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 12½ days and a maximum of 16 days. Actual time for the LM to remain on the lunar surface has doubled; it is now planned to be 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-

*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.

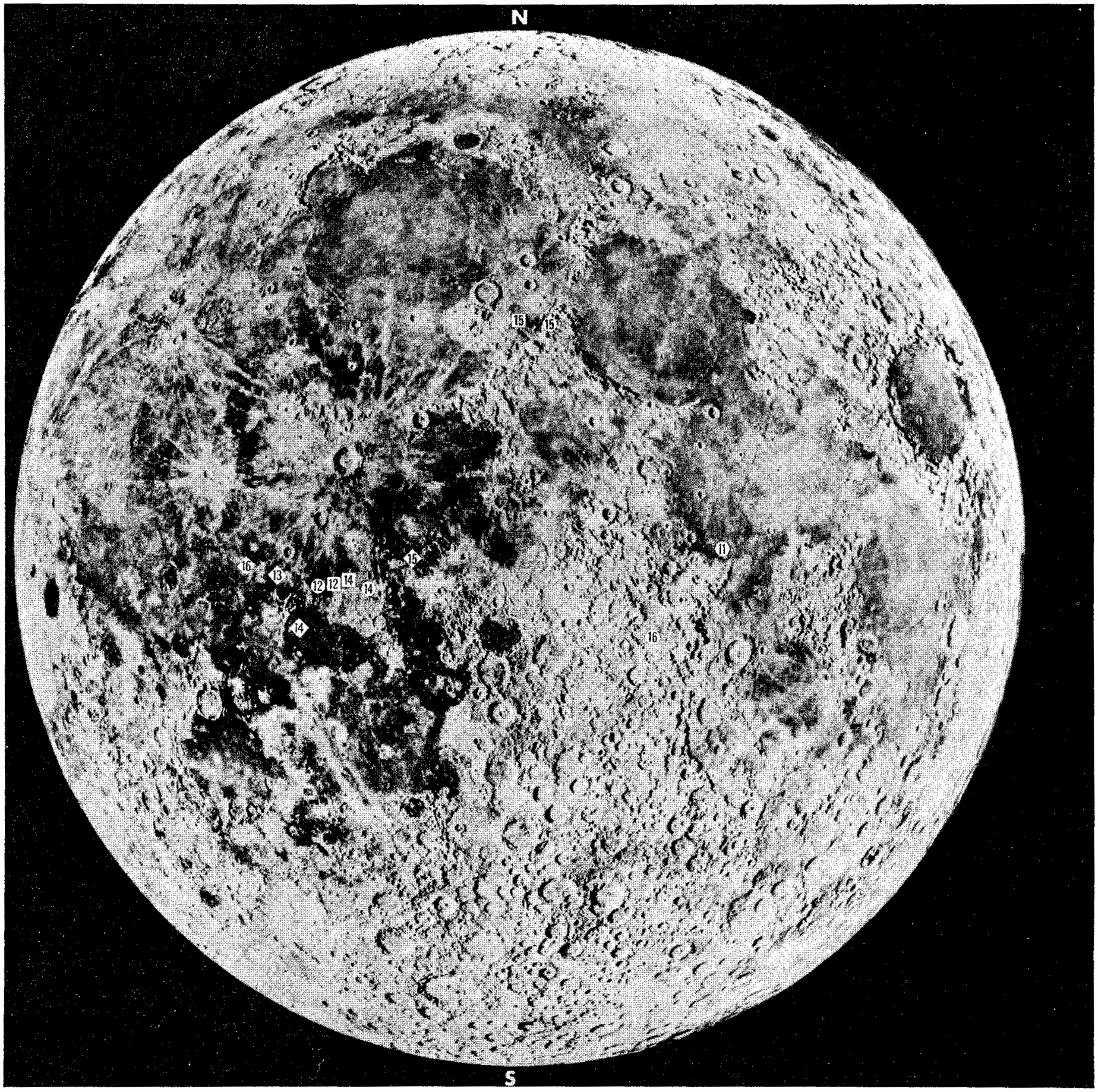

FIGURE 1.—Front side of the Moon. This side always faces the Earth. Shown here are locations of the previous Apollo landings (circles) and of the impacts on the Moon of spent S–IVB stages (diamonds) and LM ascent stages (squares). The numbers in the symbols are the mission numbers. The sound waves created 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

