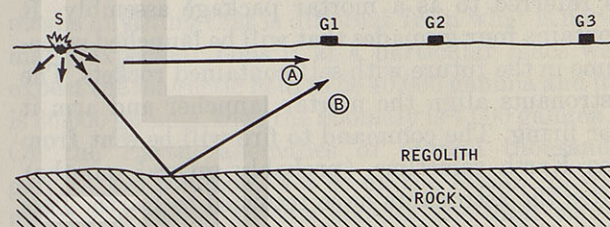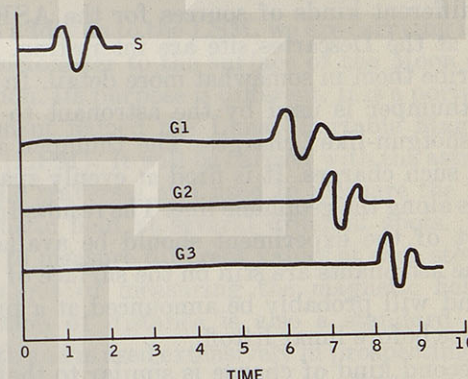
FIGURE 31.—Principle of the active seismic experiment. The geometry of the experiment is shown in the lower figure. At the source, which resembles the explosion of a shot gun or a grenade, elastic waves are sent in all directions. Some of these waves (marked A) travel in the direction of the three geophones, 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 not too great, then some of the elastic energy is returned to the surface. Such waves arrive at the geophones later than the direct waves.

duced by the source travel through the lunar soil and rock to the geophones. The geophones are similar to the stethoscope used by doctors to listen to our heartbeat. They "hear" the sound waves and transmit them over the ALSEP telemetry link to Earth. The time of the source explosion and the times at which the waves arrive at each of the three geophones 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. If the depth to solid rock at the ALSEP site is not too great, then a part of the energy in the sound waves is reflected towards the surface. The reflected waves travel farther than the direct waves, 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, the depth to the reflecting surface can be obtained.

The different kinds of sources for the ASE to be used at the Descartes site are interesting. Let me describe them in somewhat more detail. In the first, a thumper is used by the astronaut to explode "shotgun-like" charges. The thumper contains 19 such charges. It is fired at evenly spaced intervals along the geophone line. The results from this part of the experiment should be available while the astronauts are still on the surface of the Moon and will probably be announced at a press conference before lunar liftoff.

The second kind of charge is similar to that of a mortar. In fact the unit that fires these charges is referred to as a mortar package assembly. It contains four grenades that will be launched sometime in the future with self-contained rockets. The astronauts align the mortar launcher and arm it for firing. The command to fire will be sent from the Earth sometime (probably several months) after the astronauts have returned to Earth. This unit contains provisions for measuring the velocity of each grenade on launch and the exact time of launch. The grenades themselves are also interesting. Each contains a rocket motor, a high explosive charge, provisions for igniting the rocket and a device to detonate the charge, a battery, a transmitter that provides information as to the length of time of the flight and the moment of impact on the Moon, and a thread with which to measure the distance of the impact from the launcher. Because there is (almost) no atmosphere on the Moon, the thin thread trailing the grenade remains taut and
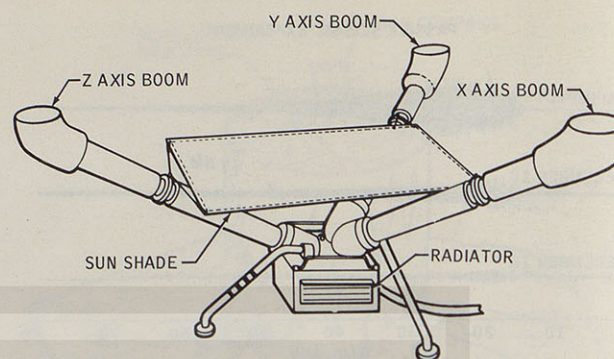
FIGURE 32.—Lunar Surface Magnetometer. Measurements are obtained as a function of time of the magnetic field at the surface of the Moon by the Lunar Surface Magnetometer. The actual sensors are located in the enlarged parts at the end of the three booms. The plate located in the center of the instrument is a Sun shade to protect the electronics in the box at the junction of the three booms from direct sunlight. The radiator cools the electronics box.

measures accurately the horizontal distance from the point of launch to the point of impact.

Within three months after the mission, we expect to launch the grenades by sending a command to the ALSEP central station. They have been designed to impact the Moon at distances of 450, 925, 2800, and 4500 feet from the launcher. The size of the explosive charge increases with distance. Any layering in the Moon at the Descartes site that is present in the first thousand feet beneath the surface will be seen with the ASE.

This technique is a standard one for the study of geology on the Earth. It is the chief way in which new oil and gas fields are looked for. This experiment is repeated on Earth millions of times each year by the oil industry. The principles are well understood.

Lunar Surface Magnetometer Experiment (LSM)

Two magnetometers will be used on Apollo 16. One, the Lunar Portable Magnetometer (LPM), is used to measure changes with distance of the Moon's magnetic field. It is discussed below. The other, the Lunar Surface Magnetometer (LSM), is used to measure the variations with time of the magnetic field at the surface of the Moon. A similar instrument was left at the Apollo 12 and 15 sites. They are still sending data to Earth. None was left at the Apollo 14 site although two measurements of the magnetic field were made there with the smaller, portable magnetometer. The LSM
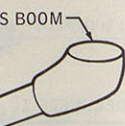
equipment is shown in figure 32. Because the magnetic field at the surface of the Moon can change in amplitude, frequency, and direction, the LSM is used to measure the magnetic field in three directions. The sensors are located at the ends of three booms. The direction of each sensor is 90° to that of each of the other two sensors.

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 part that changes with time is caused by traveling electromagnetic waves.

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. The two measurements obtained at the Apollo 14 site with the smaller portable magnetometer revealed magnetic fields of about 43 gamma and 103 gamma in two different spots. 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 now too small to affect the usual compass. Neither is its direction such that a compass would point toward the north even if the friction were made vanishingly small.

The LSM is used to measure the variation with time of the magnetic field at the surface of the Moon. The variations are caused by electromagnetic waves that emanate from the Sun and travel through space. The largest change with time in the magnetic field ever measured in space, about 100 gamma, was detected by the Apollo 12 LSM.

Variations with time in the magnetic field at the surface of the Moon are influenced greatly by the electrical properties of the interior of the Moon. Therefore, a study of these 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 the data from the LSM 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 LSM 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 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. Perhaps the data from the Apollo 16 LSM will help us understand better the conditions of the interior of the Moon.

Lunar Portable Magnetometer Experiment (LPM)

In addition to the LSM, we are carrying another magnetometer to the surface of the Moon on this mission. Its purpose is different. It is a portable instrument named the Lunar Portable Magnetometer (LPM). It will be carried with the astronauts on the traverses and used to measure the Moon's magnetic field at several different spots. We expect to measure different values at each stop. This technique of measuring the magnetic field as a function of distance is also a standard one on Earth and is used extensively in prospecting. Many ore bodies cause *anomalies* in the Earth's magnetic field. In our jargon, the word anomaly really means anything that is different from what is normally expected. Thus if at a particular place we expect the magnetic field to be 40,000 gamma and it is 36,000 gamma, then the anomaly is 4,000 gamma. On the Earth, anomalies of several thousand gamma are common. Not so on the Moon. As we mentioned earlier in this booklet, the total magnetic field of the Earth is about 50,000 gamma. Because the Moon's magnetic field is only about one-thousandth that of the Earth's field, the magnetic anomalies are much smaller.

An LPM was carried previously on the Apollo 14 mission. Unfortunately only two measurements were obtained then. Both were startling. The first, taken near the landing point (but out of the LM's magnetic field) was about 43 gamma. The second was taken on Cone Crater. It was 103 gamma. These values were startling for two reasons. First, they were much larger than we expected before-

SENSOR BOX — BUBBLE LEVEL

TRIPOD BASE

SHADOW POST

TRIPOD-SENSOR ASSEMBLY

ELECTRONICS BOX

TEMPERATURE INDICATOR STRIP

WINDOW TO VIEW MAGNETIC FIELD DIGITAL READOUT

ON/OFF SWITCH

READ SWITCH

CABLE REEL

ELECTRONICS BOX CONNECTOR CABLE
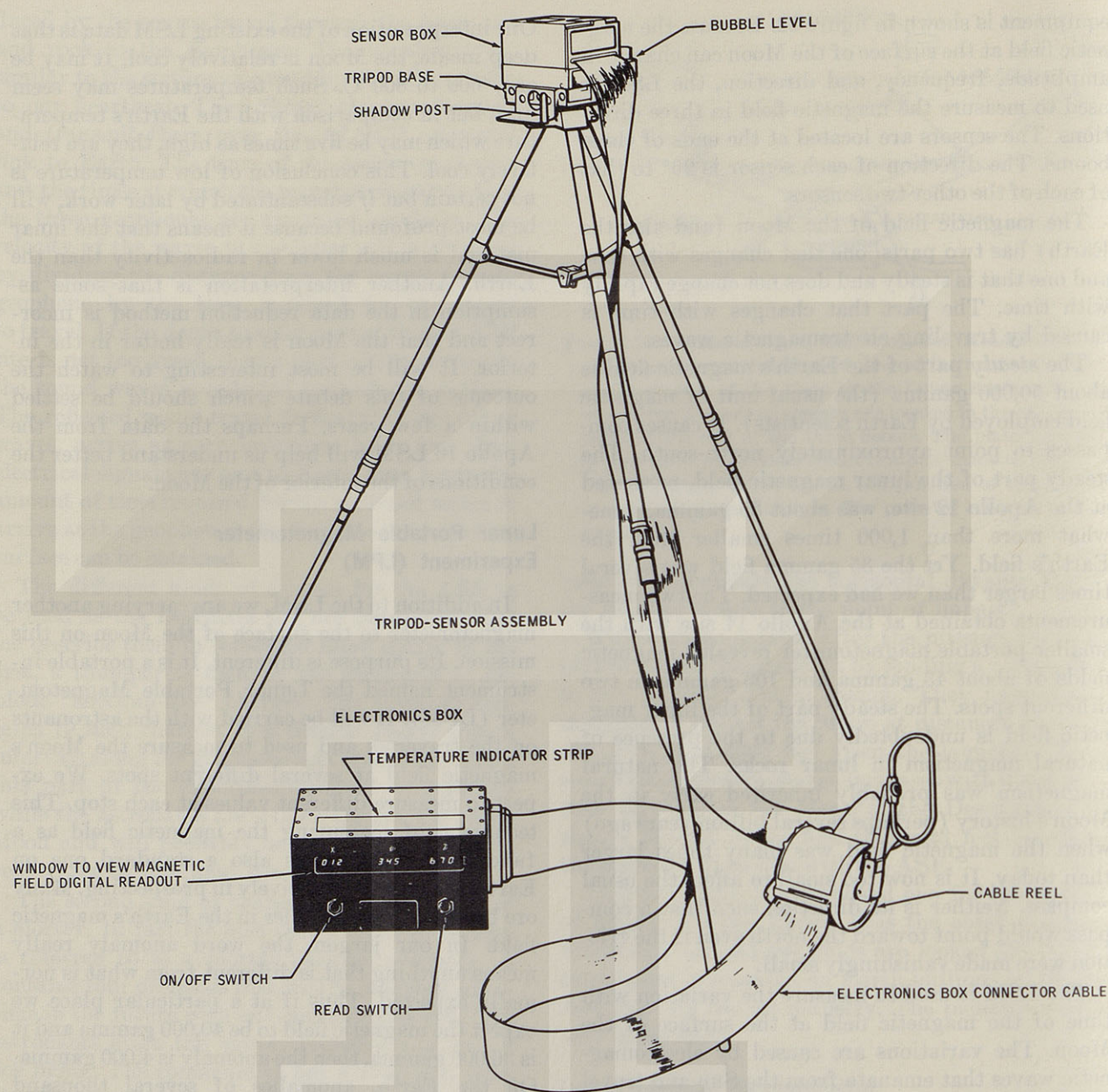
FIGURE 33.—Lunar Portable Magnetometer. This instrument is used to measure the magnetic field of the Moon at several different locations along the traverses. In use the electronics box will be mounted on the Rover. The tripod will be set about 50 feet away from the Rover. The astronaut orients the sensor box by the shadow cast by the shadow post. It is leveled by the astronaut as he watches a bubble level on the sensor box. The electric cable that connects the two boxes is a flat ribbon containing many electrical wires.

hand. We had obtained previously from satellite measurements an unequivocal indication that the *average* value for the magnetic field at the surface of the Moon could not be larger than 10 to 12 gamma. Yet these values were much larger. The difference in the two values, 60 gamma, was equally startling. We had not expected such a large

change to occur over a short distance. In order to help understand the rapid change with distance, we are most anxious to obtain several measurements on Apollo 16. These changes with distance are almost surely caused by the natural magnetization of the lunar rocks.

Natural magnetization has been known in ter-

restrial rocks for many years. You are likely already familiar with the term lodestone which is the name used for a naturally occurring magnet. The material of lodestone is magnetite, a strongly magnetic mineral. There are, of course, other magnetic minerals but magnetite is the most common. It occurs in lunar rocks also.

The equipment used in the LPM experiment is shown schematically in figure 33. The sensors are contained in a box mounted on a tripod. They are connected to an electronics box on the LRV by a flat ribbon-type electrical cable. In use, the tripod is set about 50 feet from the Rover. It must be oriented with the shadow of the Sun and leveled. The astronaut then returns to the Rover and reads the instrument. There are three digital panel meters. They resemble digital clocks. These three meters indicate the size of the three components of the Moon's magnetic field. The astronaut reports the readings over the voice communications link with Earth. (Unfortunately, the numbers that you will hear reported by the astronaut are *not* the values of the magnetic field. A calibration chart must be used to convert them. I hope though that the results will be announced over television before the mission is over.)

You may wonder why we use a tripod that must be carried away from the Rover. Also, why not combine the sensor and the electronics box to save astronaut time? The answers are simple. The Rover is magnetic. So are the astronauts. Even though the human body is essentially nonmagnetic, the astronaut carries many pieces of metal and electronic equipment that *are* magnetic. So for the actual measurement, we move the sensors away from both the astronaut and the Rover.

Solar Wind Composition Experiment (SWC)

Matter is ejected, more or less continuously, by the Sun and spreads throughout the solar system It is called the solar wind. It is very tenuous. It moves with a speed of a few hundred miles per second. The composition of the solar wind that strikes the surface of the Moon will be measured by the SWC experiment. This equipment is shown in figure 34. It is extremely simple.

The SWC flight equipment is essentially a sheet of aluminum foil like the familiar household item used to wrap food. The foil, exposed on the lunar surface to the solar wind, actually traps within it individual particles of the solar wind. The foil when returned to Earth is examined in the labora-
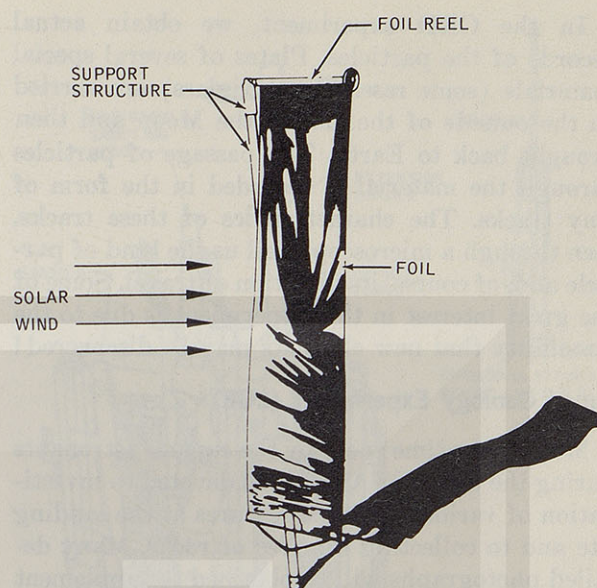
FIGURE 34.—Solar Wind Composition Experiment. Particles in the solar wind strike the aluminum foil, are trapped in it, and finally brought back to Earth by the astronauts for examination. The experiment is sponsored by the Swiss government.

tory. The particles include atoms of many chemical elements, such as hydrogen, helium, neon, argon, and so on. Sponsored by the Swiss government, this experiment is international in scope.

Cosmic Ray Detector Experiment (CRD)

Cosmic rays are just particles that have extremely large 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 "Alpha Particle Spectrometer" for discussion). But 1 to 2% 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 solar wind is discussed further in the sections "Solar Wind Composition" and Subsatellite Experiments." The range of energy of the particles is very great but some have very low energy. One purpose of the CRD experiment is to investigate the low energy particles. Another purpose is to investigate neutrons from the lunar surface.

In the CRD experiment, we obtain actual records of the particles. Plates of several special materials (some resemble plexiglass) 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!

Lunar Geology Experiment (LGE)

Most of the time spent by the *surface* astronauts during the three EVA's will be devoted to investigation of various geologic features at the landing site 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 Descartes 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 Descartes site, we plan to study thoroughly two rock units, the Descartes formation (fm) and the Cayley fm. Both of these geologic formations are widespread on the front side of the Moon. The Descartes fm covers 4.3%, the Cayley about 7% of the front side. The Cayley is the most extensive of all geologic formations in the lunar highlands. The distribution at the landing site of these two units is shown in the geologic sketch map, figure 9.

Because these two formations are so extensive, their study should provide the information needed to read an important chapter in lunar history. Samples of both units will be collected at the Descartes landing site. After the samples reach Earth, they will be studied extensively by nearly seven 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 Professor 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 hi-powered telescopes. And they re-study the existing lunar photographs in relation to the rocks. Another function, of course, is to integrate the knowledge obtained from study of the Descartes 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 each previous mission, 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 on board the LM immediately so 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 do *not* plan to collect such a sample. We wish to save both time and weight. 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 one-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 television camera allows us on Earth to follow the astronauts and to "see" some of the same fea-

FIGURE 35.—Apollo 14 television camera. The astronaut is adjusting the TV camera to obtain the best possible viewing of activities around the LM during the Apollo 14 mission. A similar television camera will be carried aboard Apollo 16. After the Rover is placed in operation the TV camera will be mounted on it. The camera is controlled from Mission Control in Houston. Note the many craters in the foreground and the boulders in the distance. The distance scale of this photograph varies greatly. The small rocks seen in the foreground are a few inches across; the boulders near the horizon are several feet in diameter. NASA PHOTO S–71–31091.

FIGURE 36.—Lunar Geological Hand Tools and Carrier. 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.

tures, though not nearly so well as the astronauts see them. A photograph of the Apollo 15 TV camera, similar to the one on this mission, is shown in figure 35. The TV camera will be mounted on the Rover during the traverses. Its location can be seen in figure 12.

Other tools used by the astronauts, together with an aluminum frame for carrying them, are shown in figure 36. 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. It will be used at one station to chip several small pieces of rock from a large boulder.

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 (figures 37A and 37B) is used to collect lunar soil and occasionally small rocks. The tongs, shown in figure 38, an Apollo 12 photograph, are used to collect small rocks while the astronaut stands erect.

