Introduction

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

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

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

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

*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.

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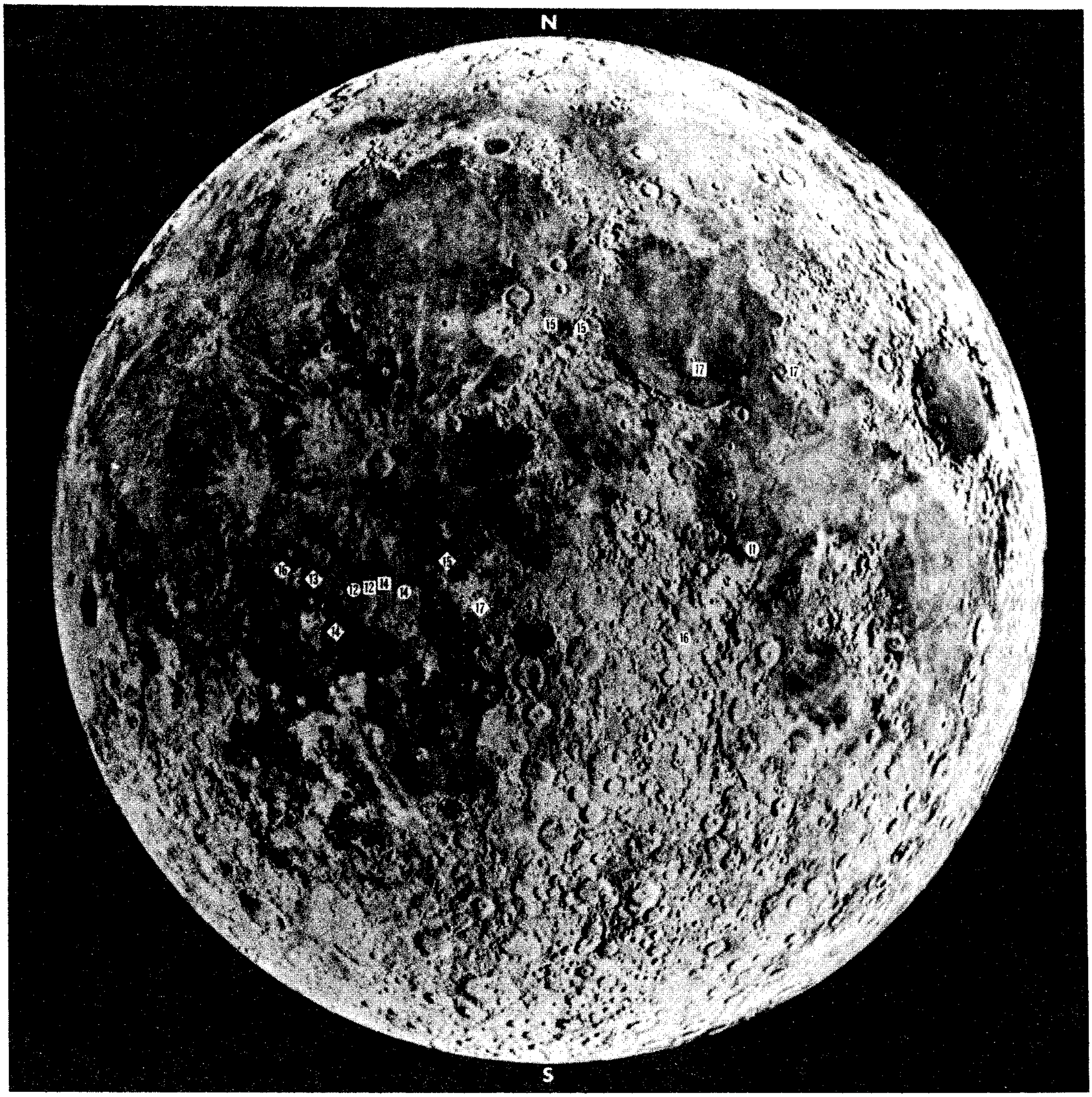

FIGURE 1.—Front side of the Moon. This side always faces the Earth. Shown here are locations of the previous Apollo landings (circles) and of the impacts on the Moon of spent S–IVB stages (diamonds) and LM ascent stages (squares). The numbers in the symbols are the mission numbers. Yes, the number 13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