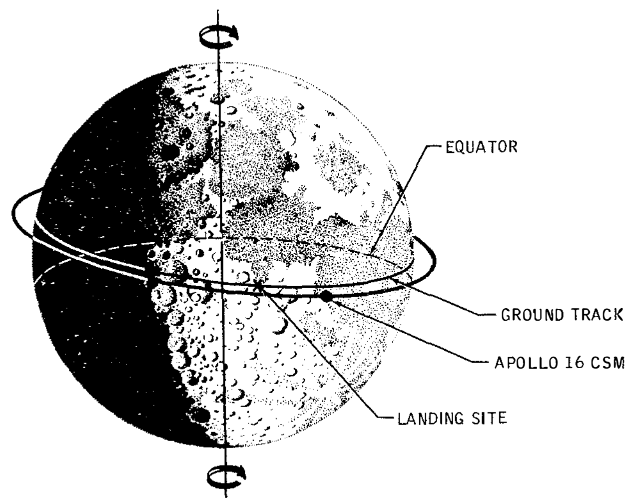

FIGURE 2.—Orbit and ground track of Apollo 16. Because the Moon rotates, the ground track is different for each revolution of the CSM.

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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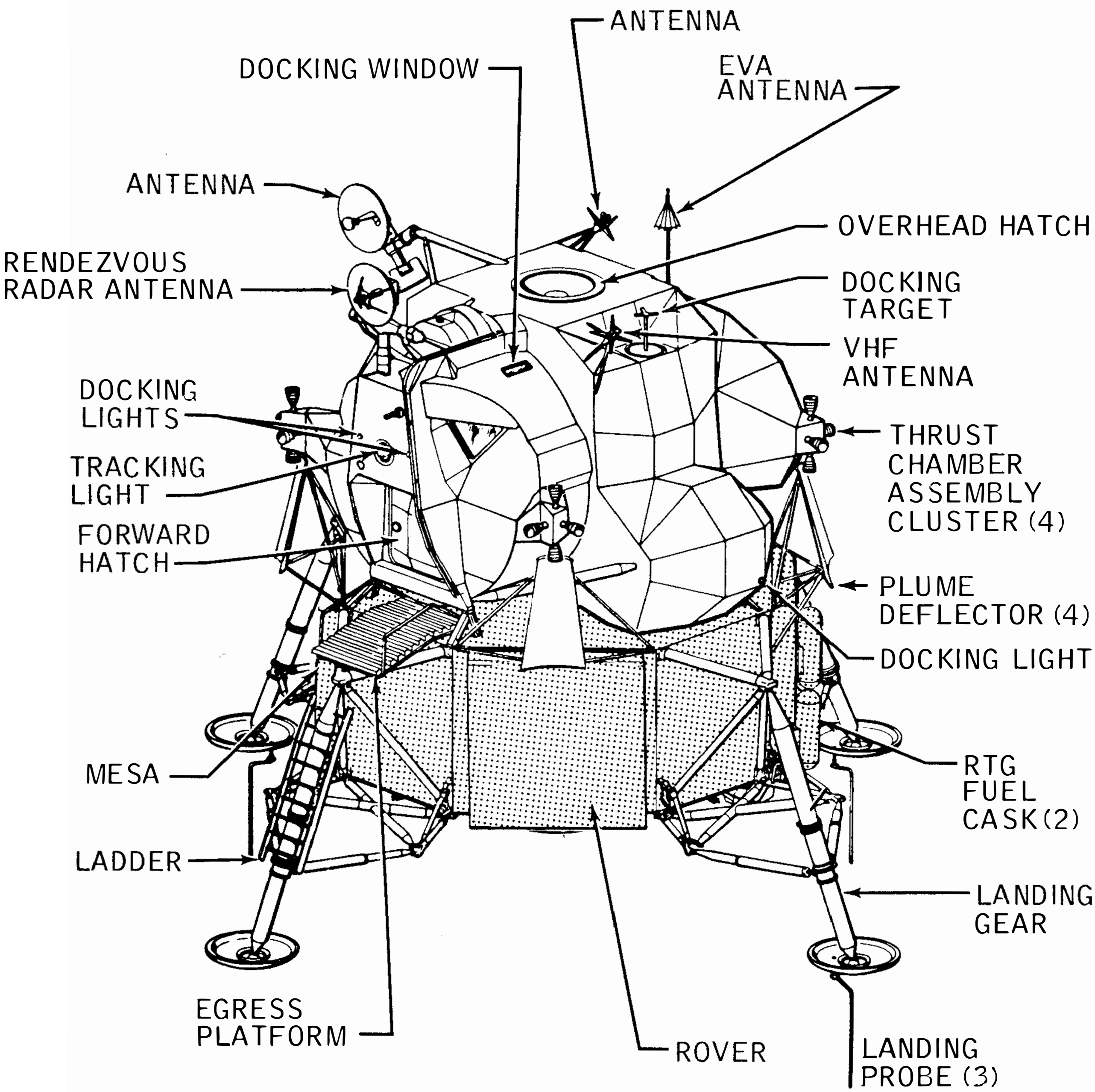


FIGURE 3.—The Lunar Module (LM). The shaded portion, the descent stage, remains on the Moon when the astronauts leave in the ascent stage to rendezvous with the CM and return to Earth. Scientific equipment is stored in the Mesa.