The drive tubes (figure 39) are used to collect core material from the surface to depths of 1 to 4½ feet. The core remains in the tubes for return to Earth. Preservation of the relative depths of the core material is especially important. The drive

FIGURE 37A.—Scoop with extension handle. Its use in Apollo 12 is shown in Figure 37B. (Page 32.)
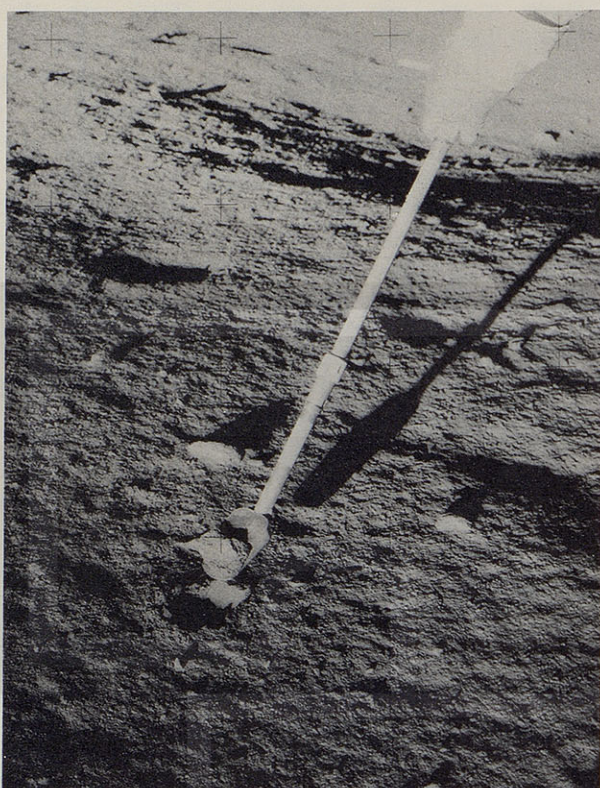
FIGURE 37B.—Note the small rock in the scoop. NASA PHOTO AS12–49–7312.

FIGURE 39.—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, three, or even four of them may be joined together to obtain a longer core. Their use in Apollo 14 may be seen in Figure 40.

FIGURE 38.—Tongs shown in use on Apollo 12 to collect a small rock. NASA PHOTO S–71–31075.

tubes were originally suggested about 7 years ago by the late Dr. Hoover Mackin, a geologist. Shown in figure 40 is a drive tube that was driven into the Moon's surface on Apollo 14. The individual tubes are about 18 inches long. As many as three tubes can be used together for a total length of about 4½ feet.

After the surface samples are collected, they are placed in numbered sample bags made of Teflon (figure 41). 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
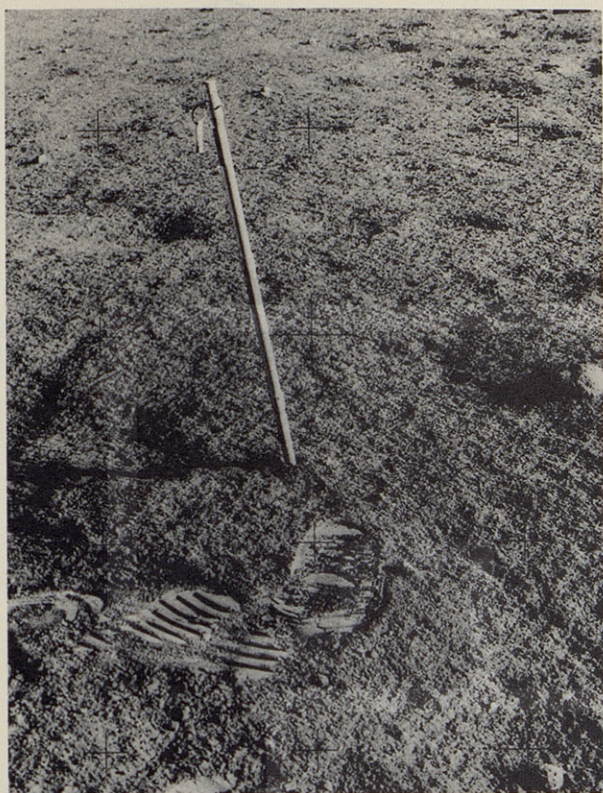
FIGURE 40.—Drive tube in lunar surface at Apollo 14 site. The relative difficulty of driving the tube into the surface is an indication of the strength of soil. Note in addition the footprints, rocks, and small craters, NASA PHOTO S–71–31082.
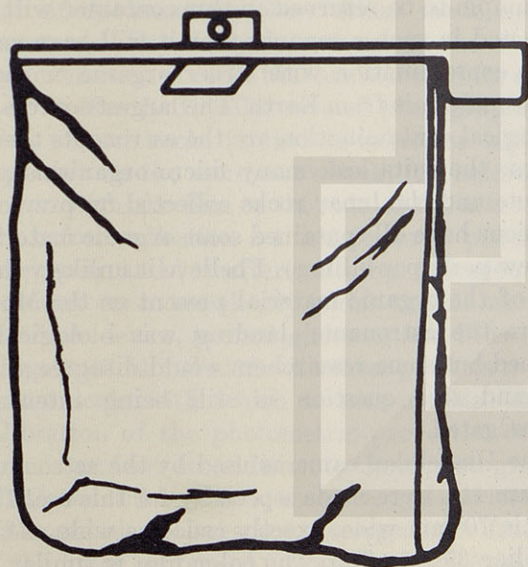
FIGURE 41.—Lunar sample bag. The bag resembles the familiar kitchen item "Baggies." It is made of Teflon. A strip of aluminum is used to close the bag.
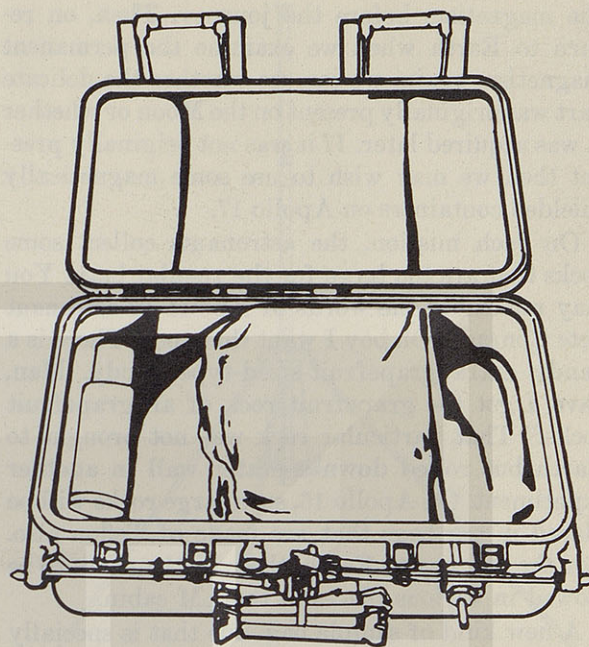
FIGURE 42.—Apollo Lunar Sample Return Container. Made of aluminum, this box is used to return lunar samples to Earth. It is about the size of a small suitcase but is many times stronger. The ALSRC has changed very little since it was first used on Apollo 11. NASA PHOTO S–71–33369.

certain desirable vacuum characteristics. These bags are about the size of the familiar kitchen storage bags. 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 42, 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.

The teflon bags do not satisfy all our requirements though. For example, we are having some difficulty in unraveling the complete story of the permanent magnetism of the lunar rocks. One part of that permanent magnetism is very delicate. We are not sure just how, or when, the rocks obtain that part. It could be due to exposure to high magnetic fields in the spacecraft, though we don't think so. It could be due to exposure to the Earth's magnetic field, though we don't think so. To help us solve this problem, we expect to carry back to the Moon a small piece of lunar rock from an earlier mission. We will have removed the delicate part of

the magnetism before the journey. Then, on return to Earth when we examine the permanent magnetism again, we can see whether the delicate part was originally present on the Moon or whether it was acquired later. If it was not originally present then we may wish to use some magnetically shielded containers on Apollo 17.

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 16, 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 LM cabin.

A new kind of sample bag, one that is specially padded, is being taken on Apollo 16. It is about the same size as the regular bag, but has padding built into the walls. We hope that these bags will protect the very thin, very fragile outer surface of the rocks. The outer one-hundredth-inch is valuable for the study of the radiation history of the rock. Such studies may eventually help us to read correctly recent chapters in the history of the Sun and our solar system. Better knowledge of such history may be useful in predicting more accurately the natural events of the next few hundred years.

We also hope that we will be able to collect some material from the very outer surface of the Moon on this mission. We need the outer few hundredths of an inch for the study of solar radiation, cosmic rays, and so on. To collect such a thin layer, we will carry a "surface sampler" if it is ready in time. In January 1972, we were still working feverishly on it. Many ways to collect the surface sample have been considered. Most of them were rejected. The technique finally adopted, though, is extremely simple. Any good seamstress could have told us how—use velvet cloth. Lay it gently on the surface. The grains will be trapped in the fabric pile. Bring back the velvet and the sample. In fact, we are using just such a simple technique after considering—and rejecting for very good engineering or scientific reasons—many, more sophisticated schemes.

A special container, termed Special Environmental Sample Container (SESC), is used to col-
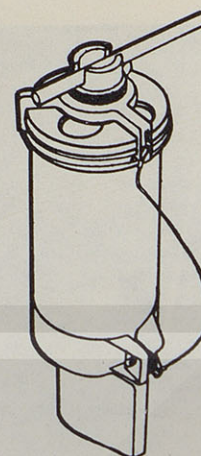
FIGURE 43.—Special Environmental Sample Container. This container has special vacuum seals to prevent gases and other materials from entering the container and being absorbed on the surfaces during the journey to the Moon. They also prevent contamination of the samples by rocket exhaust gases and the Earth's atmosphere during the return journey.

Another model, similar to the one shown here but about twice as long, will be used to store a drive core for return to Earth under vacuum conditions. This sample will be kept unopened, possibly as long as a decade, until ultra clean processing facilities are designed and built. It is our hope to preserve this sample completely uncontaminated.

lect material on the surface of the Moon for specific purposes. (See figure 43.) This container has pressure seals to retain the extremely low pressures of the Moon. It is made of stainless steel. The Apollo 16 sample to be returned in this container 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 micro-organisms 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 on the Moon before the astronauts' landing was biologically formed but some researchers would disagree with me and this question is still being intensely investigated.

The Hasselblad cameras used by the astronauts (figure 44), were made especially for this use. 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
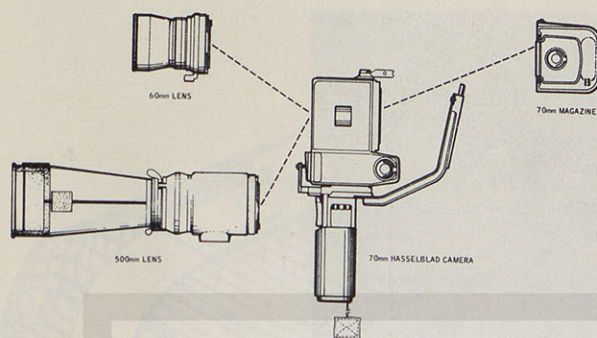
FIGURE 44.—Hasselblad camera. The film, which may be black and white or color, is 70 mm wide. Two separate lenses are used with this camera on the surface of the Moon. The 500 mm lens, a telephoto lens, shown attached to the camera in the photograph will be used to photograph distant features. NASA PHOTO S-71-32997.

FIGURE 45.—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 46, 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. The color scale, omitted from this sketch for simplicity, can be seen in other figures.

that of documenting observations made by the astronauts. Especially important is the careful documentation of rocks that are collected for study 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 45, 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 46. The photos taken before collection and after collection show clearly which rock was removed.

At some stations, still more documentation is desirable. Panoramic views are obtained by shooting many photographs of 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 15 is shown in figure 47. Others from Apollo 14 may be seen in the July 1971 issue 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.

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
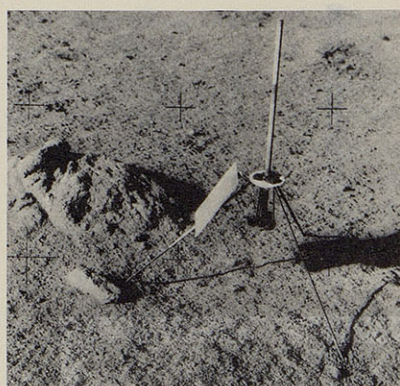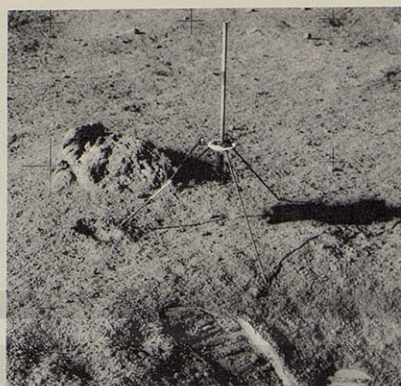
FIGURE 46.—Photographic documentation of lunar samples. These three Apollo 14 photographs indicates clearly the method used to identify the rocks that were collected. The shadows in A, together with knowledge of the time that the photo was taken, have been used to orient the specimen. A location photograph (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.
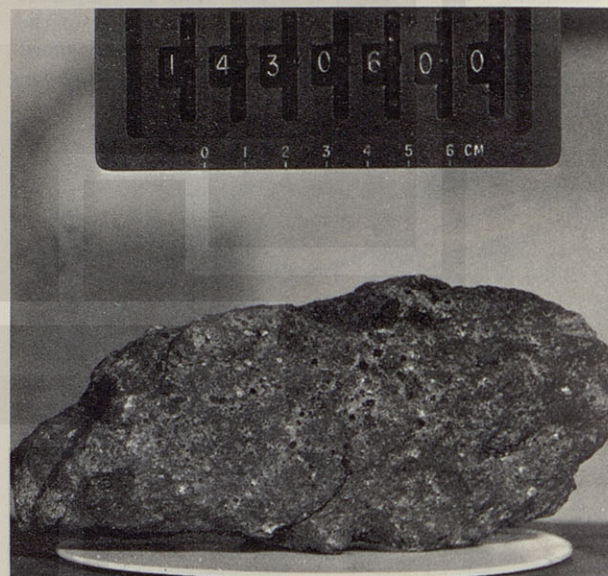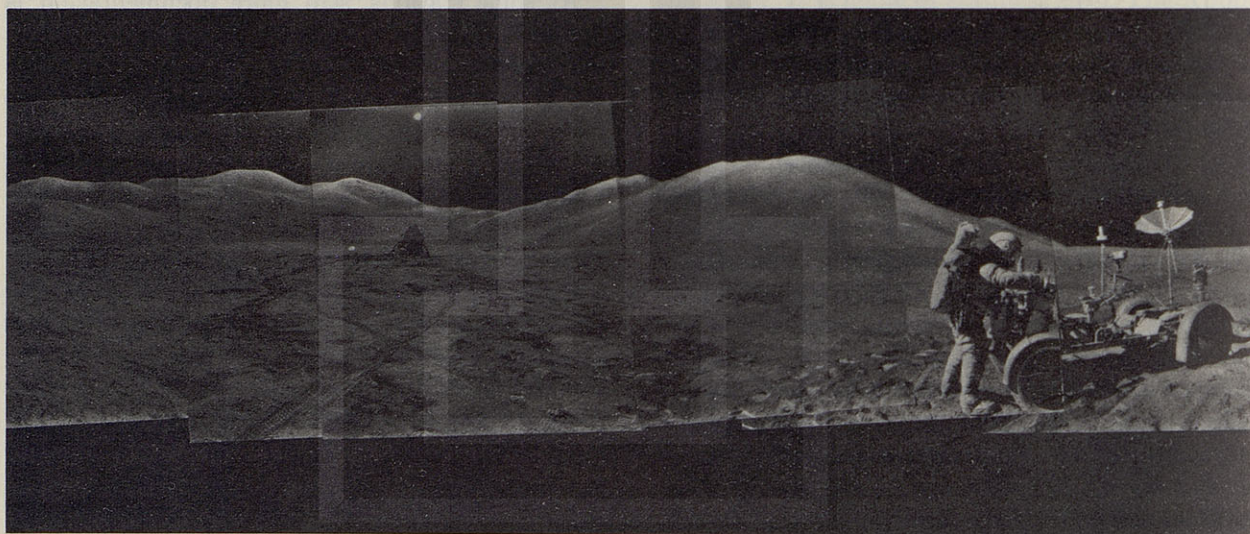
FIGURE 47.—Panoramic view obtained on Apollo 15. The method of piecing together several photos is clearly shown. Also, the difficulties of fitting the edges of the photos can be imagined from the mismatches evident here. Other panoramas from Apollo 14 may be seen in the July 1971 issue of National Geographic magazine. Note the tracks of Rover and the astronaut footsteps. Some people see a resemblance between this view and photos of Sun Valley, Idaho.
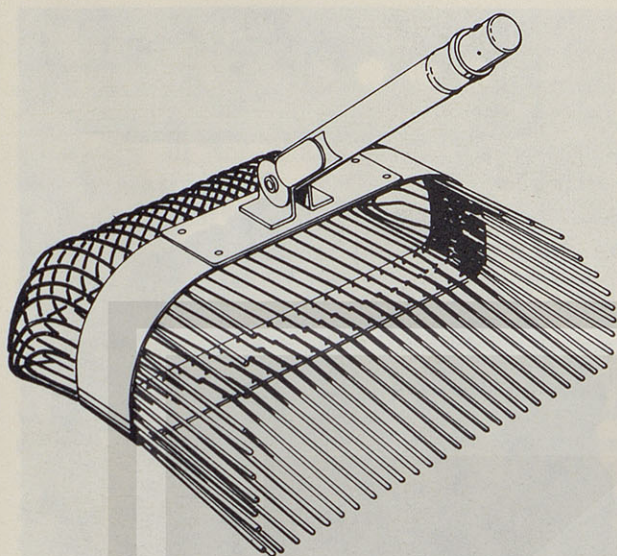
FIGURE 48.—Rake. This tool was used on Apollo 15 to collect marble-sized rocks. It will be used again on Apollo 16.

and built a tool and used it on Apollo 15 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 48. We expect to use it again on Apollo 16.

The Apollo Lunar Surface Drill (ALSD), used to drill the two holes for the Heat Flow Experiment and illustrated in figure 26, 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 3/4 inch in diameter. Individual pieces of rock are likely to be button-shaped and 1/4 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.

The Lunar Samples

In addition to the Lunar Geology Team, many other scientists study the lunar samples. In this section, I want to give you a brief glimpse of the many ways in which the samples are studied. No other material has ever held the attention of so many scientists so long.

I still vividly recall the intense excitement at the Lunar Receiving Laboratory in Houston almost 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 opened up a whole new area in science, termed Lunar Science. It 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.

One group, the mineralogists and petrologists, identified the individual minerals which formed the lunar rocks. Most of them were similar to the rocks and minerals found on Earth. A few new minerals were found. The lack of water and a significant atmosphere on the Moon has preserved the rocks and their accurate record of lunar history for several billion years. In figures 49, 50, and 51, I show photographs of three lunar rocks.

Another group, the geochemists, studied the radioactive elements thorium, uranium, and potassium in the rocks, using them as clocks to estimate the ages of the lunar samples. Most of the rocks studied so far are over 3 billion years old, much older than the rocks on Earth (with only a few exceptions). The processes of mountain formation and erosion have completely destroyed the first billion or so years of rock history on Earth. So, we study the Moon samples to learn the early history of the solar system.