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

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

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

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

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

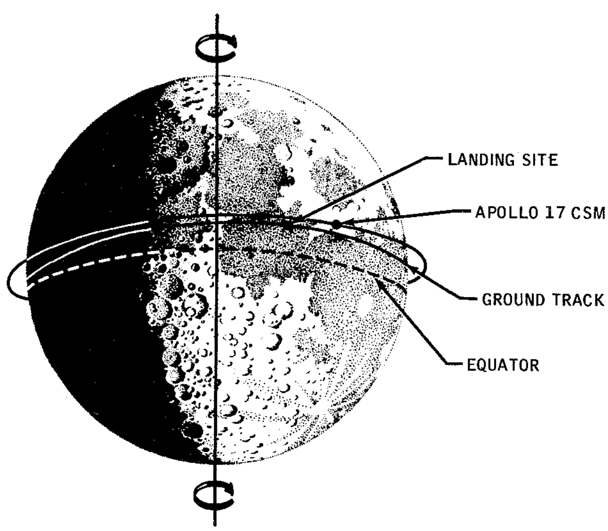

FIGURE 2.—Orbit and ground track of Apollo 17. Because the Moon rotates, the ground track is different for each revolution of the CSM.

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

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

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

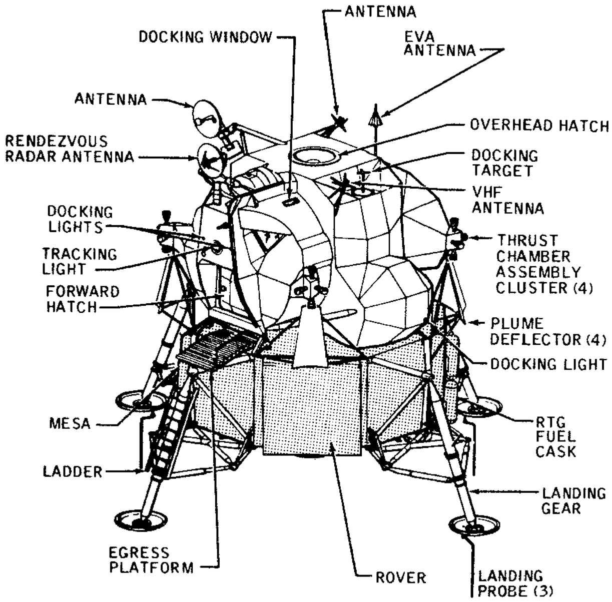

FIGURE 3.—The Lunar Module (LM). The shaded portion, the descent stage, remains on the Moon when the astronauts leave in the ascent stage to rendezvous with the CM and return to Earth. Scientific equipment is stored in the MESA.

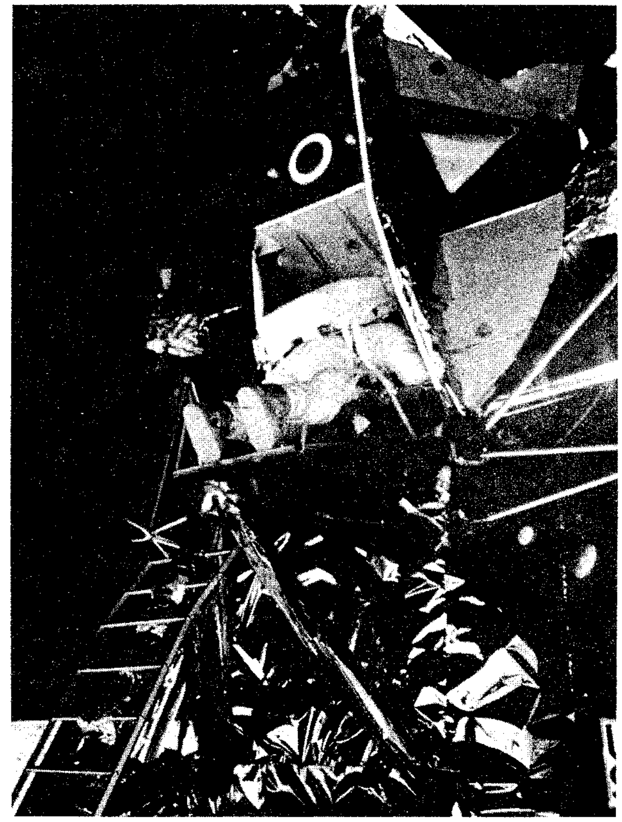

FIGURE 4.—Egress. Apollo 11 Astronaut Aldrin is shown egressing from the LM. Note the ladder that leads down one leg from the platform. NASA PHOTO S–71–31090.