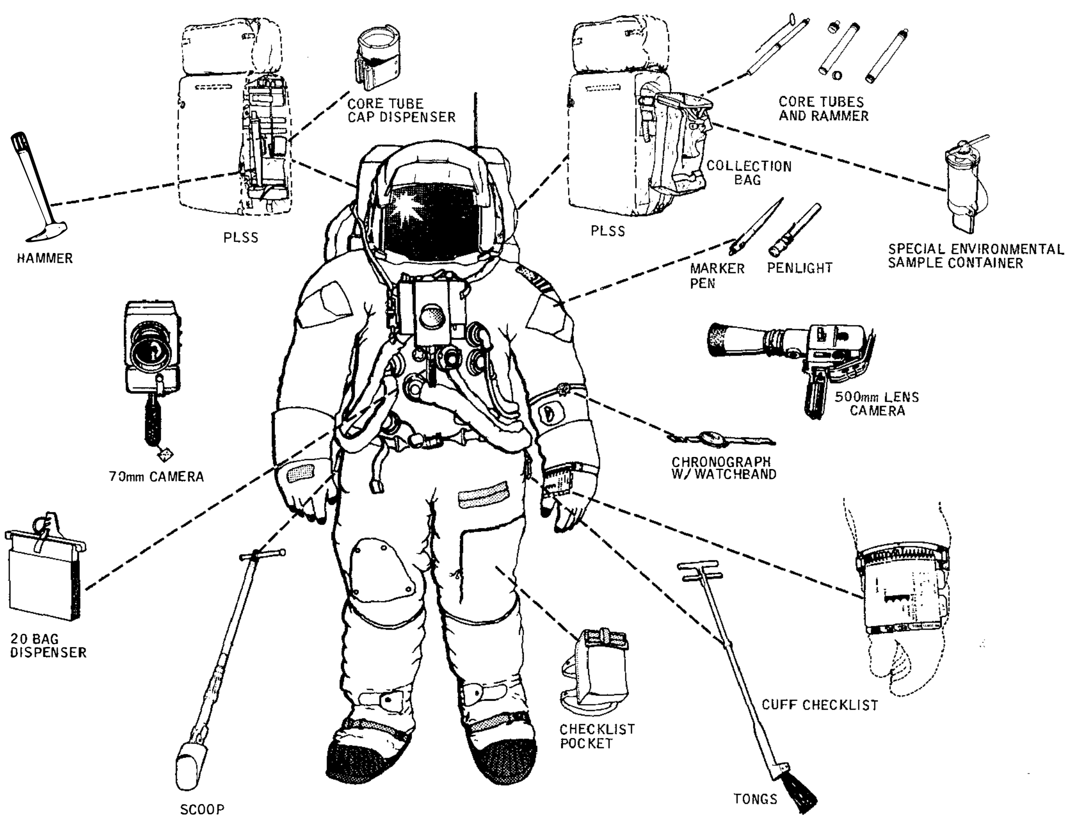


FIGURE 5.—Astronant suit and equipment. The suit prevents exposure of the astronaut to the Moon's vacuum. It incorporates many improvements over the suits used on early Apollo flights. Sketched also are several items of equipment.

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.