The composition of the rocks tells us that the Moon has undergone differentiation—a word that means the rocks once molten have crystallized in such a way that some parts of the Moon have a
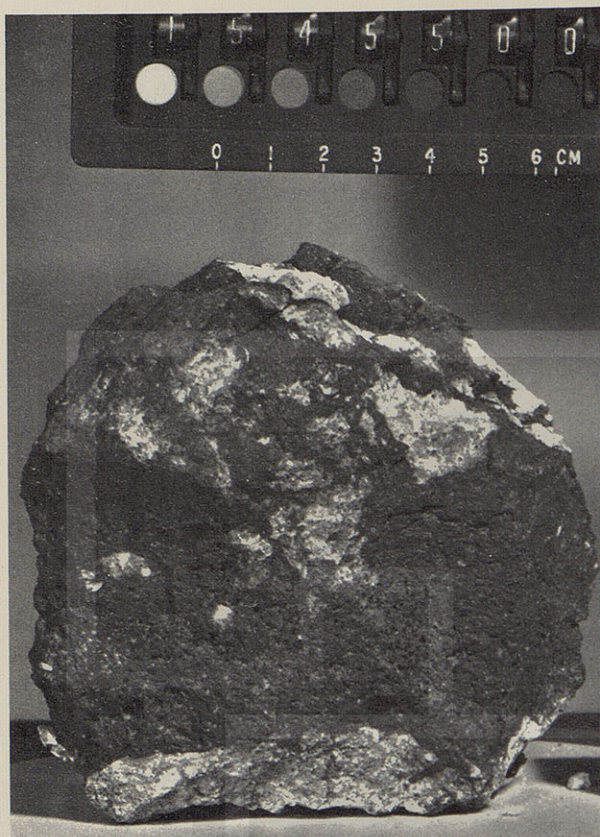
FIGURE 49.—The Black and White Rock. Sample 15455, collected on Apollo 15, is composed of two different kinds of rock and is termed a breccia. One kind shows as white, irregular spots within the second one. Note the gas holes or vugs in the dark rock. This sample weighs about ½ pound. Size of rock may be obtained with the scale shown in the figure. NASA PHOTO S-71-43889.

FIGURE 50.—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.

FIGURE 51.—Big Bertha. This sample, collected on Apollo 14, is the largest one yet brought to Earth. NASA PHOTO S-71-56345.

different chemical composition than others. The process is similar, but not identical, to that used to separate crude oil into gasoline, kerosene, lubricating oil, and other products. This differentiation is an important clue for studying lunar history. Similar processes on Earth are responsible for the formation of ore deposits. These processes are continuing today on Earth. Our evidence so far indicates that although the Moon may have been very active in its early life, it has been very quiet ever since.

As I mentioned in the section on the Solar Wind Composition Experiment, a sheet of aluminum foil on the surface of the Moon can collect particles from the solar wind. Similar particles are also trapped in the mineral crystals and glasses of the lunar samples. We have found evidence for

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nearly steady bombardment of the Moon going back for millions of years. In the samples, we have a special kind of recording of the Sun's activity that cannot be obtained in any other way. And a knowledge of the Sun's activity *is* essential, because nearly all life, weather, and human activity on the Earth ultimately depend on the Sun. Is our Sun always "benevolent"? Perhaps, but we are not yet sure. We may learn the facts necessary to answer this question from the lunar samples.

The rocks also show tiny impact pits or "zap craters." These are sometimes as large as ¼ inch in diameter. They were formed by the impact of tiny grains of cosmic dust that may have been traveling at speeds as high as 20 miles per second. Such impacts, over billions of years, have helped to wear away the rough outlines of the Moon to give the generally rounded and smoothed surfaces you can see on television from the Moon.

What about life on the Moon? We have found no chemical evidence that living things (except eight 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 381 pounds of lunar samples have been brought to Earth so far, and we expect to get almost 200 pounds more from Apollo 16, 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 ¼ inch on a side; a very few receive larger pieces. All material is returned to NASA when our work is finished. Less than 10% of the tota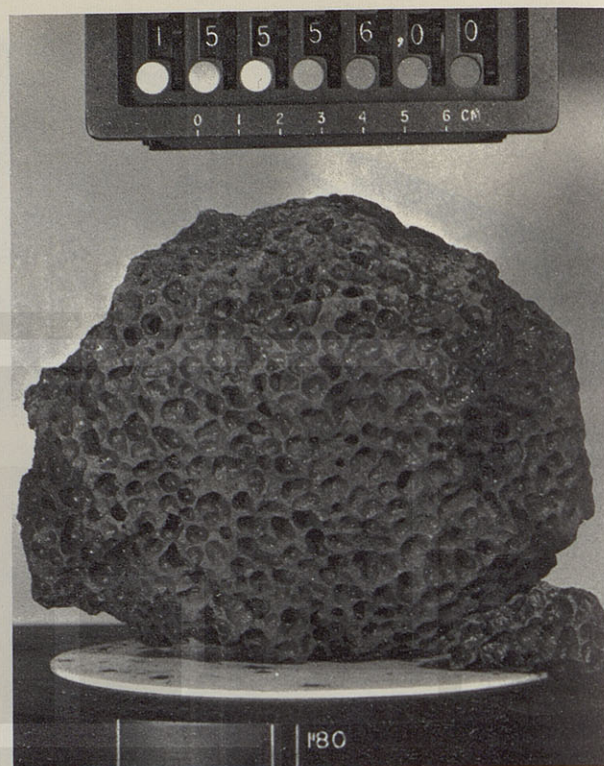l samples have been used so far for analysis; the other 90% will be carefully preserved for scientific studies in future years, probably using new and more powerful analytical tools not yet known today. These samples will be a priceless scientific heritage as well as a special kind of enduring monument to the memory of the astronauts and to the many scientists, engineers, tax-
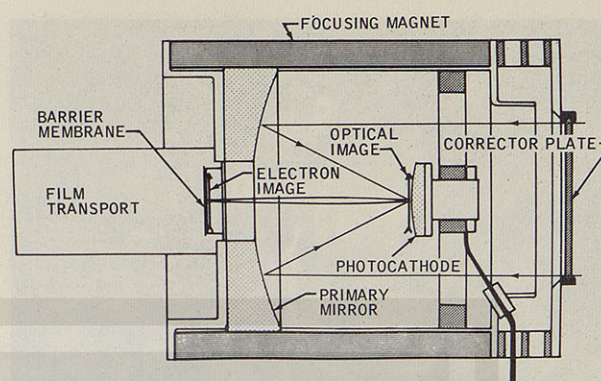
FIGURE 52.—Schematic diagram of the Lunar Surface Ultraviolet Camera/Spectrograph. See text for discussion.

payers, and others who made the Apollo missions possible.

Lunar Surface Ultraviolet Camera-Spectrograph (UVC)

This camera-spectrograph, which I will call UVC, will provide the first astronomical observations made from the Moon. With it, we hope to study the Earth's upper atmosphere, magnetosphere (see section on "Subsatellite" and figures 52 and 53), and their interaction with the solar wind. The first object photographed with the UVC will be the Earth. We hope also to study the interstellar gas which is present throughout "empty" space and to study the uv haloes that appear around galaxies. By pointing the camera towards the lunar horizon we should detect the presence of any volcanic gas near the Descartes site. And finally, with the UVC, we will evaluate the Moon as a possible site for future astronomical observations. Because the terrestrial atmosphere limits the quality of such observations from Earth, astronomers have long wished for a telescope mounted on the Moon. Perhaps the Moon will be an ideal base for future astronomical observations.

The method of recording the images in the UVC is very interesting. Electrons, rather than light waves, are used. Why? Because greater sensitivities to the uv light can be obtained. Let's follow the paths of the light and the electrons in the camera. See figure 52. The light rays that enter the camera are focused by a spherical mirror onto a surface that is coated with a salt (potassium bromide) which emits electrons. These electrons are then moved by a high voltage (25,000 volts) toward a film and are focused by a magnet.
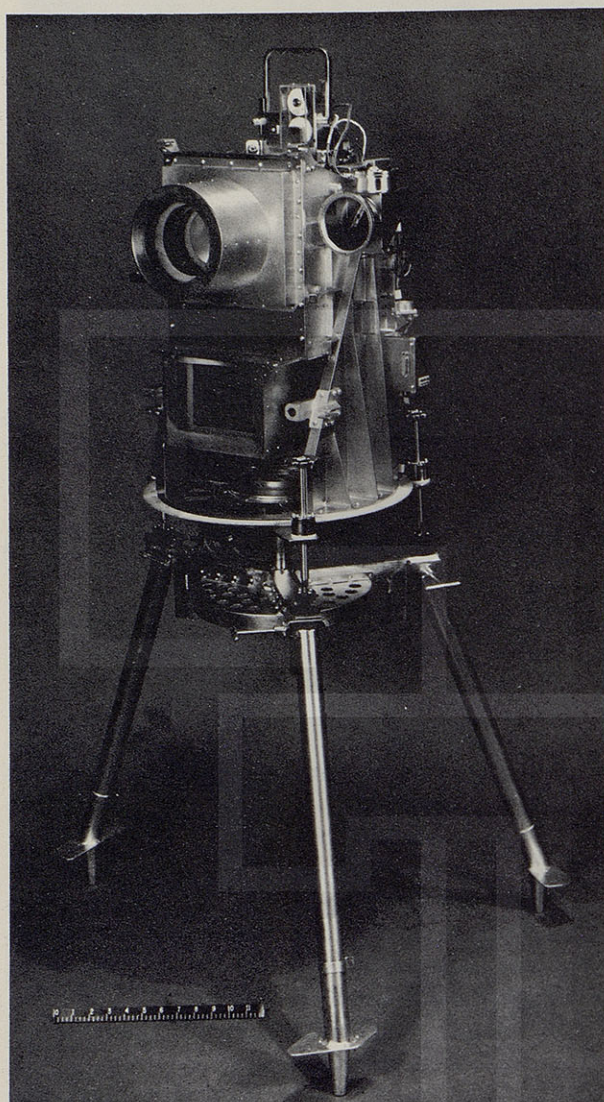
FIGURE 53.—Photograph of the lunar surface Ultraviolet Camera/Spectrograph. This equipment will provide the first astronomical observations taken from the Moon's surface. Photo courtesy Dr. Thornton Page.

The optical image is duplicated, faithfully, by the electron image which is formed on the film. The film differs from ordinary photographic film in that it is highly sensitive to electrons. The conversion of uv light to electrons may seem complicated to you. It isn't really very complicated though and does give very faithful images. Its main advantage is an increase in speed of 10 to 20 times that of a similar conventional photographic camera. In addition, the UVC is insensitive to visible light, a most important consideration because the Earth is a thousand times brighter when viewed with visible light than when viewed with uv.

A photograph of one model of the UVC, similar to the one on Apollo 16, is shown in figure 53. This camera is used in two different ways. In the first, direct images are obtained. These photographs are similar to regular photographic images with the very important difference that uv light is used rather than visible light. In the second, an optical device (technically termed grating) is used to break up the light into its individual frequency components. These individual components are then recorded on the film. Such data are extremely important. They allow us to determine the chemical elements present in the original light source. When the camera is used in the second way, it is termed a spectrograph. Spectrographic techniques have given us the chemical composition of the Sun and stars. In operation, the astronaut sets up the camera, levels it, and points it toward the target to be photographed. The sequence of operation is then automatic and the astronaut proceeds with other work. Sometime later he points the camera toward another target and so on. The final operation, of course, is to bring back the exposed film.

Soil M

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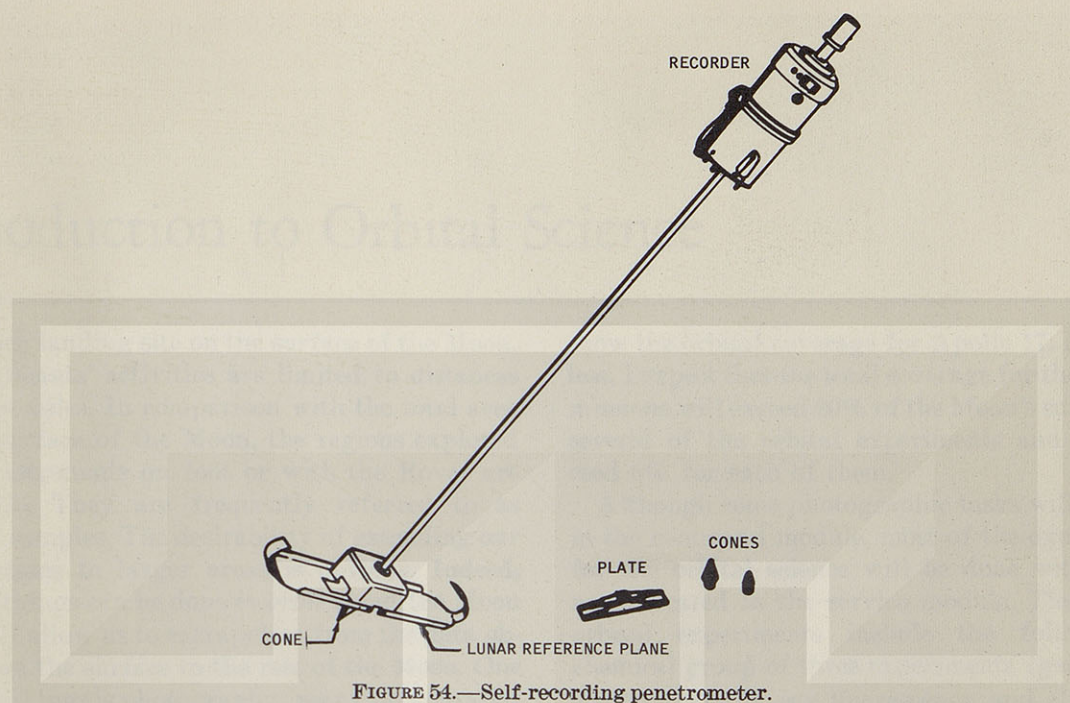
FIGURE 54.—Self-recording penetrometer.

Soil Mechanics Experiment

The mechanical properties of the lunar soil are important for both engineering and scientific reasons. Future design of spacecraft, surface vehicles, 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. To obtain data, many observations will be made during the performance of the other experiments. Such items as the quantity of dust blown from the Moon by the exhaust from the descending LM, the

amount of dust thrown up by the wheels on the Rover and the depth to which the astronauts sink while walking, are all important factors in estimating the properties of the lunar soil. Several figures in this booklet show these data. For example, see the drive tube and foot prints in figure 40 and the Rover tracks in figure 47. In addition to these qualitative observations, the astronauts will carry equipment with them with which to measure quantitatively the bearing strength of the soil, a recording penetrometer. It is illustrated in figure 54.

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 scheduled to be obtained on 16 and 17, have been greatly increased over those of earlier missions.

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 is shown in figure 55. The coverage for the present mission, Apollo 16, is shown in figure 56. At the time of writing this guidebook (January 1972), the landing site for Apollo 17 had not been chosen. So I do not show the orbital coverage for Apollo 17. Nonetheless, I expect that the total coverage for these three missions will exceed 20% of the Moon's surface for several of the orbital experiments and will exceed 5% for each of them.

Although some photographic tasks will be done in the command module, most of the experiments for the orbital science will be done with equipment located in the service module. The various orbital experiments include the following—a chemical group of three experiments (gamma-ray spectrometer, X-ray fluorescence, and alpha particle spectrometer), S-band transponder, mass spectrometer, several photographic cameras with a laser altimeter, and a subsatellite (with S-band transponder, particle shadows/boundary layer, and magnetometer).

The equipment for the orbital science experiments, carried in the service module, 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 57. The location of the equipment for the individual experiments in the SIM is shown in figure 58. The names and addresses of the principal investigator of each orbital experiment are given in Table 5.
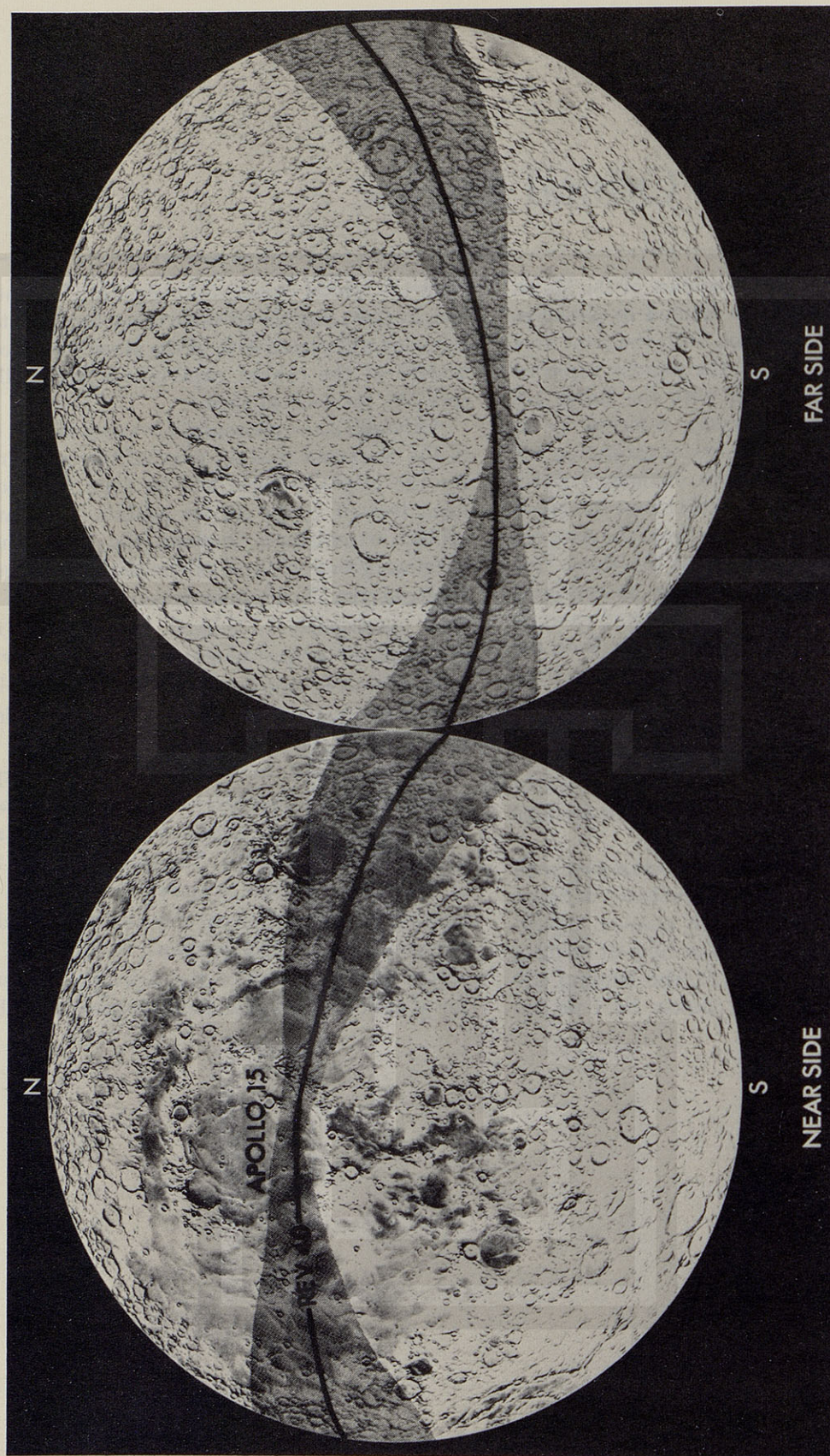
FIGURE 55.—Orbital Path for Apollo 15. Because the landing site of Apollo 15 was located well away from the equator the command module covered a rather large area of the Moon's surface. Data from the "chemical group" of experiments indicate the distribution of certain elements on the Moon's surface. The coverage of the farside of the Moon, never seen from Earth, is especially valuable. Almost 10,000 photographs 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.