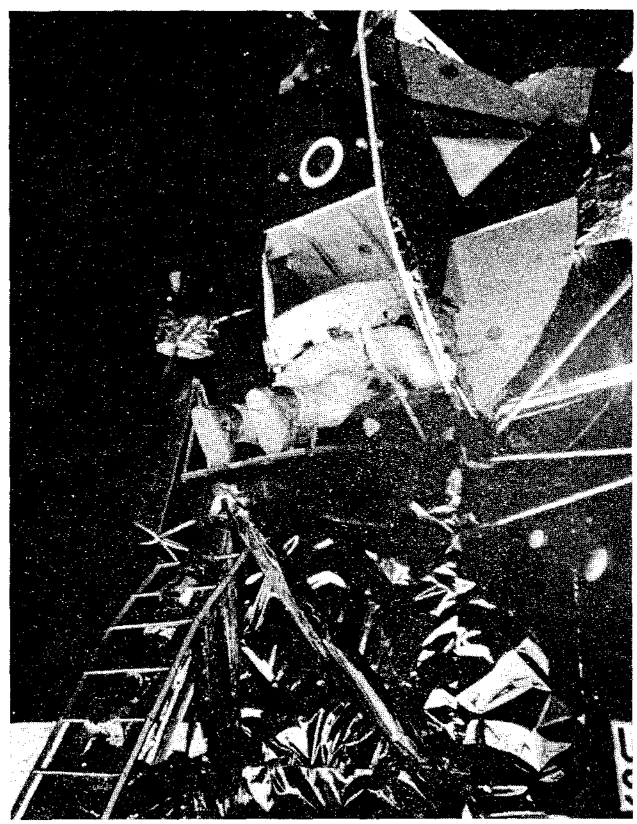


FIGURE 4.—Egress. Apollo 11 astronaut Aldrin is shown egressing from the LM. Note the ladder that leads down one leg from the platform. NASA PHOTO S–71–31090.

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

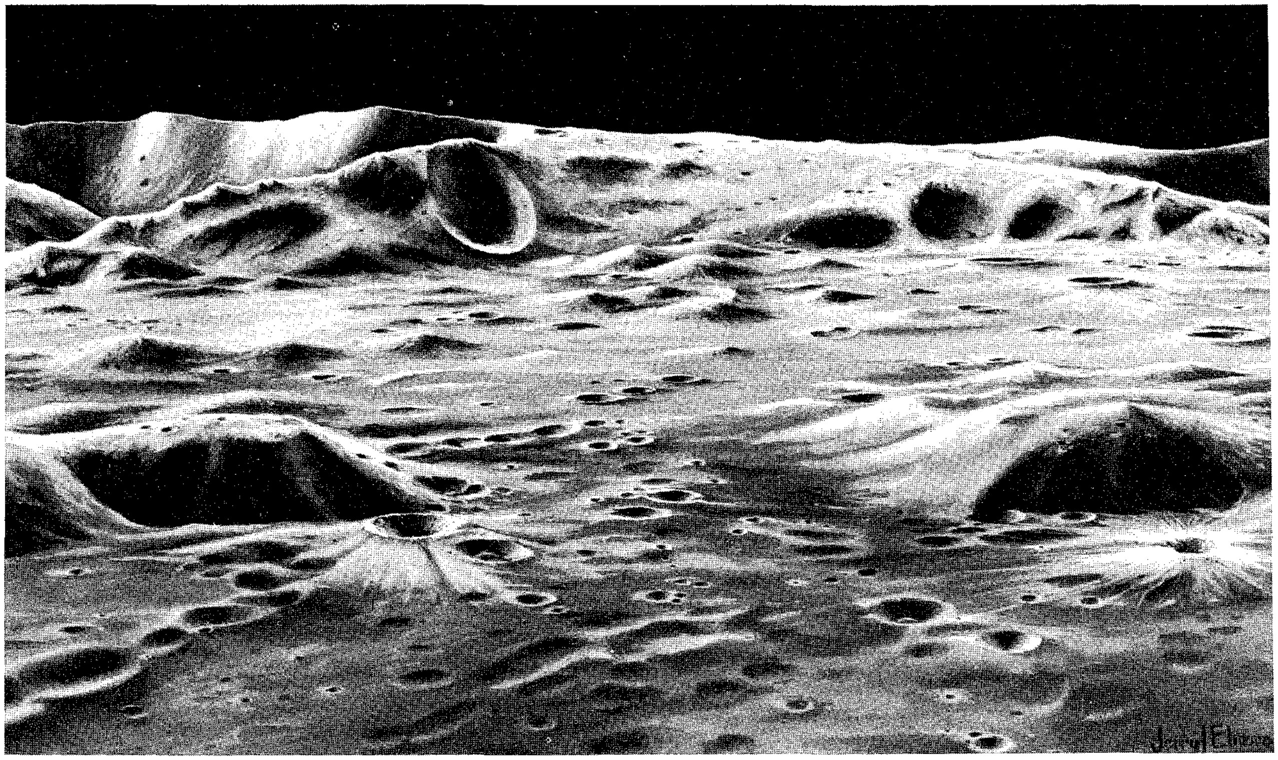


FIGURE 6.—The Descartes region, landing site of Apollo 16. We are looking due east and downward at an angle of about 10°. The bright rayed crater in the lower right hand corner is South Ray. The one slightly to the left of center and in the foreground is North Ray crater. The planned touchdown point 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

* 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.

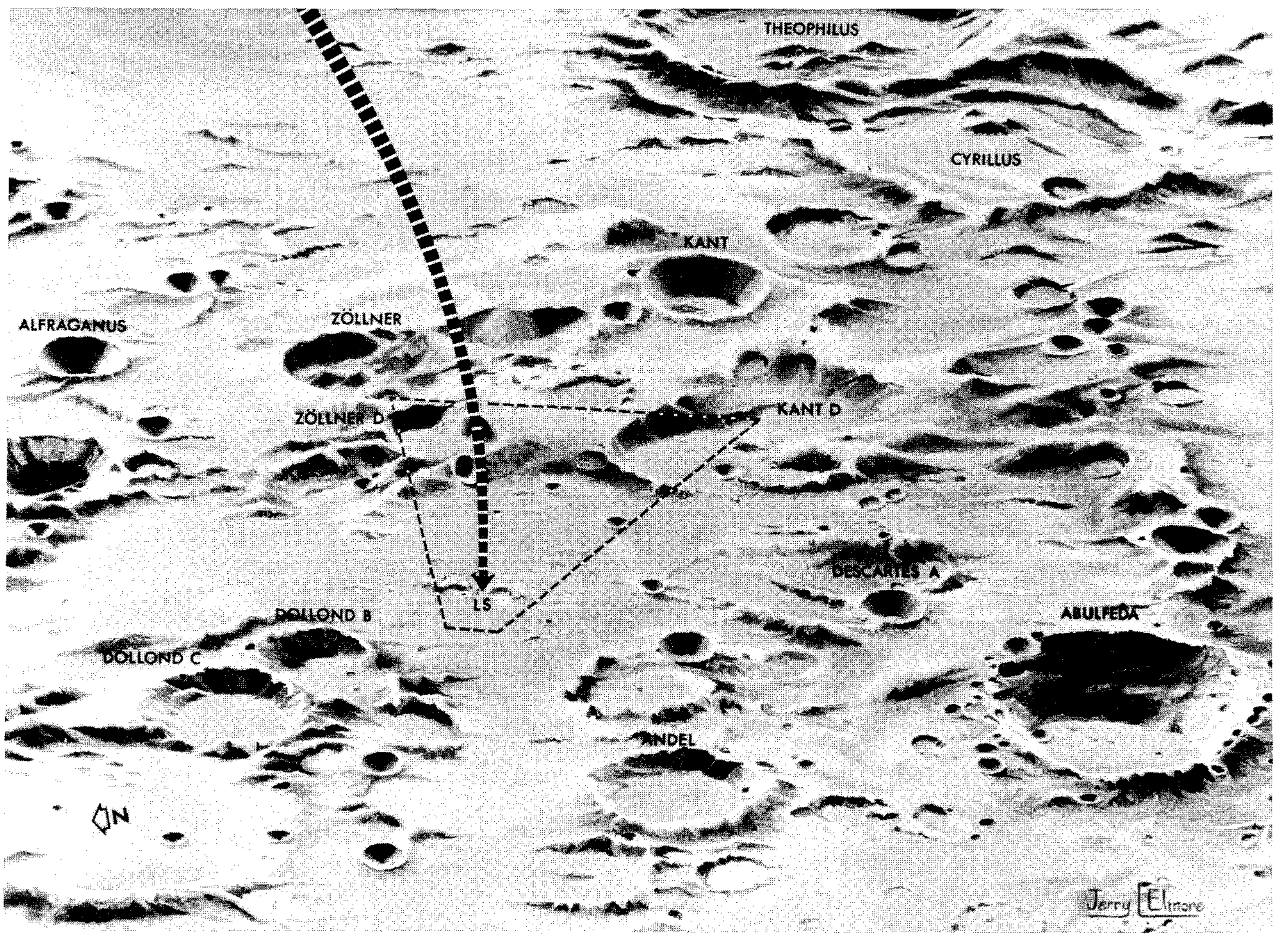
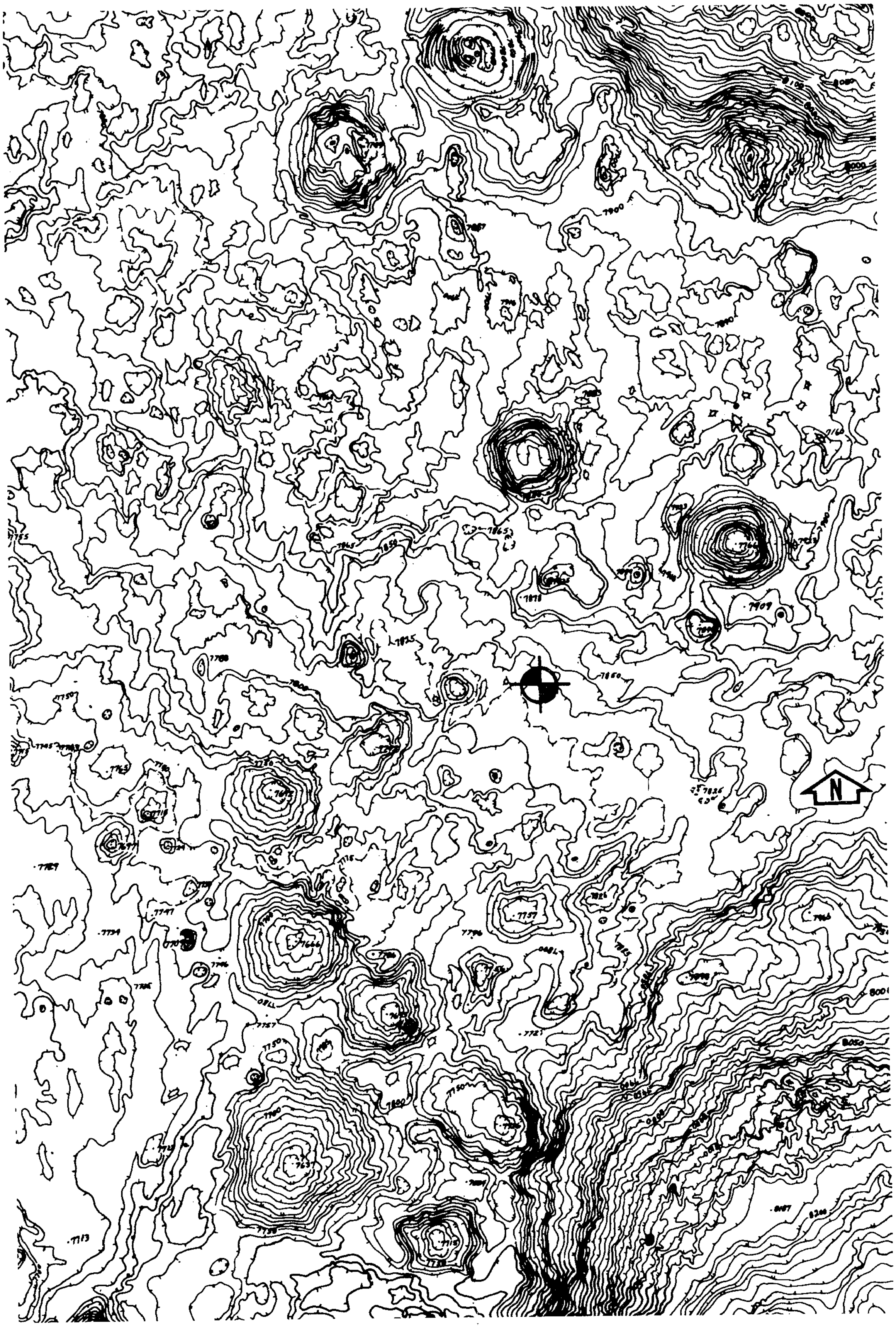