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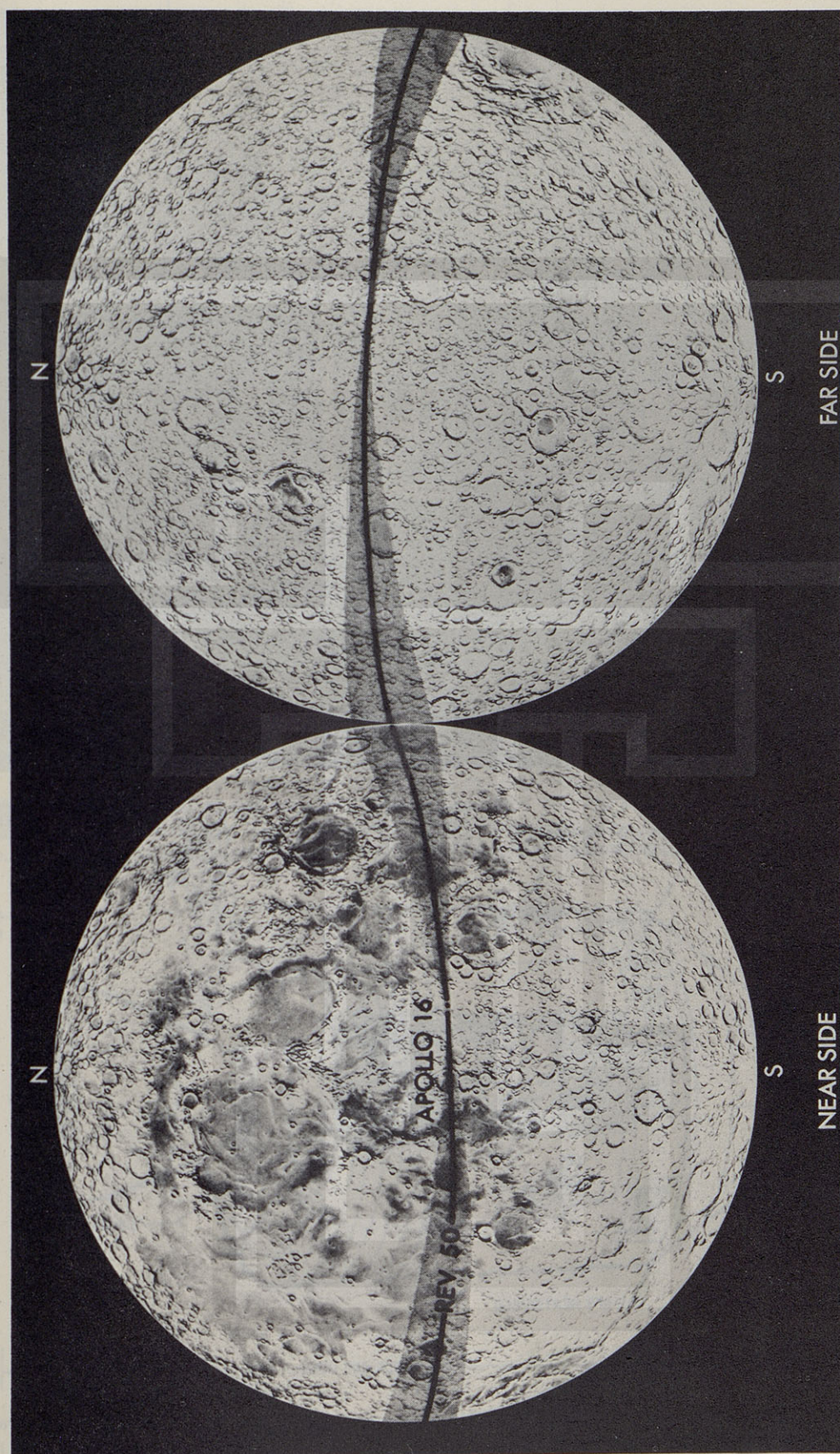
FIGURE 56.—Orbital Path for Apollo 16. See also caption for figure 55. BASE MAP COURTESY OF NATIONAL GEOGRAPHIC SOCIETY.
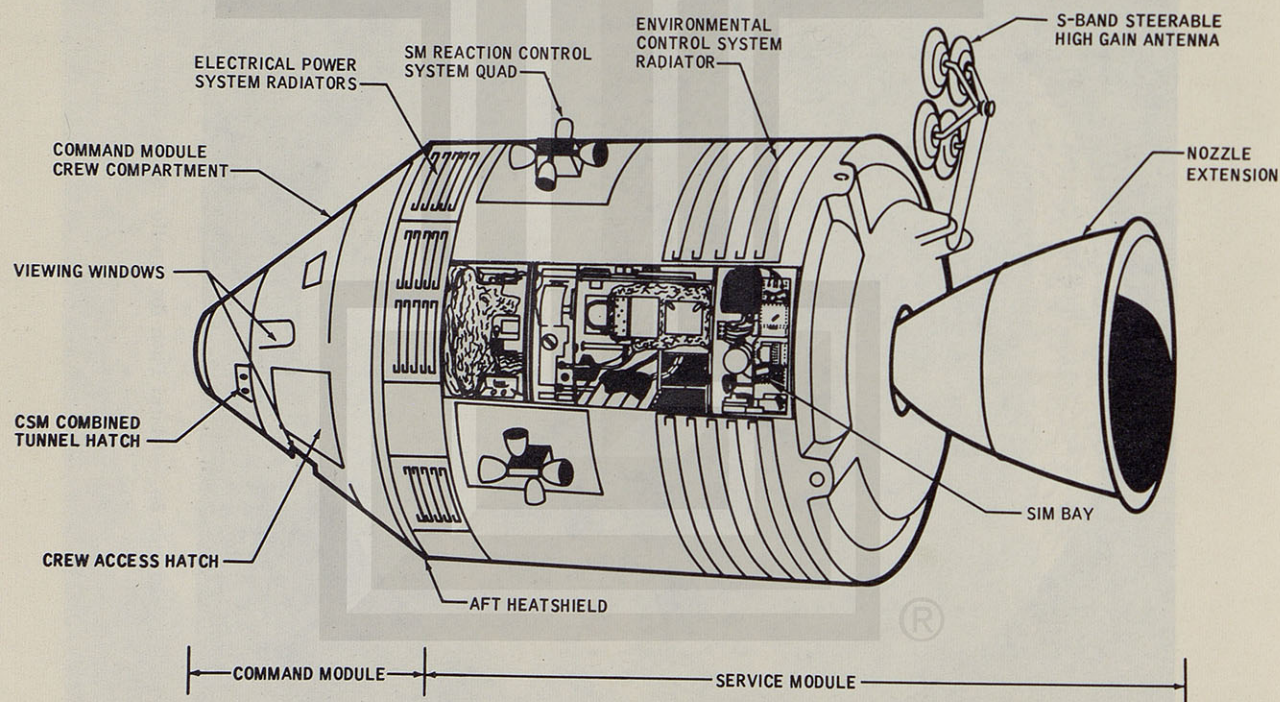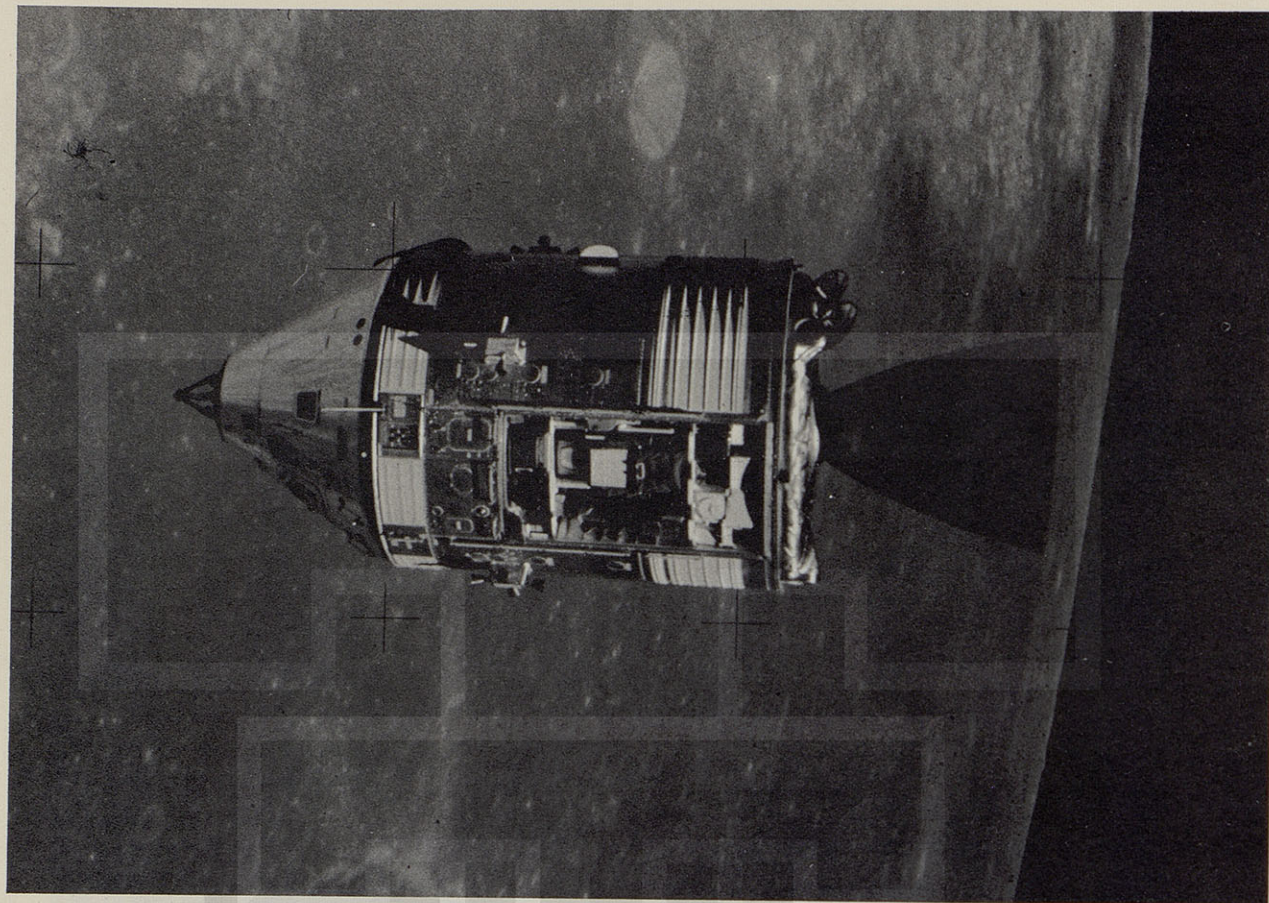
Figure 57.—Location of Scientific Instrument Module (SIM) in the Service Module, Apollo 15 photograph was taken from the LM with the Moon for background. NASA PHOTO AS15-88-11972. Sketch shows details and names.

STELLAR CAMERA LENS PROTECTIVE COVER

MAPPING CAMERA

LASER ALTIMETER

GOLDEN SLIPPER FOOT RESTRAINT

SUBSATELLITE PROTECTIVE COVER

SUBSATELLITE

X-RAY/ALPHA PARTICLE PROTECTIVE COVER (DEPLOYED)

GAMMA-RAY SPECTROMETER

ALPHA & X-RAY SPECTROMETER HOUSING

MAPPING CAMERA FILM CASETTE

NITROGEN CONTROL

PANORAMIC CAMERA

PANORAMIC CAMERA FILM CASETTE
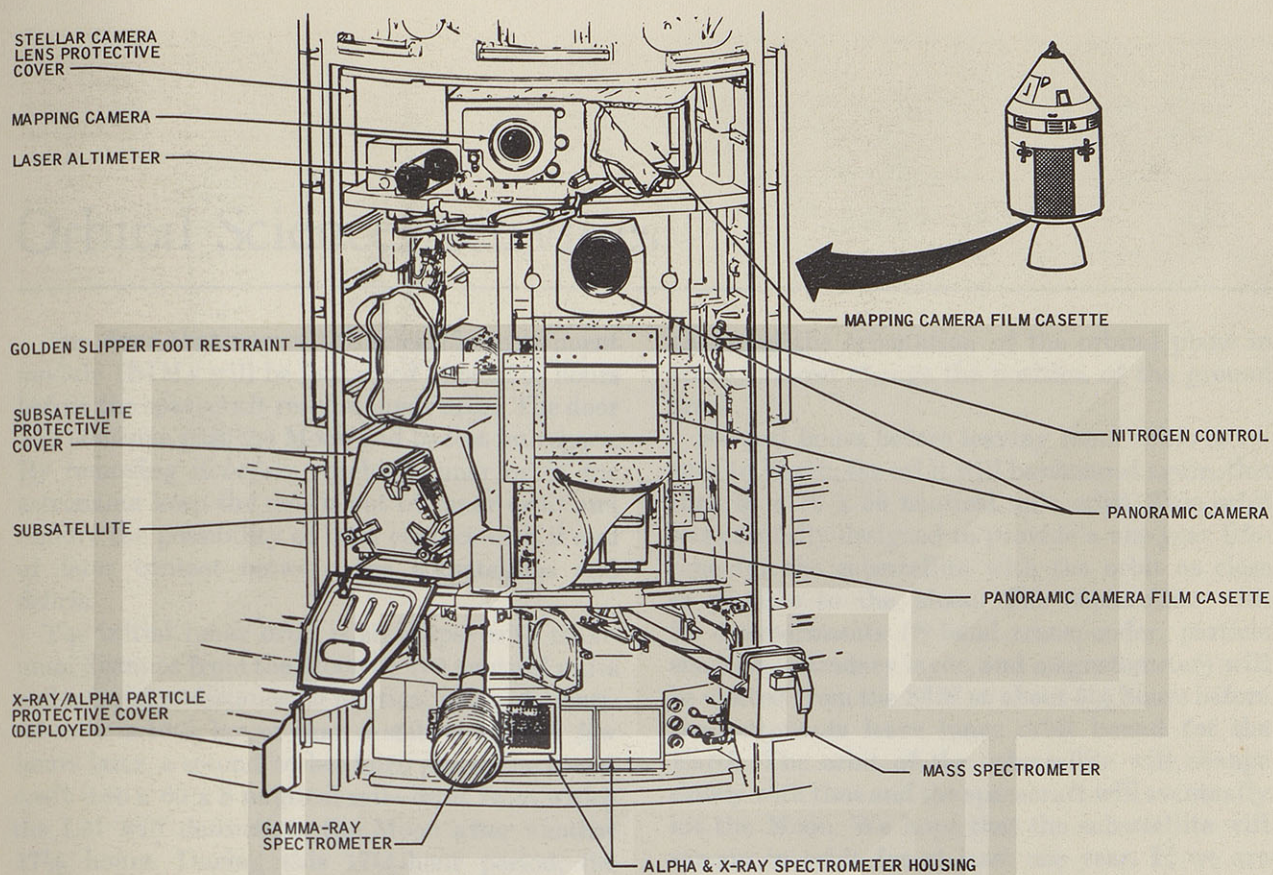
MASS SPECTROMETER

FIGURE 58.—SIM Bay. Shown here is the location within the scientific instrument module (SIM) of the equipment for each orbital experiment. The sensors for the gamma ray spectrometer and the mass spectrometer both extend outward on a boom about 25 feet when the instruments are in use. The subsatellite is launched while the service module is in orbit around the Moon; it remains behind in orbit after the astronauts leave lunar orbit to return home. Before the CM is separated from the SM the film cassettes must be retrieved. NASA PHOTO S-72-16852.

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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 it and of later contact between the subsatellites and debris.

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% larger than a statute mile. A few hours later, a second rocket burn places the spacecraft into a 60 x 8 nautical mile orbit from which the LM will descend to the Moon after another 17½ hours. During this 17½-hour period, the SIM experiments (X-ray, alpha particle, gamma ray, and mass spectrometer) and cameras will scan the lunar surface. The S-band transponder experiment also will be performed.

Then shortly before the LM touchdown, a third rocket 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 20 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 and photographic film 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, and will be crashed onto the Moon's surface to provide a source for the passive seismic experiment. About 20 hours after lunar liftoff, we change the position of the orbit around the Moon to increase the coverage of the Moon's surface with the orbital science experiments. Technically, this operation is called a plane change. In figure 2, you may have noticed that the orbit of the spacecraft lies in a plane. By changing the orientation of the orbital plane in space, we can change the position of the ground track.

Several hours before leaving lunar orbit to return to Earth, the orbit will be changed again, this time to a 76 x 56 nautical mile orbit. This orbit was carefully designed to provide a one-year lifetime for the subsatellite with the orbit as close as possible to the Moon. The subsatellite with its 3 experiments (S-band transponder, particle shadows/boundary layer, and magnetometer) will be ejected from the SIM at about 5½ hours before the astronauts leave lunar orbit bound for the Earth. The orbit of the subsatellite will change slowly with time and the spacecraft will eventually hit the Moon. We hope that the subsatellite will remain in orbit for at least one year. If we are lucky, it may remain considerably longer.

The total time in lunar orbit during which the SIM experiments and photography can be performed is about six 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 weight of the film which can be returned to Earth.

Let us look briefly now at each of the various orbital experiments.

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 textbook on the physics of lunar experiments. It is my hope that I can provide enough elementary information on the experiments that you understand how the experiment works. I hope then to show you a brief glimpse of the results that were

obtained on the Apollo 15 mission. Undoubtedly there are many surprises yet to come from the Apollo 15 data; results from Apollo 16 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 58.

The 24-inch panoramic camera, figure 59, is used to obtain high resolution panoramic photographs with both stereoscopic and regular (technically termed monoscopic) coverage of the Moon's surface. (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 72, for descriptions of the sets available.) Several automatic features have been incorporated into this camera. For example, the camera 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). It also tilts forward and backward to provide stereo coverage. In addition, in order to prevent blurring of the image, the camera automatically compensates for the forward motion of the spacecraft. And finally, one sensor detects the ratio of the forward velocity to the height of the spacecraft above the Moon's surface and automatically corrects for it. 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 this camera will provide an image on the film from an orbital altitude of 60 miles that gives 3 to 6 feet resolution of the Moon's surface. That resolution means we can see on the photograph an object as small as 3 to 6 feet.

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
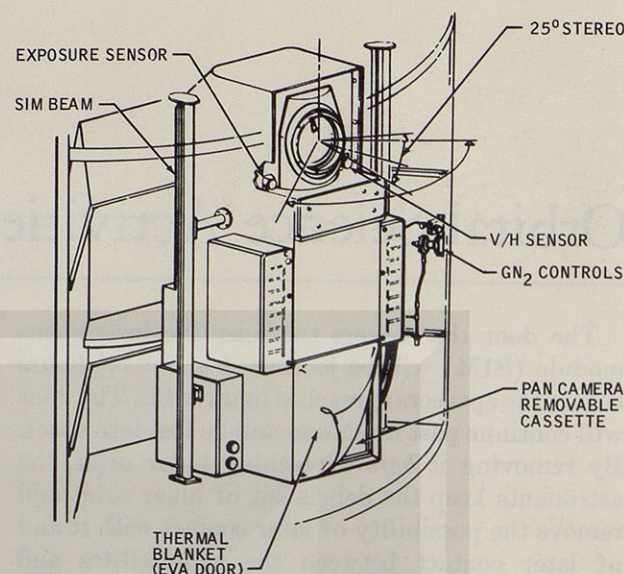
FIGURE 59.—24-inch Panoramic Camera. In operation, the entire assembly scans across the enclosure, a total of 108°. The camera lens tilts 25° forward and backward along the track of the spacecraft to provide stereo coverage. The film cassette is retrieved by the command module pilot on EVA in space.

astronauts, normally the CM pilot, during an EVA. The sequence of operations is indicated schematically in figure 60. The quality of the single photograph taken of Al Worden on Apollo 15 when he retrieved the film was not sufficient for me to reproduce the photo here. Instead, in figure 61, you can see 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.