FIGURE 7.—General geography of the Descartes region. The ruggedness of the lunar highlands is shown very well in this sketch of the region by artist Jerry Elmore. Note the flat bottoms of the large craters. We are looking due east. The trajectory of the descending LM is shown as the heavy dashed line.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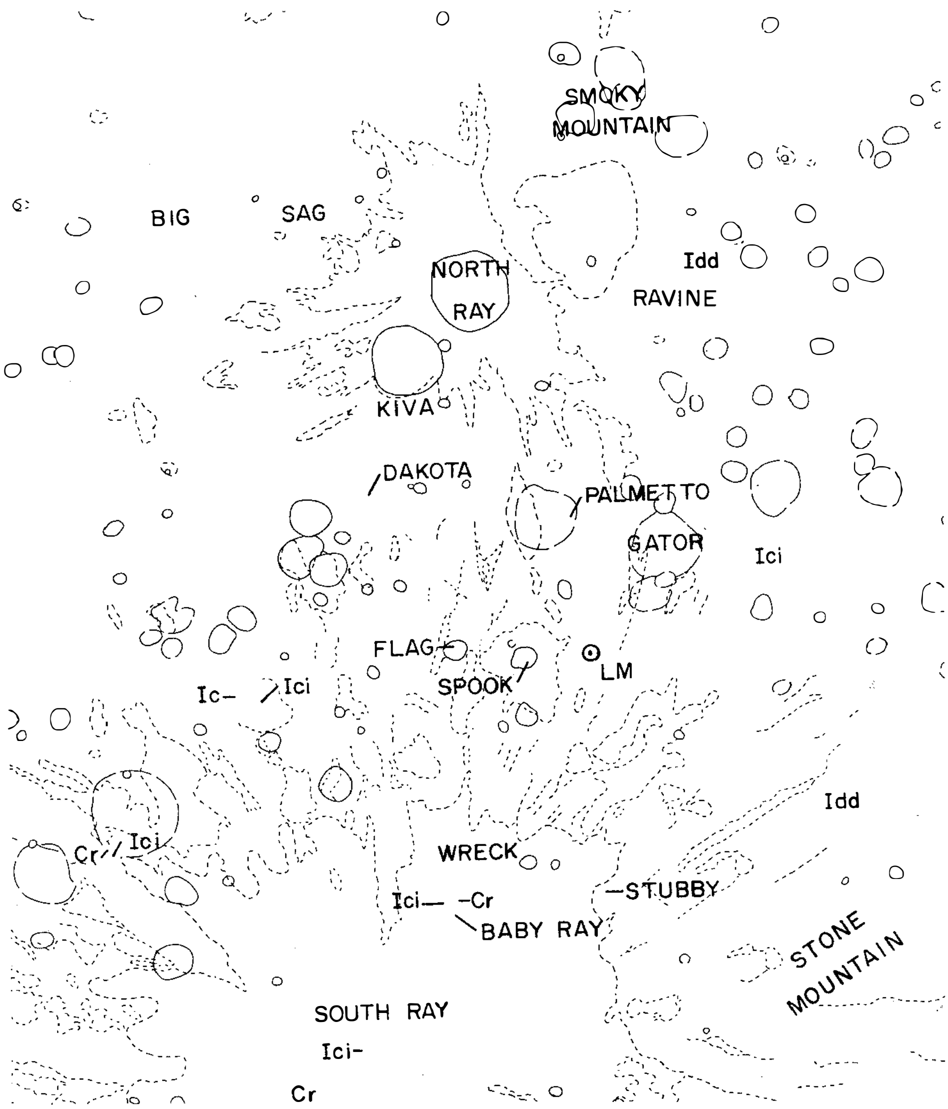