Another camera in the SIM is the 3-inch mapping camera sketched in figure 62. It is really two cameras in a single assembly. Photographs of the lunar surface are obtained through the 3-inch cartographic lens and photographs of the star-field are taken through a different 3-inch lens pointed in exactly the opposite direction to permit the exact location of the camera to be determined later. Thus, 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 photography is that we cannot obtain in the

25° STEREO

V/H SENSOR

GN$_2$ CONTROLS

PAN CAMERA
REMOVABLE
CASSETTE

A   B   C
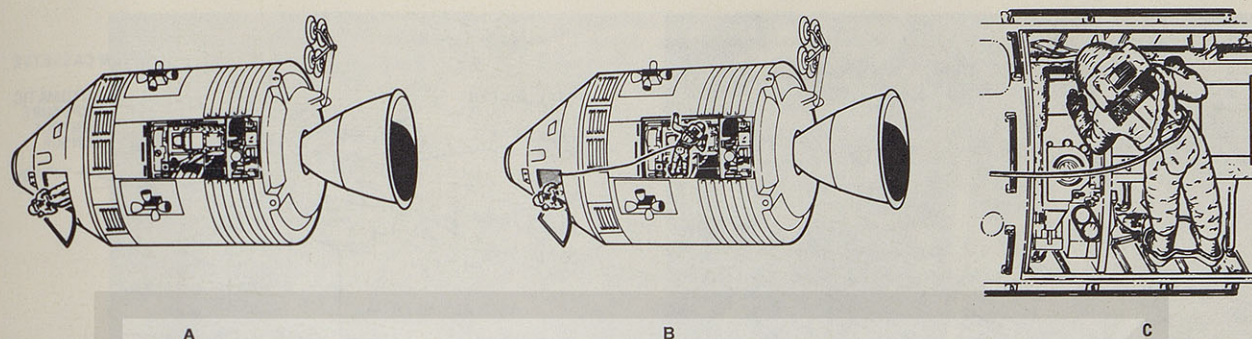
FIGURE 60.—Retrieving film from the SIM. In A, the astronaut is shown egressing through the CM hatch. All three astronauts must wear spacesuits to protect themselves against the vacuum of space. In B, an astronaut has moved to the vicinity of the SIM and is preparing to remove the film from one camera. 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. The other astronaut documents the procedure with photographs and verbal descriptions. He also helps by passing the cassettes to the astronaut in the CM for storage. NASA PHOTO S–72–16323.

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.

The Laser Altimeter

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 subtraction, we get the elevation of the lunar surface.

The results of the Apollo 15 laser altimeter for one revolution are shown in figure 63. 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 two 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 1.2 to 2½ miles deep, Oceanus Procellarum is rather smooth and is depressed about ½ mile. The Apennines are rather high standing, about 1½ miles.

Chemical Group of Orbital Experiments

Three experiments, known as the Chemical Group, will be used on Apollo 16 to obtain data that will help us to extrapolate what we learn from the study of the Moon at the Apollo 16 site. In each of these experiments, we measure something that is related to the composition of the Moon's surface over an area immediately below the orbiting spacecraft. Each of the sensors "sees" a finite area on the Moon's surface. Accordingly, a measurement at any point along the orbital path is an *average* value for several square miles of Moon immediately below the spacecraft. Let's examine each of the three experiments in the Chemical Group.

X-ray Fluorescence Experiment (XFE).—In this experiment we use two phenomena that you are almost surely familiar with, although you may

FIGURE 62.—Three-inch Mapping Camera and Laser Altimeter. This camera contains two complete cameras, one for photographing the Moon's surface, another for photographing the stars to obtain precise location 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 58. Above, we see a simple line drawing. Below, we see a photograph of the camera. Gaseous nitrogen is used to maintain pressure in the camera.

FIGURE 61.—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 16, 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 photographs. NASA PHOTOS AS9–19–2995 and AS9–02–3064.

never have thought of them working in combination. X-rays, discovered about 75 years ago by W. K. Roentgen, are used nowadays for many things—to "see" broken bones, decayed teeth, the flow of blood in arteries (when mixed with a suitable dye), and so on. I know of no better illustration of the great *practical* benefits that come from the laboratories of *pure* research. Within 3 months of Roentgen's discovery, X-rays were being used in a nearby hospital as an aid to surgery. There are many other nonmedical uses also. For example they are also used to identify many substances, including minerals.

X-rays have many of the properties of light; they travel in straight lines, they are electromagnetic waves, they can be diffracted, they can be reflected, and so on. Like light, they also darken photographic film. They *can* be detected and

FARSIDE / NEARSIDE altimetry diagrams
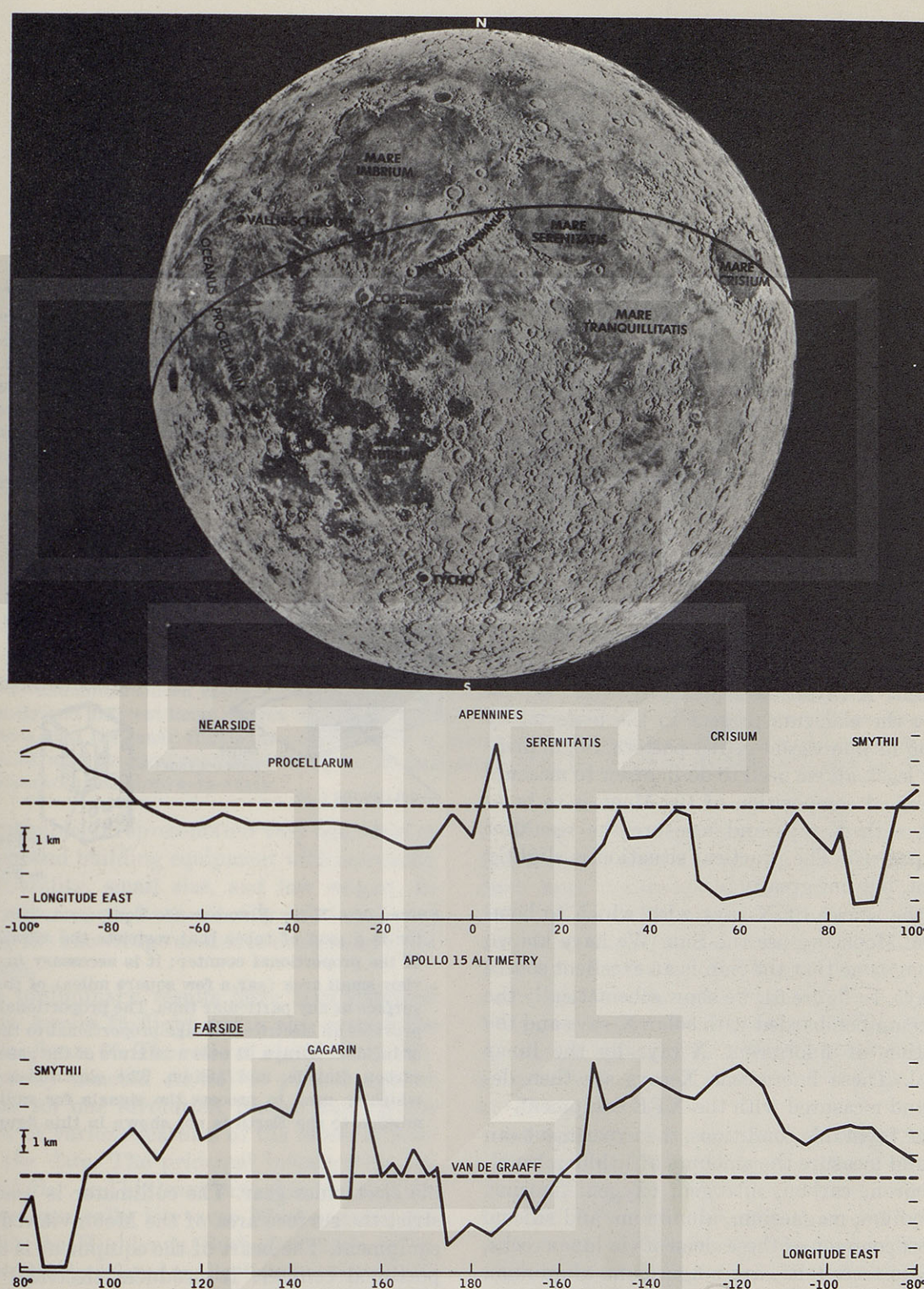
FIGURE 63.—Results of the Apollo 15 Laser Altimeter. Data are shown for one revolution only. The elevation of the surface of the Moon along that single ground track (above) is shown in diagram. The dashed line represents the elevation of a sphere with radius of 1737 km. Based on work of William Kaula in the Apollo 15 Preliminary Science Report. NASA PHOTOS S–72–16337 and S–72–16322.

measured by the well known Geiger Counter used in prospecting for radioactive minerals but usually more sophisticated instruments are used today.

Fluorescence is the phenomenon on which the very familiar fluorescent light bulb is based. It involves the displacement of an electron from its most comfortable orbital position in an atom. When the electron returns to that position, it releases energy in the form of light. The fluorescent material in the light bulb is the thin white coating on the inner surface. Of course the light bulb has been carefully designed so that most of the radiation is in the form of visible light. For most solids though the energy released by the returning electron is in the form of X-rays.

One of the standard techniques for the identification of an unknown substance is that of X-ray fluorescence. In this technique, the substance is bombarded with X-rays. The incident X-rays knock electrons out of their most comfortable orbital positions. When these electrons return, other X-rays are produced with wavelengths and energies that are characteristic of the material. Because no pair of elements produce patterns of fluorescent X-rays that are exactly alike, we can identify the elements present in the material by studying its fluorescent X-ray pattern. So, in principle at least, all we need to do in order to measure the chemical composition of the Moon is to bombard it with X-rays and measure the resultant X-ray pattern. The practical situation is slightly different, but not greatly !

For the source of X-rays with which to bombard the Moon, we use the Sun. We have known for a long time that the Sun is an excellent source of X-rays. In figure 64, we show schematically the Moon being bombarded with solar X-rays and the production of fluorescent X-rays by the lunar material. These fluorescent X-rays are then detected and measured with the XFE equipment.

Under favorable conditions, the experiment can detect and 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.

The equipment on board the SM that we use to measure the X-rays is simple in principle but includes very sophisticated electronic devices. It is shown schematically in figure 65. It consists of a collimator, proportional counter, and considera-
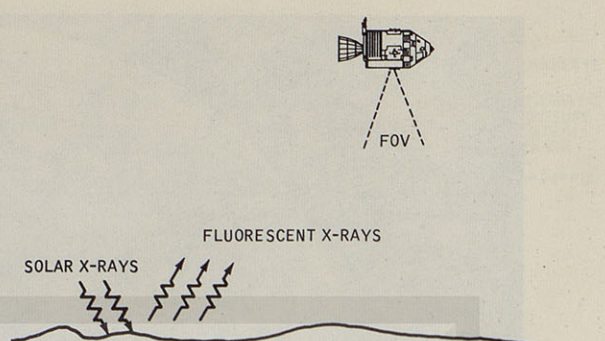
FIGURE 64.—X-ray Fluorescence Experiment. X-rays from the Sun hit the Moon's surface. They excite the atoms of the lunar material and produce fluorescent X-rays. The fluorescent X-rays are characteristic of the material and are detected and measured with equipment on board the service module. The absence of a lunar atmosphere is necessary for this experiment to operate successfully. Shown also is the field of view (FOV) of the instrument.
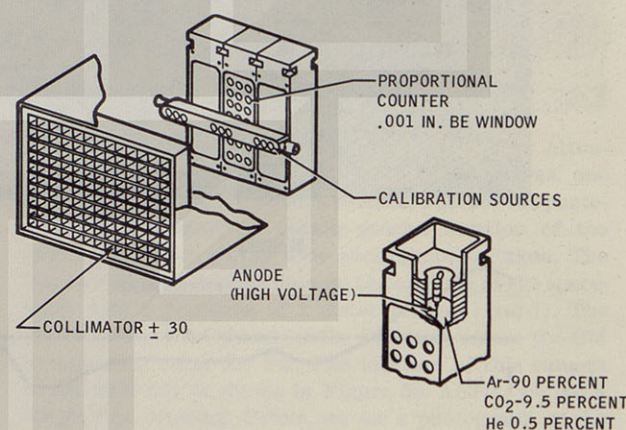
FIGURE 65.—X-ray Fluorescence Equipment. The collimator is a grid of tubes that restricts the viewing angle of the proportional counter; it is necessary in order to view small area (say a few square miles) of the Moon's surface at any particular time. The proportional counter provides an electrical voltage proportional to the energy of incident X-rays. It uses a mixture of the gases argon, carbon dioxide, and helium. The electronics package which is used to process the signals for radio transmission to the Earth is not shown in this figure.

ble electronics gear. The collimator is used to restrict the surface area of the Moon viewed by the equipment. The heart of the equipment is the proportional counter. It produces electrical signals from the X-rays so that they can be readily processed and sent to Earth. A rather sophisticated set of electronics not shown in figure 65 is used in this experiment.

Like other equipment used in our exploration of the Moon and space, this equipment is the most ad-
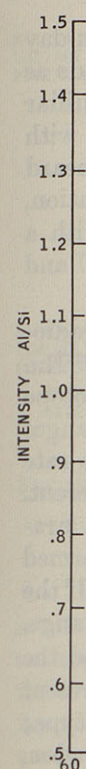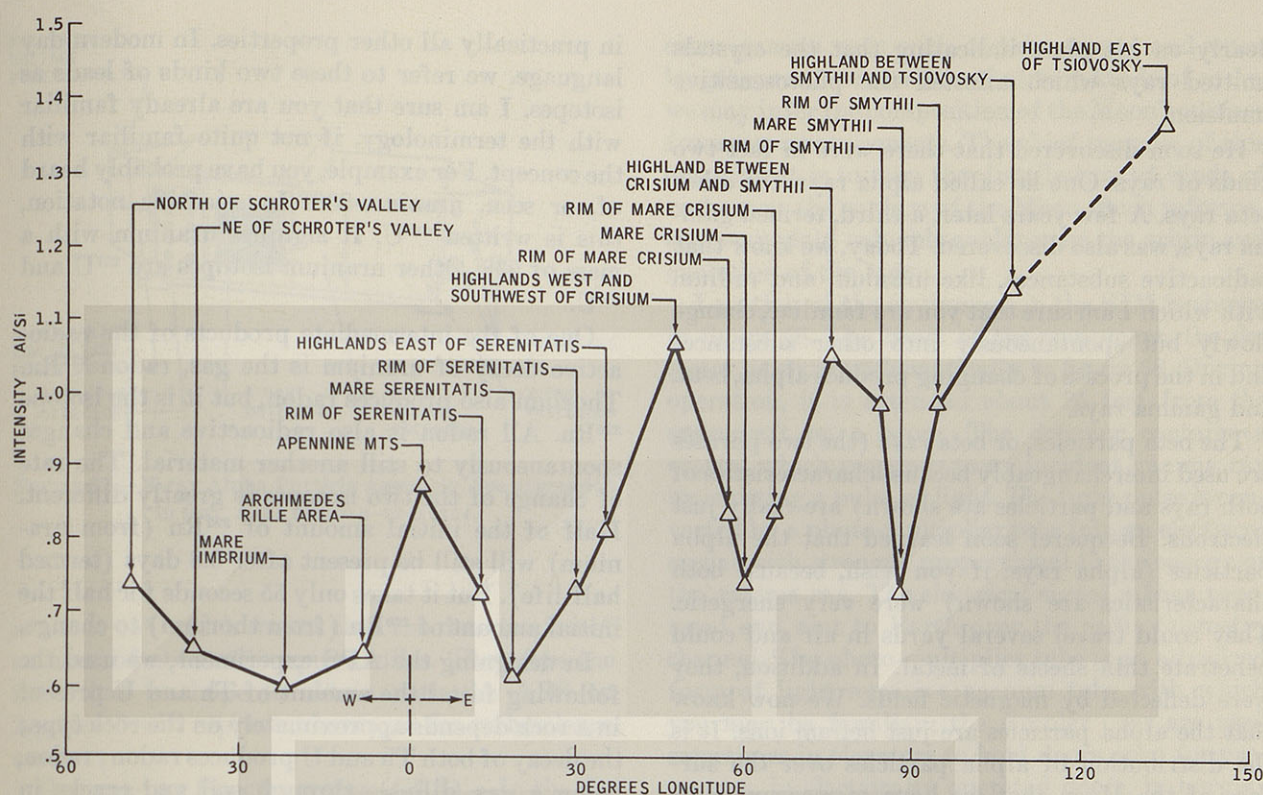
FIGURE 66.—Aluminum-silicon ratios measured along one track of Apollo 15. Note the excellent correlation between the intensity and different lunar regions. The maria have low ratios, the Highlands have high values. These data support the idea that the lunar Highlands consist mostly of anorthosite, an aluminum silicate rock. Similar data will be obtained with identical equipment on Apollo 16. Data provided by Dr. I. Adler, the Principal Investigator of this experiment. NASA PHOTO S-72-16319.

vanced possible. It represents our very best effort at designing and building equipment with extremely high reliability, small size, and low weight. In many instances, we have actually advanced considerably the knowledge needed to design and build equipment.

Some preliminary results have been obtained from the Apollo 15 flight which also carried the XFE. See figure 66. 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. The principal investigator, Dr. Isadore Adler, and his team have 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. But the whole story is a complete chapter in itself and, although extremely interesting, is much too long to pursue here.

In addition to its use in studying the Moon, the XFE equipment has another, very important use

in X-ray astronomy. Yes, we *can* "see" things in space with X-rays. About a hundred X-ray sources have been discovered outside our solar system. Some of them also produce radio waves. Some are very faint stars. But their main radiation of energy is in the form of X-rays. Frankly, we do not yet understand the nature of these very distant objects. The great advantage of looking with X-rays from spacecraft rather than from Earth is due to the absorption in the Earth's atmosphere of practically all X-rays from space.

Alpha Particle Spectrometer (APS).—Within a few months after the discovery by Roentgen of X-rays, Henri Becquerel discovered radioactivity. He had left a salt of potassium and uranium (which you and I now know are radioactive) on a photographic plate that was enclosed in black paper. He wished to expose the material to sunlight in order to see if sunlight produced any effect on the salt that could be detected photographically. After several cloudy days though, he decided to develop the film anyhow. Imagine his surprise when the outline of the crystals showed

clearly on his plate indicating that the crystals emitted rays which affected the photosensitive emulsion.

He soon discovered that there were in fact two kinds of rays. One he called alpha rays, the other beta rays. A few years later, a third, termed gamma rays, was also discovered. Today, we know that radioactive substances, like uranium and radium with which I am sure that you are familiar, change slowly but spontaneously into other substances and in the process of changing produce alpha, beta, and gamma rays.

The beta particles, or beta rays (the two phrases are used interchangeably because characteristics of both rays and particles are shown) are really just electrons. Becquerel soon learned that the alpha particles (alpha rays, if you wish, because both characteristics are shown) were very energetic. They could travel several yards in air and could penetrate thin sheets of metal. In addition, they were deflected by magnetic fields. We now know that the alpha particles are just helium ions. It is the distribution of alpha particles over the surface of the Moon that we hope to measure with the APS. Let's see why that information might be of value to us.

The study of samples of both rock and soil returned to the Earth from the Moon shows that uranium and thorium are present in significant amounts. Do not let me mislead you. The key word here is significant. The amount is extremely small. For example, in some of the lunar rocks neither of these two elements is present in quantities larger than a few parts in ten million. Thus, in ten million pounds of such rock we would have only a few pounds of uranium scattered throughout it. For mining purposes, this amount is far too small. Yet for scientific purposes, it is highly significant and can be easily measured with modern instruments.

Both thorium and uranium are radioactive. Hence, both change spontaneously into other materials. The final product of the decay process of each of these two elements is lead. One of the intermediate products of each element is radon, a gas.

Early in the investigation of radioactivity, it was discovered that some elements seemed to have different mass but otherwise identical properties. For example, it was found that while uranium and thorium both ultimately decayed to lead, the mass of the lead that was produced by uranium was different from the mass of the lead produced by thorium. Yet the two kinds of lead were identical in practically all other properties. In modern day language, we refer to these two kinds of leads as isotopes. I am sure that you are already familiar with the terminology, if not quite familiar with the concept. For example, you have probably heard of, or seen, uranium-238. In scientific notation, this is written ^{238}U. It signifies uranium with a mass of 238. Other uranium isotopes are ^{237}U and ^{235}U.

One of the intermediate products of the radioactive decay of uranium is the gas, radon ^{222}Rn. Thorium also produces radon, but it is the isotope ^{220}Rn. All radon is also radioactive and changes spontaneously to still another material. The rate of change of the two isotopes is greatly different. Half of the initial amount of ^{222}Rn (from uranium) will still be present after 3.8 days (termed half-life). But it takes only 55 seconds for half the initial amount of ^{220}Rn (from thorium) to change.

In designing the APS experiment, we used the following facts: the amount of Th and U present in a rock depends approximately on the rock type; the decay of both Th and U produces radon; radon, being a gas, diffuses through soil and cracks in rocks to the surface of the Moon where it then follows a ballistic trajectory (a short and efficient way of saying that it follows the same path as a bullet would if shot from a gun) above the surface of the Moon to some other point on the Moon. You might be interested in knowing that the initial velocity of these gas particles is about 500 ft/sec and that typically they reach an altitude of 5 miles before they fall back to the Moon's surface. Practically none escapes from the Moon. So, how in our APS experiment, orbiting at 60 miles, can we measure the radon present at 5 miles, or less, in order to infer the rock type immediately below?

Let's see.

When radon decays spontaneously to the next material in the series, it produces alpha particles. These alpha particles can travel much higher above the Moon and hence will be picked up by our instrument. Thus the radon is detected by measuring the energies of alpha particles.

The equipment for the APS and the X-ray experiment, both part of the same assembly, is shown schematically in figure 67. The location is shown in figure 58. The alpha particle detectors are solid state devices that produce an electrical signal when hit by an alpha particle. The electrical signal is amplified, processed, and the data sent back to Earth. The field of view of the instrument

FIGURE 67.—X-ray Alpha Particle Assembly. See discussion in text. NASA PHOTO S-72-16334.

is about 45° which means that the detector "sees" an area of about 120 square miles. Therefore the data that we hope to obtain with the APS on Apollo 16 will represent averages for rather large areas.

Gamma-ray Spectrometer (GRS).—In the decay of radioactive materials, alpha, beta, and gamma rays are produced. Of the three, the gamma rays are the most penetrating. Therefore gamma rays that are produced on the Moon's surface, or within a few millimeters of it, may be detected and measured with equipment on board the SM. Be-

cause gamma rays with certain energy and wave lengths are characteristic of certain kinds of rocks, we may infer the composition of the Moon's surface from our measurements. The chief purpose of this experiment is to map the distribution of kinds of rocks over the surface of the Moon. Such information may yield valuable evidence on the origin and evolution of the Moon.

Location of the equipment in the SIM is shown in figure 58. The heart of the equipment, the detector, is shown schematically in figure 68. During operation, it is extended about 25 feet from the spacecraft on a boom. The detector contains a crystal which responds to an incident gamma ray by emitting a pulse of light. The light pulse is converted by a photo-multiplier tube into an electrical signal with strength proportional to the energy of the gamma ray. The electrical signal is then processed and sent to Earth over the radio telemetry channel. The photo-multiplier tube is an advanced form of light sensitive vacuum tube with which you may be familiar; the simpler ones are used sometimes in elevators to hold doors open for passengers, in electrically operated doors, in burglar alarm systems and so on. They are especially popular with hobbyists.

The detector crystal will produce a light pulse from the passage of any charged particle also. Yet we wish to "see" only the gamma rays. To eliminate these effects, the crystal is surrounded by a
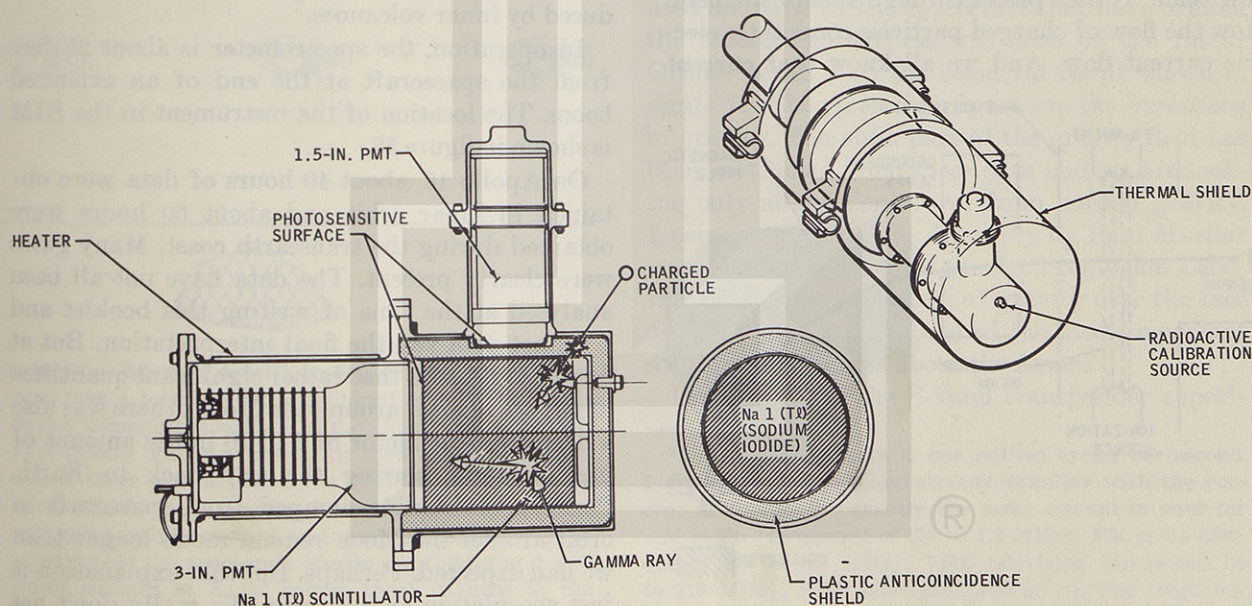
FIGURE 68.—Gamma Ray Detector. The detector, in use, is located 25 feet from the spacecraft on a boom. See discussion in text. See figure 58 for location in the SIM of the gamma ray equipment.

second material which emits light from charged particles but not from gamma rays. Thus the two can be distinguished. The electrical signals produced by charged particles are cancelled in the electronics processing and no false data are generated.

A gamma ray spectrometer similar in all respects to the Apollo 16 equipment was flown on Apollo 15. The final results of that experiment are not yet available but the hardware worked correctly and the analysis is now in progress. I expect that the results will be significant and that they can be correlated with the geological features of the Moon. One feature of the data appears to be a high concentration of radioactivity in Oceanus Procellarum (relative to the rest of the Moon).

Mass Spectrometer Experiment (MSE)

In this experiment we measure the composition and density of gas molecules along the flight path. Early instruments and the basic technique were developed shortly after the turn of the century. The principle can be understood by referring to figure 69. Gases enter the instrument through an inlet manifold, termed plenum, 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 we all know that 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.

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 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 16 mass spectrometer.

In the Moon's atmosphere, which as you know is extremely thin, we expect to find such light gases as hydrogen, helium, and neon, with neon probably 10 times as abundant as the others. These gases come from the solar wind. Argon is likely present from the decay of radioactive potassium (^{40}K). Certain other gases, such as carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, sulfur dioxide, and water vapor may have been produced by lunar volcanoes.

In operation, the spectrometer is about 25 feet from the spacecraft at the end of an extended boom. The location of the instrument in the SIM is shown in figure 58.

On Apollo 15, about 40 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 analysed 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. Perhaps the liquids dumped from spacecraft in orbit around the Moon remain much longer than we had expected. Perhaps. But that explanation is just speculation at this time. We really don't yet understand why the Apollo 15 instrument saw so much gas in its orbits around the Moon.

FIGURE 69.—Principle of the Mass Spectrometer. The magnetic field is perpendicular to the plane of the paper. See discussion in text.

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 70. 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
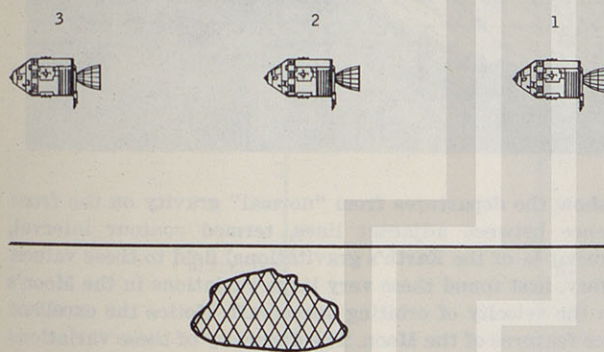
FIGURE 70.—Effect of density on Spacecraft Velocity. Suppose that a large chunk of material of high density is buried beneath the surface of the Moon. The spacecraft at position 1 will be pulled gently forward by it. At position 2, there will be only a net downward force and no horizontal force. At position 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.

it is very small, in the velocity of the orbiting CSM can be measured with extremely high precision.

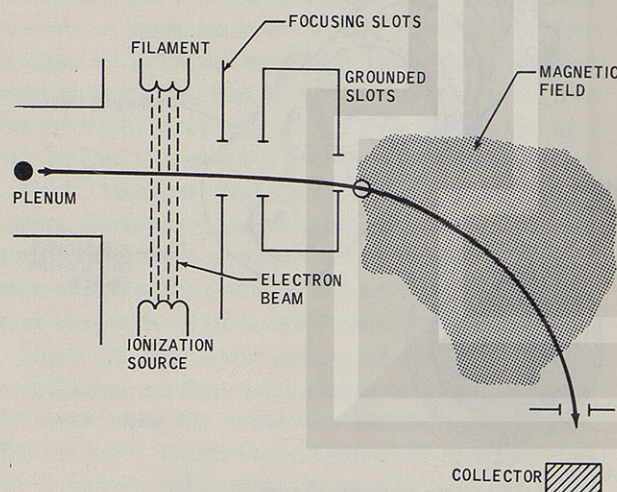These high precision measurements of the changes in velocity are obtained in the following way. From Earth a radio wave of very stable frequency* of 2115 MHz is transmitted to the orbiting spacecraft. When the radio wave is received by the spacecraft, the frequency is multiplied by the constant 240/221 (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 frequency muliplied 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 phenomenom, 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 variation 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 beautiful result shown in figure 71. 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 Mueller 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 16, the S-band transponder experi-

*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.
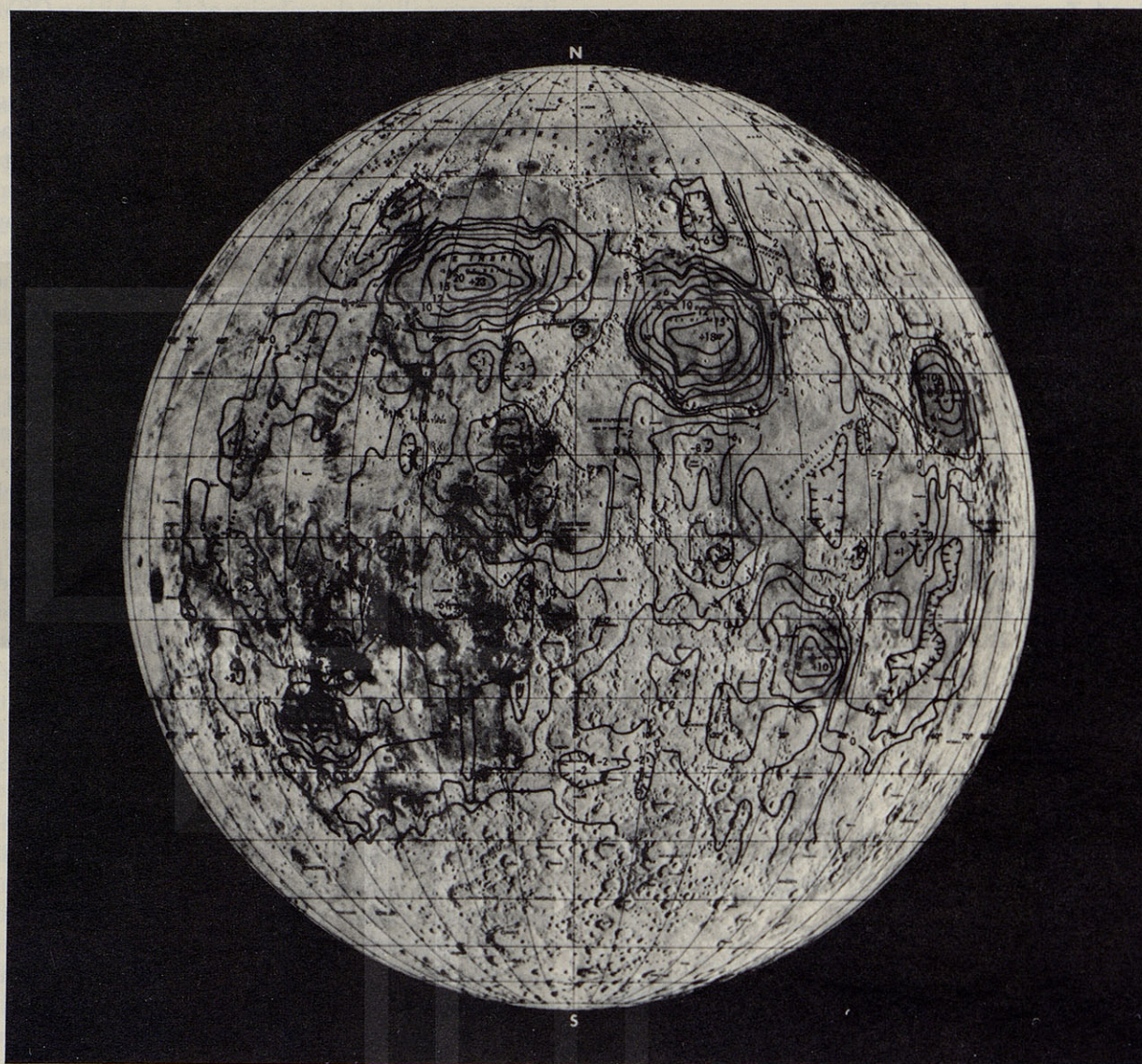
FIGURE 71.—Lunar Gravity. These lines, called contour lines, show the departures from "normal" gravity on the front side of the Moon. The units are 100 milligals. The difference between adjacent lines, termed contour interval, is 200 milligals. To obtain total gravity, you must add the usual ⅙ of the Earth's gravitational field to these values. Mueller 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 feature 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.

ment will obtain data from three spacecraft, the orbiting CSM, the LM, and the subsatellite. Because the subsatellite will stay in lunar orbit for many months, and possibly several years, many new data should become available from it.

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.

Bistatic Radar Investigation

Even in space exploration, one sometimes gets something for (almost) nothing. Such is the case with the bistatic radar investigation. In this experiment, we study the radio signal that is normally used in communications between the CSM and Earth. We compare the signal that comes directly to Earth from the orbiting CSM with the signal that is reflected from the Moon's surface. These relations are shown in figure 72. The type of antenna used to receive these rather faint radio signals is shown in figure 73. From a comparison of these two signals, we are able to learn several things about that part of the Moon immediately below the orbiting CSM. We are able to measure certain electrical properties of the outer few yards of the Moon's crust, determine the average slope of the Moon's surface, and detect rocks buried to depths of perhaps 50 to 60 feet. Such data will

FIGURE 73.—The large radio receiving antenna at Stanford University. This unit collects the energy received as radio waves over the 150 foot "dish" and focuses it at the small feature, termed feed point, seen near the center. It is then sent through high quality amplifiers. This antenna and similar ones located at several sites around the Earth (so that the Moon is always in view) are used both to communicate with spacecraft and to measure their changes in velocity. See text for further discussion. PHOTO COURTESY OF H. T. HOWARD.

be extremely useful when synthesized with the other information from the Moon.

Subsatellite Experiments

Carried in the Apollo 16 SIM is a small, 85 lb., scientific spacecraft that will be placed in orbit around the Moon and left there when the astronauts return to Earth. It is the particles and fields subsatellite or subsatellite for a shorter name. Its location is shown in figure 58. It is sketched in figure 74. This satellite is completely self-contained. It carries its own power supply (solar cells that deliver 24 watts), solar sensors (to let us know the direction in which the satellite is pointing), a battery pack of silver-cadmium cells (for power when the satellite is in the shadow of the Moon), a data storage unit (magnetic core memory, similar to those used in some large computers), an S-band communications system, and the equipment for two scientific experiments. Data that are obtained on the backside of the Moon are stored in the memory unit and then, on command from the Earth when the satellite is in view, sent to

FIGURE 72.—Bistatic Radar Experiment. The radio communication signals from the spacecraft travel along two paths. One comes directly to the receiving antennas on Earth. The other travels to the Moon, is reflected, and then travels directly to the receiving antennas. Comparison of these two signals allows us to recognize the changes caused by the reflection from the Moon. Such changes are the basic data of this experiment from which we infer the electrical properties of the outer few yards of the Moon. The Moon and spacecraft are not shown to the same scale.

FIGURE 74.—The Apollo 16 Particles and Fields Subsatellite. In the lower figure, the subsatellite is shown in the folded configuration in which it is carried in the SIM. It rests on a guide rail. On command from the CM, it is ejected from the SIM and assumes the configuration shown in the top figure. It remains in orbit at least several months and possibly years. NASA PHOTOS S-72-16304 and S-72-16311.

Earth in about 8 minutes. A similar satellite was left behind in lunar orbit by the Apollo 15 crew. It is still sending data to us. I will use some of the results obtained with it for illustration.

The subsatellite carries two experiments, one to measure particles and the other to measure magnetic fields. A third experiment, the S-band transponder, requires no additional equipment on the satellite and is entirely passive; it is discussed in the section "S-band transponder" elsewhere in this guidebook.

In order to understand clearly the purpose of the magnetometer and particles experiments, let me discuss briefly some space physics. The Earth has a magnetic field. It is convenient for most of us to visualize that magnetic field as having "field

lines." You may remember that iron filings placed on a sheet of paper over a magnet will stand on end and, in fact, line up with the individual magnetic field lines. We can visualize the magnetic lines of the Earth as being similar to those shown in figure 75. However, the field lines for the Earth are really not quite like I have shown them in figure 75. In fact, on the side of the Earth towards the Sun, the field lines are compressed; on the side away from the Sun the field lines are stretched. They extend in very long loops. This correct situation is shown in figure 76. We have verified this concept of the compression and stretching of the Earth's magnetic field lines shown in figure 76 with measurements made from previous satellites equipped with magnetometers.