FIGURE 9.—Geologic sketch map of the Descartes region. The various symbols on this map are used to indicate different features and different kinds of rocks that have been discovered already through observations made of the Moon through Earth-based telescopes and with spacecraft photography. Most of the 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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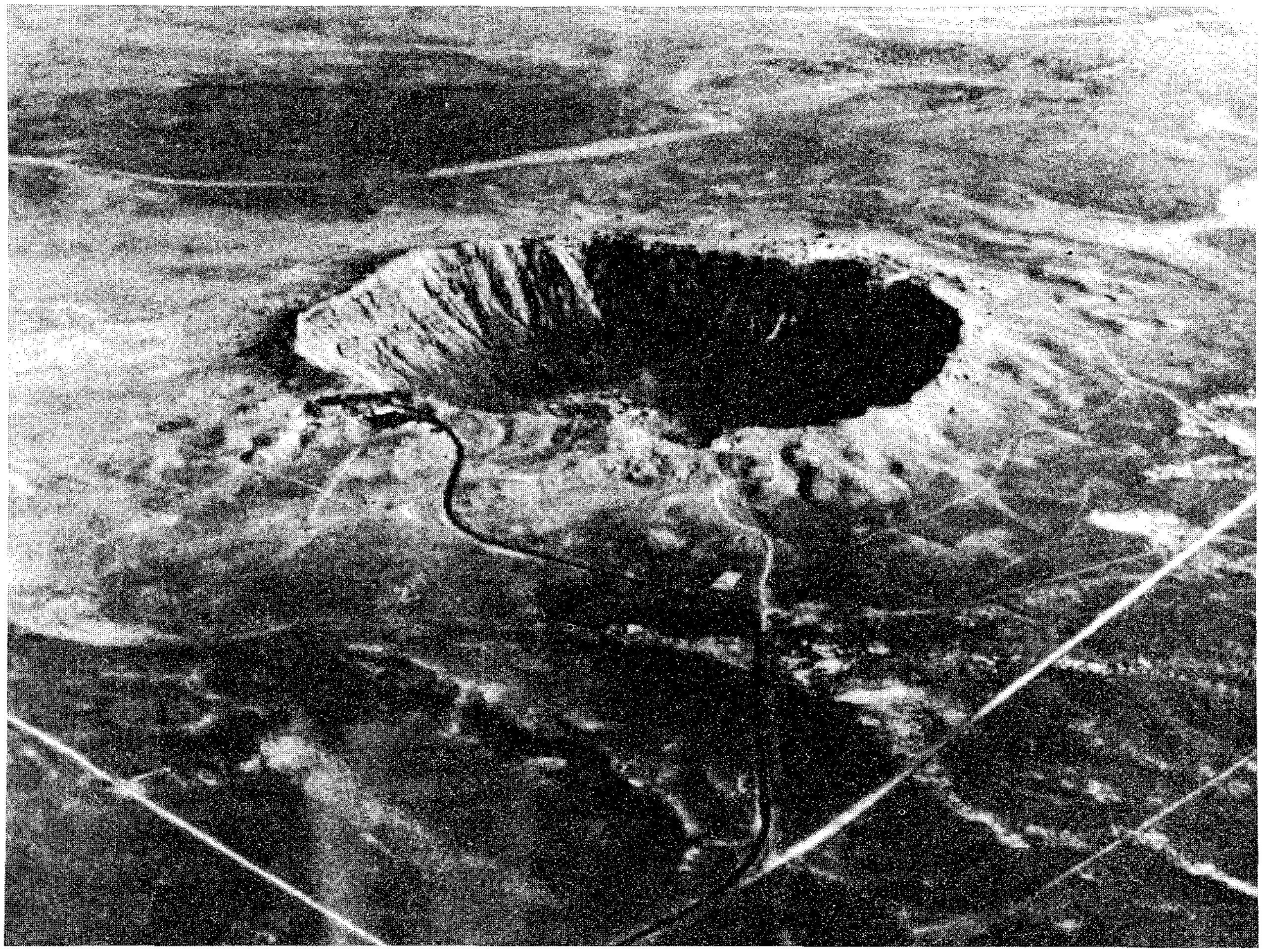