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 solar wind "blows" the Earth's magnetic field lines around behind the Earth. Different regions with different characteristics are known by different names. The large region behind the Earth with relatively few lines is called the geomagnetic cavity; it extends out to a distance at least 100 times the Earth's radius. We do not know how much further it may extend. We have not had satellites in the more distant region for measurements. The region around the cavity is disturbed by the interaction of the solar wind and the Earth's magnetic field. It is the magnetosheath.

The Moon rotates about the Earth at a distance
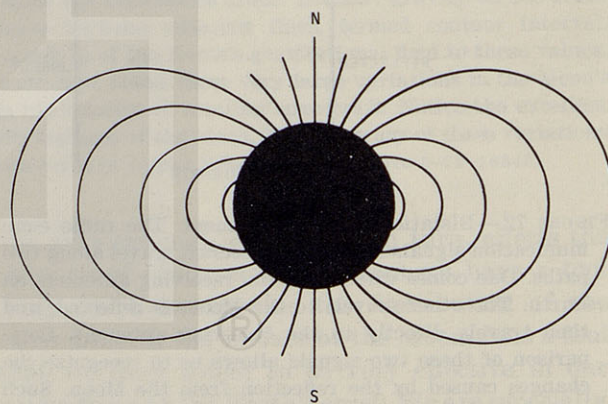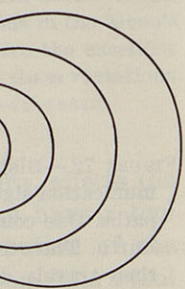
FIGURE 75.—Idealized Magnetic Field of the Earth. In the absence of the solar wind, the magnetic field lines of the Earth would be symmetrical about the Earth.
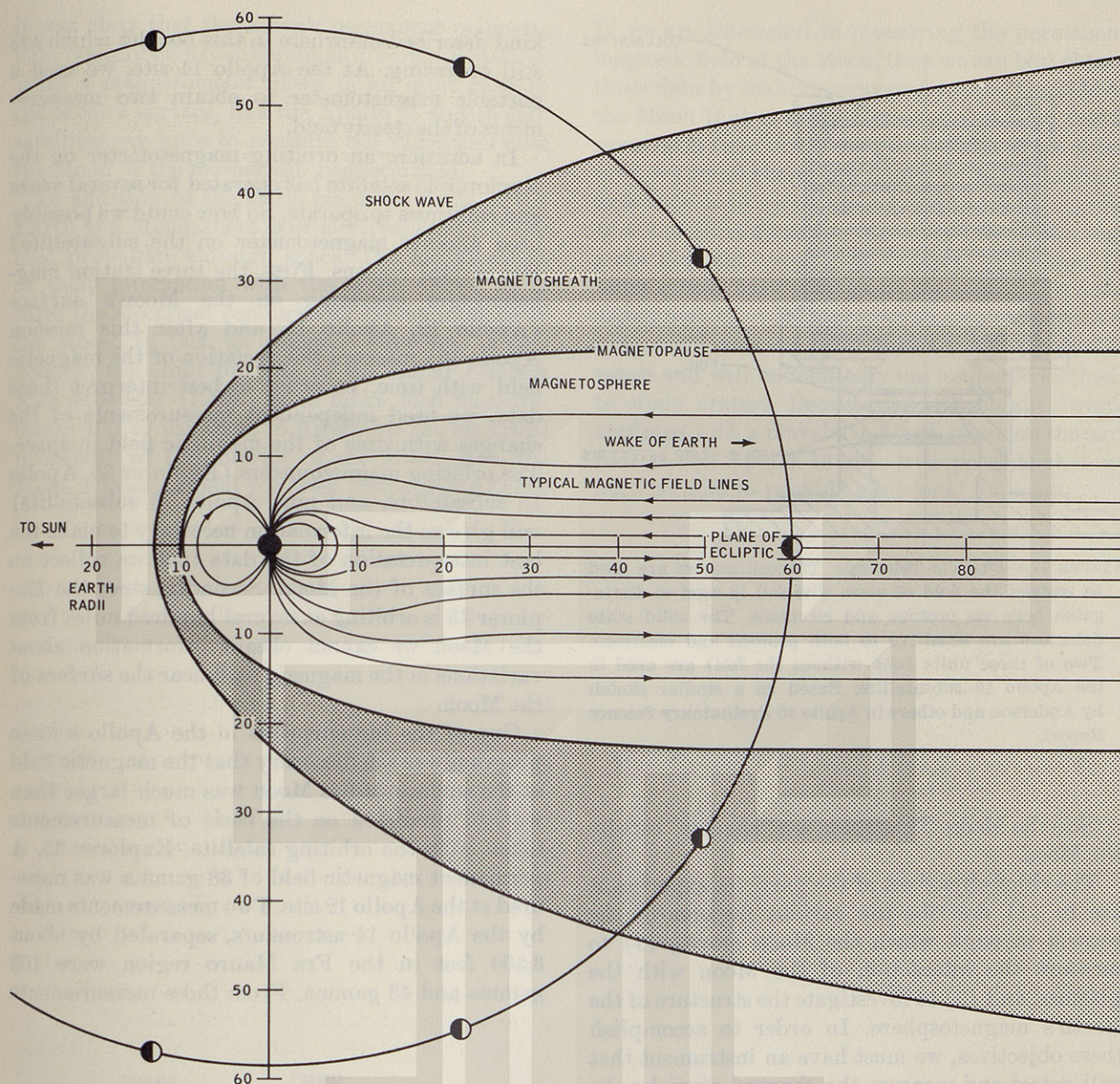
FIGURE 76.—Observed magnetic field of the Earth. The solar wind "blows" the magnetic lines toward the back side of the Earth forming the magnetosheath and the geomagnetic cavity. The geomagnetic cavity extends to at least 100 earth radii. The Earth and Moon are not sketched to scale. The Moon completes an orbit about the Earth every 28 days. NASA PHOTO S–72–16321.

of 60 Earth radii, 240,000 miles. Thus the Moon passes through a part of interplanetary space in which there is almost no effect from the Earth's magnetic field; it also passes through the magnetosheath and the geomagnetic cavity. These different regions affect the solar wind and magnetic fields on the Moon in different ways. Thus in order to interpret a particular set of data from either the magnetometer or from the particle experiment, it is necessary to know the location of the Moon with respect to the Earth and Sun when the data were taken.

The Moon has a very small magnetic field, less than one-thousandth that of the Earth. It interacts with the solar wind in a completely different way than does the Earth. The Moon acts as a barrier. In the absence of a significant magnetic field, the solar wind on the front side of the Moon simply
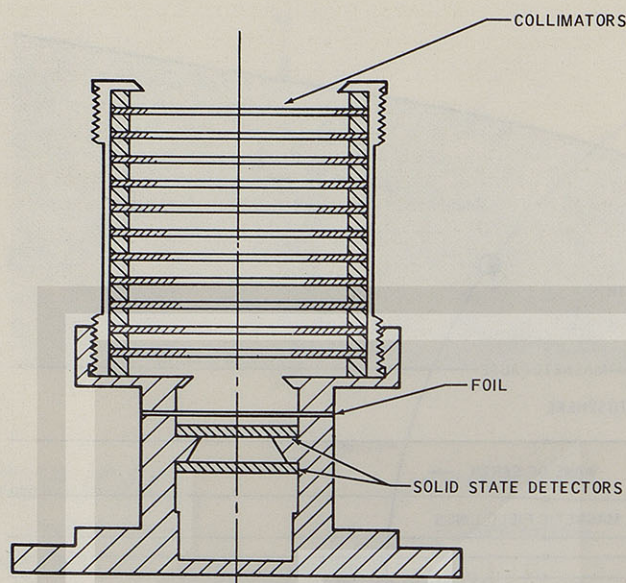
FIGURE 77.—Particle Telescope. The collimators are used to restrict the field of view. The foil is used to distinguish between protons and electrons. The solid state detectors are sensitive to both protons and electrons. Two of these units (one without the foil) are used in the Apollo 16 subsatellite. Based on a similar sketch by Anderson and others in Apollo 15 Preliminary Science Report.

strikes the Moon. Thus there is a "shadow" cast by the Moon.

The chief objectives of the particles experiment are to (1) describe the various features of the plasma through which the Moon moves, (2) to measure the interaction of the Moon with the plasmas, and (3) to investigate the structure of the Earth's magnetosphere. In order to accomplish these objectives, we must have an instrument that will detect and measure the charged particles. In figure 77, I show schematically one of the two particle telescopes. Basically, it is a tube with collimators to restrict the viewing angle and solid state detectors. With these instruments and the associated electronics, we can measure the direction and the energy of the charged particles—either electrons or protons. We can also distinguish between electrons and protons. An example of the data obtained on Apollo 15 is shown in figure 78. There I have plotted the relative number of electrons as a function of the position of the spacecraft.

Let's discuss the other experiment on board the subsatellite, the magnetometer. We already have magnetometers on the Moon. At the Apollo 12 and 15 sites, there are surface magnetometers of the

kind described elsewhere in this booklet which are still operating. At the Apollo 14 site, we used a portable magnetometer to obtain two measurements of the steady field.

In addition, an orbiting magnetometer on the Explorer 35 satellite has operated for several years and continues to operate. So how could we possibly need another magnetometer on the subsatellite? For several reasons. First, the three station magnetometers operating on the Moon's surface (Apollo 12, Apollo 15, and after this mission Apollo 16) measure the variation of the magnetic field with time. In order to best interpret those data, we need independent measurements of the changes with time of the magnetic field in space. The orbiting magnetometers (Explorer 35, Apollo 15 subsatellite, and now Apollo 16 subsatellite) will give us the information necessary to make the best interpretation of the data that we collect on the surface of the Moon. Secondly, since the Explorer 35 is orbiting at several hundred miles from the Moon we cannot obtain information about variations in the magnetic field near the surface of the Moon.

One of the big surprises in the Apollo science program was the discovery that the magnetic field at the surface of the Moon was much larger than we had predicted on the basis of measurements taken with the orbiting satellite, Explorer 35. A permanent magnetic field of 38 gamma was measured at the Apollo 12 site. Two measurements made by the Apollo 14 astronauts, separated by about 3,500 feet in the Fra Mauro region were 103 gamma and 43 gamma. From those measurements
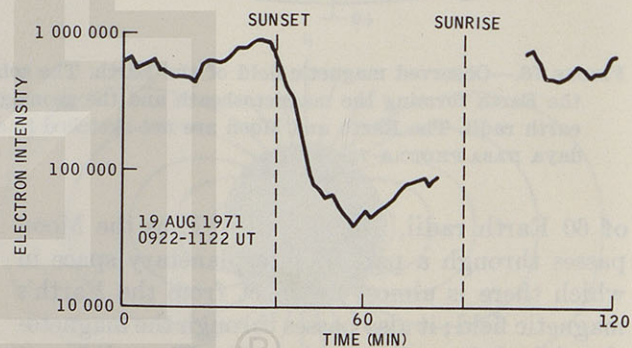
FIGURE 78.—Relative Numbers of Electrons measured with the Apollo 15 Particle Telescope on August 19, 1971. The large decrease is caused by the Moon's shadow. The break in the curve is due to lack of data. Based on work by Anderson and others reported in the Apollo 15 Preliminary Science Report.

it was clear that the Moon's permanent magnetic field is significantly different at different locations. With a magnetometer flown in an orbit close to the Moon's surface, like the Apollo 15 and 16 subsatellites, we hope to measure the variations over the Moon of the permanent magnetic field.

In addition to the static magnetic fields of the Earth and Moon, there exist electromagnetic fields that propagate through space. The measurement of their interaction with the Moon allows us to infer the electrical conductivity of the interior of the Moon. In fact, as discussed elsewhere in this booklet, the chief purpose of the Lunar Surface Magnetometer (LSM) is to make such measurements and to use them to determine the electrical properties of the interior of the Moon. Now the Moon acts as a shield for these propagating fields.

If we are interested in measuring the permanent magnetic field of the Moon, then we can best obtain those data by making measurements on the side of the Moon that is away from the Sun. The variations with time of the magnetic fields from space are very small there. See figure 78. A preliminary examination of some data obtained with the Apollo 15 subsatellite from the far side of the Moon suggests that the very large craters, those over 60 miles across, have permanent magnetic fields associated with them. If this preliminary result proves to be valid, then we shall have a truly remarkable result and will undoubtedly use magnetic methods to study craters. Because we will obtain several readings with a portable magnetometer on the surface at the Apollo 16 site, it is possible that we may be able to provide additional evidence.

The Crew

The prime crew consists of John Young, Commander, Charlie Duke, LM pilot, and Ken Mattingly, CM pilot. Young was the pilot with Gus Grissom on the first manned Gemini flight almost exactly 7 years ago. A year later, he was command pilot on Gemini 10 with Mike Collins as the pilot. For Apollo missions, he was backup CM pilot on Apollo 7, CM pilot on 10, and backup commander on 13. Duke served as backup LM pilot for Apollo 13. Ken Mattingly was the CM pilot on Apollo 13. Because of exposure to German measles, Ken was removed from flight status on that mission only a few days before launch.

The Apollo 16 backup crew consists of Fred Haise, Commander, Stu Roosa, CM pilot, and Ed Mitchell, LM pilot. Several photographs of the prime and backup crews are shown in figures 79 through 86.

This crew, like previous ones has undergone intensive training during the past few months and somewhat more casual training during the last few

FIGURE 80.—Astronauts John Young and Charlie Duke. They are shown here on a geology training trip to Taos, New Mexico. Note the hand tools and the microphones. Their observations are recorded on tape recorders and later analyzed to improved their powers of observation and techniques of reporting. The rocks in the background are basalts. NASA PHOTO S–71–51605.

FIGURE 79.—Astronauts John Young and Charlie Duke. Young holds a sample bag while Duke practices with the scoop. Note the gnomon. The backpacks simulate PLSS's. The cameras and tools are very similar to the flight articles. Note the layers in the distant wall. These layers are basalt flows. NASA PHOTO S–71–49398.

years. In addition to the many exercises needed to learn to fly proficiently their spacecraft, 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

FIGURE 81.—The Rio Grande Gorge near Taos, New Mexico. This photograph symbolizes the beauty of the American West. The rocks are basalt. At one time in the past, they were continuous across the gorge. The steady erosion by the flowing water, now seen far below the surface, has cut the valley. Astronaut Charlie Duke is studying the geology. The horizon isn't really curved—the wide angle photographic lens produced this effect. NASA PHOTO S–71–51613.

FIGURE 82.—Astronauts Fred Haise and Ed Mitchell. Haise is about to shoot a series of photographs to document the sample to be collected. Mitchell is setting the gnomon in place. The rock on the surface and exposed in the walls of the Rio Grande gorge is basalt. If you look closely at the photograph you can see some holes in the rocks caused by gas when the rock was liquid. These holes are called vesicles and have an entirely different origin from the zap pits in lunar rocks. Some lunar rocks also contain vesicles as well as zap pits. NASA PHOTO S–71–49406.

FIGURE 83.—Fred and Ed meet a geological problem. Before each field exercise, several experienced geologists prepare maps in minute detail. Between the time that the maps were prepared for this exercise and the time they were used, this thin basalt flow, in Hawaii in September 1971, covered a part of the area. So the flow was not shown on the map. The astronauts recognized the flow, corrected the map and proceeded with the day's training. NASA PHOTO S–72–16313.

FIGURE 84.—Astronauts John Young and Charlie Duke. Young is shooting a picture of the distant wall of the Rio Grande gorge near Taos, New Mexico with the 500 mm telephoto lens on the Hasselblad camera. The rocks exposed in the walls of the gorge are basalts. I believe they are similar to the ones that Young and Duke will collect at the Descartes site. The piles of loose and broken rocks that you see here at the foot of the walls are called talus, a term that you may hear during the 16 misson. The curved horizon is an optical effect of the wide angle lens used by A. Patnesky to take this photograph. NASA PHOTO S–71–51614.
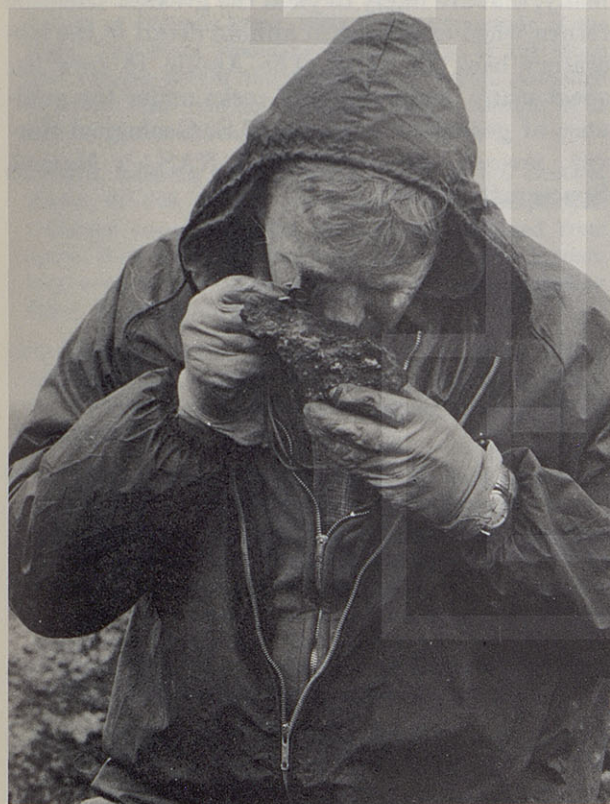
FIGURE 85.—Astronaut Stu Roosa. Even though the CM pilot will not examine rocks on the Moon's surface, an understanding of geology is absolutely essential. Roosa is shown here studying intensely a piece of basalt. This picture, taken in Iceland four years ago, indicates the long and continued effort 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 86.—Astronauts Ken Mattingly and Neil Armstrong. They are shown studying geology in Iceland about four years ago. Note the geologic hammer carried by Mattingly. NASA PHOTO S-67-38609.

ALSEP, but more importantly, they understand the scientific purposes behind the various experiments.

Most of the time on the lunar surface during Apollo 16 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, how-ever, 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 16 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.

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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. $1.00 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. $1.00 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 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 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.

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-ten-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 radar 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. (See text and figure 76.)

BOW SHOCK
The shock wave produced by the interaction of the solar wind with the Earth's magnetosphere. (See text and figure 76.)

CARTOGRAPHY
The production and science of accurately scaled maps.

CASSETTE
kuh-seí
Photographic film container.

CISLUNAR
sis-lune-ar
Pertaining to the space between the Earth and Moon or the Moon's orbit.

COLLIMATOR
A device for producing beams of parallel rays of light or other electromagnetic radiation.