FIGURE 10.—Meteor crater. This crater, about a half mile across, 600 feet deep, and located near Flagstaff. Arizona, was caused by the impact of a large meteorite with the Earth in prehistoric times. Thousands of pieces of the meteorite have been found in the surrounding area. This feature has been studied 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

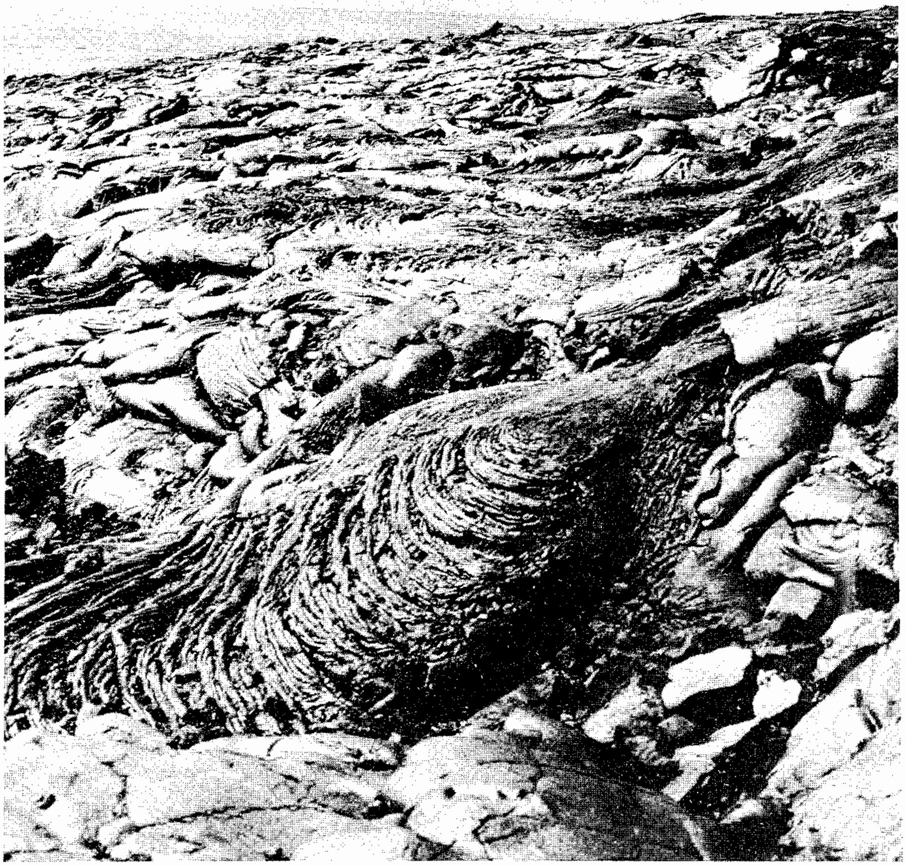

FIGURE 11.—Basalt flow on Earth. This rock, now solidified, poured out on the surface of the Earth as a hot liquid. The surface is very smooth. Examination of the rock with a microscope reveals that it contains mineral crystals set in glass. The feature in the central foreground that resembles thick 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.