COLORIMETRIC
koĺ-i-má-ter
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-moĺ-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-erŕ-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 *dopṕ-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-kliṕ-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 1837 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 *fiĺl-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 U.S., the Colorado Front Range is a good example.
GALACTIC *ga-lak̆-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 *geǵ-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-odd́-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
knoẃ-mon

GRADIEN
graý-dee-un

IMBRIAN

INGRESS
iń-gress

IN SITU
in-síte-u

LIMB

LITHOLO

LUNATIO

MANTLE

MARE
maár-ray

MARIA
maaŕ-ya

MASCONS
mass-conz

MASS SPI
mass spek-t

METEORI
me-te-oh-rite

METRIC

MICROSC

MINERA

MONOPOL
moń-oh-pole

MORPHO
mor-foí-uh-

MOULTO

NADIR

NAUTICA

NEUTRO

OCCULTA
ah-cull-taý-

OZONE
oh-zone

P-10

PANORA

Term	Definition
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 *gray-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 *in-gress*	A verb meaning to enter. It is used in connection with entering the LM. See also "egress."
IN SITU *in-site-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 three 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 *mon-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% 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-tay-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-nuḿ-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-moŕ-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 *reǵ-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-therḿ-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 *taíl-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 suitabl esignal. 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-rain-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).

Acronyms and Abbreviations

ALSD	Apollo Lunar Surface Drill		LM	Lunar Module
ALHT	Apollo Lunar Hand Tools		LMP	Lunar Module Pilot
ALHTC	Apollo Lunar Hand Tool Carrier		LOI	Lunar Orbit Insertion
ALSEP	Apollo Lunar Surface Experiments Package		LP	Long-Period
ALSRC	Apollo Lunar Sample Return Container (Rock Box)		LPM	Lunar Portable Magnetometer
			LRL	Lunar Receiving Laboratory
AMU	Atomic Mass Unit		LRRR	Laser Ranging Retro-Reflector (Pronounced LR–Cubed)
ASE	Active Seismic Experiment			
BLSS	Buddy Secondary Life Support System		LRV	Lunar Roving Vehicle (Rover)
BW	Black and White		LSAPT	Lunar Samples Analysis and Planning Team
CAPCOM	Capsule Communicator, the single individual on Earth who talks directly with the crew		LSM	Lunar Surface Magnetometer
			LSPET	Lunar Sample Preliminary Examination Team
CCIG	Cold Cathode Ion Gauge		LSUV	Lunar Surface UV Camera
CM	Command Module		MC	Mapping Camera
CSM	Command and Service Module		MCC	Mission Control Center
CDR	Commander		MESA	Modularized Equipment Stowage Assembly (A storage area in the LM that contains science equipment)
CRD	Cosmic Ray Detector			
C/S	ALSEP Central Station			
CSVC	Core Sample Vacuum Container		MIT	Massachusetts Institute of Technology
DAC	Data Acquisition Camera		MPA	Mortar Package Assembly
DPS	Descent Propulsion System		MSC	Manned Spacecraft Center
DOI	Descent Orbit Insertion		MSFN	Manned Space Flight Network
DSEA	Data Storage Electronics Assembly		NASA	National Aeronautics and Space Administration
ETB	Equipment Transfer Bag			
EVA	Extravehicular Activity		NM	Nautical Mile
FMC	Forward Motion Compensation		PC	Panoramic Camera
FOV	Field of View		PET	Preliminary Examination Team
FWD	Forward		PI	Principal Investigator
GASC	Gas Analysis Sample Container		PLSS	Portable Life Support System
GCTA	Ground-Commanded Television Assembly		PM	Portable Magnetometer (also LPM)
GET	Ground Elapsed Time		ppm	Parts per Million
GMT	Greenwich Mean Time		PSCB	Padded Sample Collection Bag
GLA	Grenade Launch Tube Assembly		PSE	Passive Seismic Experiment
GN$_2$	Gaseous Nitrogen		RCH	A very small, though fuzzy, unit of length
HBW	High-Speed Black and White		RCS	Reaction Control System
HCEX	High-Speed Color Exterior		REV	Revolution
HEC	Hasselblad Electric Camera		RTG	Radioisotope Thermoelectric Generator
HEDC	Hasselblad Electric Data Camera		SC	Stellar Camera
HFE	Heat Flow Experiment		S/C	Spacecraft
IMC	Image Motion Compensation		SCB	Sample Collection Bag
IR	Infrared		SEQ	Scientific Equipment Bay
JPL	Jet Propulsion Laboratory		SESC	Surface Environment Sample Container
KSC	Kennedy Space Center		SEVA	Standup Extravehicular Activity (An Apollo 15 term, not planned for 16)
LBW	Low-Speed Black and White			
LCRU	Lunar Communications Relay Unit		SIDE	Suprathermal Ion Detector Experiment
LDD	Lunar Dust Detector		SIM	Scientific Instrument Module
LESC	Lunar Environment Sample Container		S–IVB	Saturn IVB (rocket stage)
LDAC	Lunar Surface 16-mm Data Acquisition Camera		SM	Service Module
			SME	Soil Mechanics Experiment
LGE	Lunar Geology Experiment		SP	Short-Period

SPS	Service Propulsion System	TV	Television
SRC	Sample Return Container (=ALSRC)	UHT	Universal Hand Tool
SSD	Surface Sampler Device	USGS	U.S. Geological Survey
SWC	Solar Wind Composition Experiment	V/h	Velocity-to-Height
SWP	Science Working Panel	VHBW	Very High-Speed Black and White
TEC	Transearth Coast	VHF	Very High Frequency (the same term applies
TEI	Transearth Injection		to VHF television)

Tables

Table 1.—*Timeline of Apollo 16 Mission Events*

Event	Time from liftoff hours and minutes	Day	Central Standard Time
Launch	0:00	4/16	11:54 a.m.
Earth Orbit Insertion	0:12	4/16	12:06 p.m.
Trans Lunar Injection	2:33	4/16	2:27 p.m.
Lunar Orbit Insertion	74:29	4/19	2:23 p.m.
Descent Orbit Insertion	78:36	4/19	6:30 p.m.
Spacecraft Separation	96:14	4/20	12:08 p.m.
Lunar Landing	98:47	4/20	2:41 p.m.
EVA 1	102:25	4/20	6:19 p.m.
EVA 2	124:50	4/21	4:44 p.m.
EVA 3	148:25	4/22	4:19 p.m.
Lunar Liftoff	171:45	4/23	3:39 p.m.
Spacecraft Docking	173:40	4/23	5:34 p.m.
Trans Earth Injection	222:21	4/25	6:15 p.m.
Trans Earth EVA	242:00	4/26	1:54 p.m.
Pacific Ocean Splashdown	290:36	4/28	2:30 p.m.

Table 2.—*LRV Exploration Traverse*

(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.)

Station/activity	Segment time (hr:min)	Elapsed time at start (hr:min)	Geological features	Observations and activities
			EVA I	
LM	1:37		Cayley Plains	Egress, observe LM, prepare for departure from Moon, deploy LRV
ALSEP	2:24	1:37	Cayley Plains	ALSEP deployment. See Table 3 for details
Travel	0:14	4:01	Across Cayley Plains and Rays.	Observe Station 2 area and distribution of ray material
1—Flag Crater	0:30	4:15	Flag Crater, about 300 meters in diameter in Cayley Plains; adjacent ray from South Ray Crater	Exploration of the crater and excavated Cayley material, observations of adjacent ray: PAN Crater sampling LPM Site Measurement Rake/Soil Sample
Travel	0:06	4:45	Across Cayley Plains and Rays.	Assess Station 2 region for best sampling area
2—Spook Crater Vicinity	0:31	4:51	Spook Crater (about 300 m diameter) and small blocky crater to the north.	Inspect and describe the geology at this station. Divide time between Spook and blocky crater: PAN Documented sampling, including: Spook Crater rim Blocks associated with small crater 500 mm photography of outlying areas Grand Prix

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TABLE 2.—*LRV Exploration Traverse*—Continued

Station/activity	Segment time (hr:min)	Elapsed time at start (hr:min)	Geological features	Observations and activities
			EVA I	
Travel	0:08	5:22	Across Cayley Plains	Observe and describe ray patterns; area of EVA II route to Stone Mountain
3	0:50	5:30	Cayley Plains near LM and ALSEP	Soil/Rake Sample Double Core Tube Documented Sampling Soil Mechanics—trench and penetrometer measurements 500 mm Photography (if not done at Sta. 2) Soil Samples from Trench, Retrieve 2.6 m core Arm MP
LM	0:40	6:20	Cayley Plains	Closeout—store samples, ingress
LM	0:50	00	Cayley Plains	Egress and EVA preparation
Travel	36	50	Across Cayley Plains and Rays from South Ray to the lower slopes of Stone Mtn.	Observe and describe distribution of Rays, abundance of blocks, and secondary craters. Note the slope of Stone Mountain. Describe changes of the regolith.

4—Stone Mountain.	1:00	1:26	Small craters at base of terrace in Descartes formation. The highest point reached in the Descartes formation on Stone Mountain.	Observe, describe, and sample Descartes formation:
				PAN—(take one at beginning and a second at the most distant point from the LRV during sampling)
				Documented sampling, including
				  Rake/Soil Sample
				  Double core (consider triple)
				LPM reading
				500 mm photography—include upslope targets
				Penetrometer

Travel	03	2:26	Descartes formation	Observe and describe terraces and any changes in bedrock and regolith
5—Stone Mountain.	0:45	2:29	Intermediate area in crated and terraced region of Descartes formation.	Station to be selected at some intermediate point on the way down Stone Mountain PAN Documented sampling 500 mm photography of South Ray Crater
Travel	07	3:14	Descartes formation	Observe and describe craters, blocks

6—Stone Mountain.	0:30	3:21	In Descartes formation at base of Stone Mountain.	Note and describe characteristics of Descartes formation and local gelogy and compare to adjacent Cayley:
				Describe upslope terraces:
				PAN
				Documented sampling, including:
				  Surface Sampler (one on undisturbed soil, one on top of rock; return rock)
				  Elongated SESC (single core)

Travel	07	3:51	Descartes formation	Observe terraces and any changes of bedrock and regollth
7—Stone Mountain-Stubby Crater Area.	0:20	3:58	In Descartes formation at base of Stone Mountain near Stubby.	Observe and describe relations between Cayley and Descartes formations in Stubby area: PAN Documented sampling of Stubby rim 500 mm photography, including south wall of Stubby
Travel	07	4:18	Across Cayley formation to Rays from South Ray Crater.	Observe and describe changes in regolith and note characteristics of Rays

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TABLE 2.—*LRV Exploration Traverse*—Continued

Station/activity	Segment time (hr:min)	Elapsed time at start (hr:min)	Geological features	Observations and activities
			EVA I	
8—Rays From South Ray Crater.	55	4:25	In Rays from South Ray Crater overlying Cayley.	Observe and describe blocky Ray area: PAN / Double core (single if triple taken on Stone Mountain) / Rake/Soil Sample / Documented sampling, including / Possible use of padded bags / Possible boulder/permanent shadow SESC / Sample large boulder
Travel _____	14	5:20	Cayley Plains _____	Describe characteristics of Cayley and Rays
9 _____	0:15	5:34	Cayley Plains adjacent to South Ray deposits.	Examine, describe and sample Cayley/Ray area: PAN / Documented Sampling / Surface Soil Sample / Shallow Trench Soil Sample
Travel _____	07	5:49	Across Cayley Plains	
10 _____	20	5:56	Cayley Plains _____	Radial sampling of small crater
Travel _____	05	6:14	Across Cayley Plains	
LM _____	0:40	6:19	Cayley Plains _____	Closeout—store equipment and samples, ingress
			EVA III	
LM _____	0:45	00	Cayley Plains _____	Egress and prepare for traverse
Travel _____	39	45	Across Cayley toward North Ray.	Observe Cayley, Describe features near Palmetto Crater / Observe Rays and describe the material seen on the approach to North Ray Crater
11—North Ray Crater.	0:55	1:24	South rim of North Ray Crater.	Examine and describe ejecta and the crater interior / Stereo Pan / Documented sampling / 500 mm photography of crater rim and interior / Polarametric photography and sampling
Travel _____	03	2:19	Around North Ray rim _____	Note and describe variety and distribution of block
12—North Ray Crater.	1:00	2:22	Area of very large blocks on east rim on North Ray Crater.	Block field with large blocks of different albedo: PAN / 500 mm photography of interior of North Ray / Documented sampling / Boulder sampling / Rake/soil
Travel _____	08	3:22	From North Ray to base of Smoky Mountain (Descartes formation).	Observe and describe transition to Smoky Mountain
13—Travel _____	0:10	3:30	North Ray ejecta blanket ____	Rock/Soil Sample
	07	3:40	_____	Observe and describe number, variety, and geographic distribution of blocks
14—Smoky Mountain.	0:40	3:47	Crater cluster at base of Smoky Mountain.	In Descartes formation: PAN / Documented sampling of Smoky Mountain / Double core / Rake/soil / 500 mm photography of Smoky Mountain
Travel _____	09	4:27	South across Cayley Plains towards Palmetto Crater.	Observe and describe Smoky Mountain and changes of Cayley characteristics
15 _____	0:10	4:36	Dot Prime Crater _____	Soil sample / Rock sample / LPM reading

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TABLE 2.—*LRV Exploration Traverse*—Continued

Station/activity	Segment time (hr:min)	Elapsed time at start (hr:min)	Geological features	Observations and activities
			EVA I	
Travel_____	09	4:46	Toward Palmetto Crater_____	Observe and describe changes in soil and rocks on approach to Palmetto Crater
16—Palmetto Crater	15	4:55	Rim of subdued crater 1 km in Cayley Plains.	PAN Soil and Rock Sample LPM
Travel_____	06	5:10	Across Cayley plains south of Palmetto toward LM.	Observe lateral changes in Cayley characteristics
17_____	33	5:16	Cayley plains_____	Documented sampling: Soil/rake sample LPM
Travel_____	16	5:49	Across Cayley plains toward LM.	Observe characteristics of Cayley plains
LM_____	55	6:05	Cayley plains_____	Grand Prix #2 Closeout: store samples and equipment: Ingress

TABLE 3.—*ALSEP Timeline*

Time hour/min.	ACTIVITY	
	Commander	LM pilot
1:25_____	Remove ALESP from LM_____	Remove RTG fuel from LM
1:40_____	Drive LRV to ALSEP site_____	Carry ALSEP to its site
1:50_____	Connect RTG to central station_____	HFE drill 1 hole
2:00_____	Deploy LSM_____	HFE emplace and connect probe 1
2:20_____	Install central station_____	HFE emplace and connect probe 1
2:30_____	Install central station_____	HFE set up equipment drill 2 hole
2:40_____	Install central station_____	HFE emplace and connect probe 2
2:50_____	ASE implant geophones_____	ASE implant geophones
3:00_____	ASE thumper_____	ALSEP photos
3:10_____	ASE thumper_____	ALSEP photos
3:20_____	ASE thumper_____	ALSEP photos
3:30_____	ASE thumper_____	ALSEP photos
3:40_____	ASE set up mortar_____	Deep core drilling
3:50_____	Core recovery_____	Drilling. Core recovery
4:00_____	Core recovery_____	Core recovery

TABLE 4.—*Apollo Science Experiments*

The science experiments carried on each Apollo mission are more numerous and also more complex than those carried on the previous missions. None of the Apollo 11 experiments is operating today (December 1971). About half of the Apollo 12 experiments still operate and all of the Apollo 14 and Apollo 15 experiments are operating. We expect that many of the experiments will continue to send data to the Earth for several years after the end of the Apollo Program.

At the time of writing this booklet (December 1971), the choice of landing site for Apollo 17 has not yet been entirely settled. Alphonsus though is the leading contender.

Number	Experiment	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 (Alphonsus)
	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		
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
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	
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
S-078	Laser Ranging Retro-Reflector	X			X	X		
S-080	Solar Wind Composition	X	X		X	X	X	
S-151	Cosmic-Ray Detection (Helmets)	X					X	
S-152	Cosmic Ray Detector (Sheets)						X	X
S-184	Lunar Surface Closeup Photography	X	X		X			
S-198	Portable Magnetometer				X		X	
S-199	Lunar Gravity Traverse							X
S-200	Soil Mechanics					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		X
	Neutron Flux Monitor (Proposed)							

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.

LUNAR SURFACE EXPERIMENTS

Experiment	Principal investigator	Instrument contractor
Lunar Passive Seismology	Dr. G. V. Latham, Lamont-Doherty Geological Observatory, Columbia University, Palisades, N.Y. 10964	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
Medium Energy Solar Wind	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.
Lunar 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, United States 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.
Portable Magnetometer	Dr. Palmer Dyal, Code 204–4, Ames Research Center, Moffett Field, Calif. 94034	Ames Research Center (in-house)

LUNAR SURFACE EXPERIMENTS—Continued

Experiment	Principal investigator	Instrument contractor
Lunar Gravity Traverse	Dr. M. Talwani Lamont-Doherty Geological Observatory, Columbia University, Palisades, N.Y. 10964	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—Dallas, Post Office Box 30365, Dallas, Tex. 75230	Bendix
Lunar Surface Gravimeter	Dr. Joseph Weber Department of Physics & Astronomy, University of Maryland, College Park, Md. 20742	Bendix
Lunar Dust Detector	Mr. J. R. Bates, Code TD5 Manned Spacecraft Center, Houston, Tex. 77058	
Neutron Flux Monitor (Proposed experiment; it is now under-going review.)	Dr. D. S. Burnett Division of Geology and Planetary Sciences, California Institute of Technology, Pasadena, Calif. 91109	
Soil Mechanics	Dr. James K. Mitchell University of California, Berkeley, Calif.	

LUNAR ORBITAL EXPERIMENTS

Experiment	Principal investigator	Instrument contractor
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
Alpha Particle Spectrometer	Dr Gorenstein American Science & 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—Dallas, Post Office Box 30365, Dallas, Tex. 75230	University of Texas—Dallas, Division of Atmospheric and Space Sciences, Post Office Box 30365, Dallas, Tex. 75230

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

LUNAR ORBITAL EXPERIMENTS—Continued

Experiment	Principal investigator	Instrument contractor
Far UV Spectrometer	Mr. W. E. Fastie The John Hopkins University, Baltimore, Md. 21218	Applied Physics Laboratory, 8621 Georgia Ave., Silver Springs, Md. 20910
Bistatic Radar	Mr. H. T. Howard Stanford Electronics Laboratory, Stanford University, Stanford, Calif. 94305	
IR Scanning Radiometer	Dr. Frank J. Low Rice University, Post Office Box 1892, Houston, Tex. 77001	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 Blvd., 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 Blvd., Torrance, Calif. 90503. Subcontractor to TRW Systems Group
Lunar Sounder	Dr. R. Phillips, Team Leader Mail Code 183–510, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, Calif. 91103	North American Rockwell, Downey, Calif. 90242
SM Orbital Photographic Tasks 24-Inch Panoramic Camera	"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	"Photo Team" Mr. F. J. Doyle, Chairman	Fairchild Camera and Instrument Corp., 300 Robbins Lane, Syosset, Long Island, N.Y. 11791
SM Orbital Photographic Tasks	"Photo Team" Data Analysis, Dr. W. M. Kaula, Institute of Geophysics & Planetary Physics, UCLA, Los Angeles, Calif. 90024	RCA Aerospace Systems Division, Post Office Box 588, Burlington, Mass. 01801
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, Stoney 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 cameras	CSM "Photo Team" Mr. F. J. Doyle, Chairman	

TABLE 6.—*Scientific Equipment Suppliers*

The companies that built scientific equipment for the Apollo program, including 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	Stanford, 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 Gravity Traverse
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
The Singer Co., Kearfott Division	Little Falls, N.J	Pendulous Vertical Sensors
Paillard	Sinden, N.J	Hasselblad Cameras and Equipment

TABLE 6.—*Scientific Equipment Suppliers*—Continued

Company	Address	Responsibility
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—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 Geotech 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