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

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

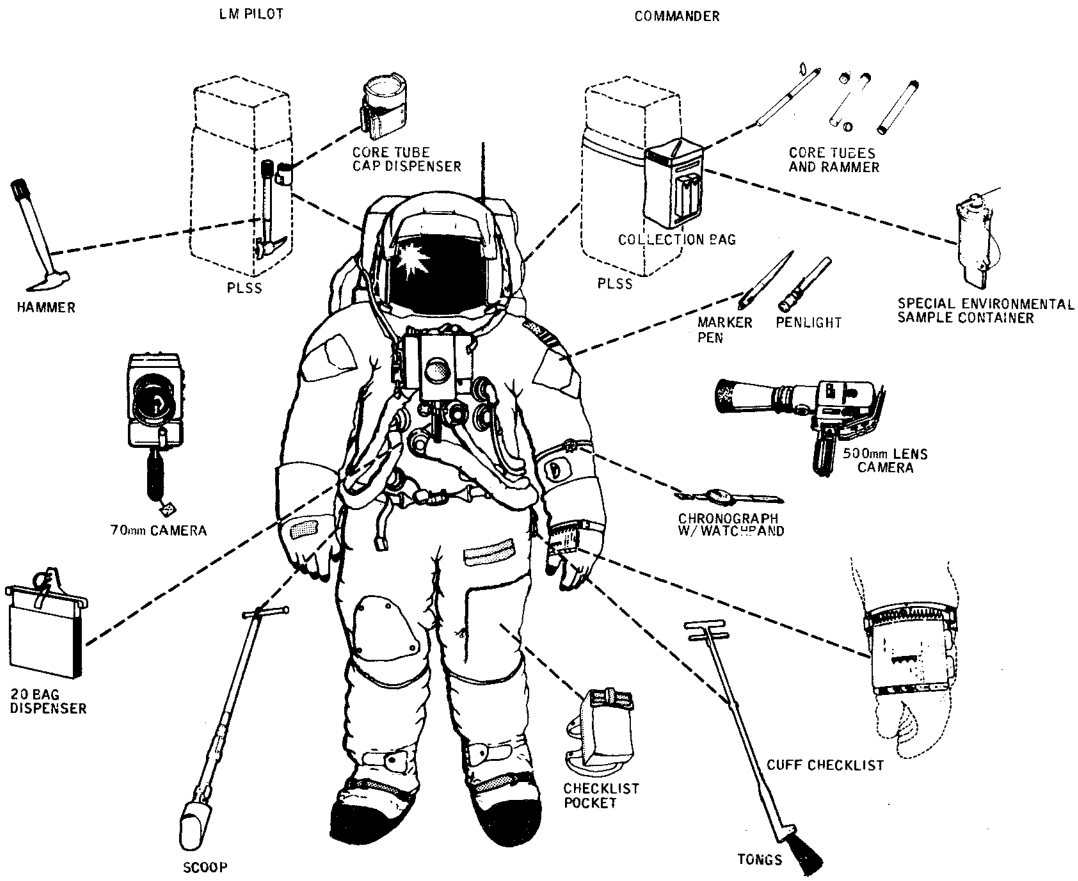

FIGURE 5.—Astronaut suit and equipment. The suit prevents exposure of the astronaut to the Moon's vacuum. It incorporates many improvements over the suits used on early Apollo flights. Sketched also are several items of equipment. NASA PHOTO S-71-29731.

Landing Site Description

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

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

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

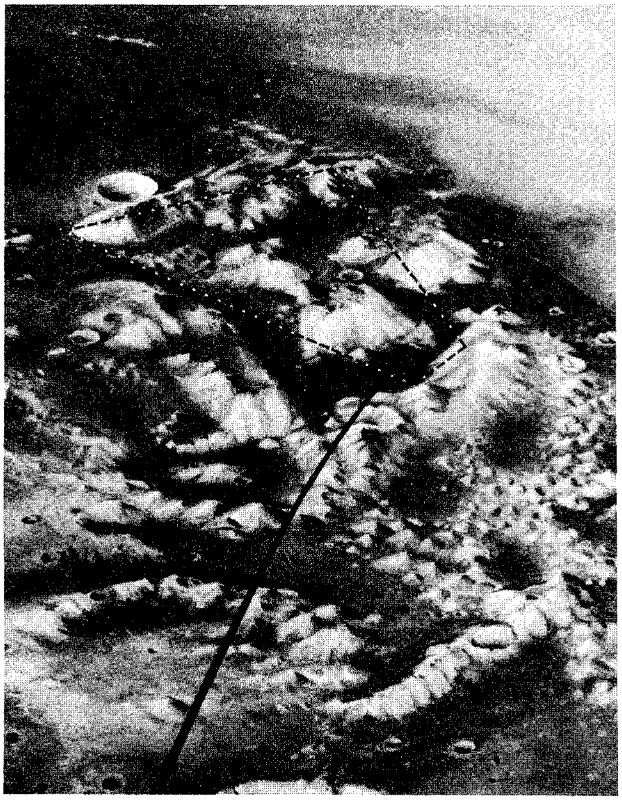

FIGURE 7.—The Region around Taurus-Littrow. The dashed area is the outline of figure 6. The heavy black line is the path of the descending LM. NASA PHOTO S–72–50304

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

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

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

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

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

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

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

DESCRIPTION OF ROCK UNITS

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

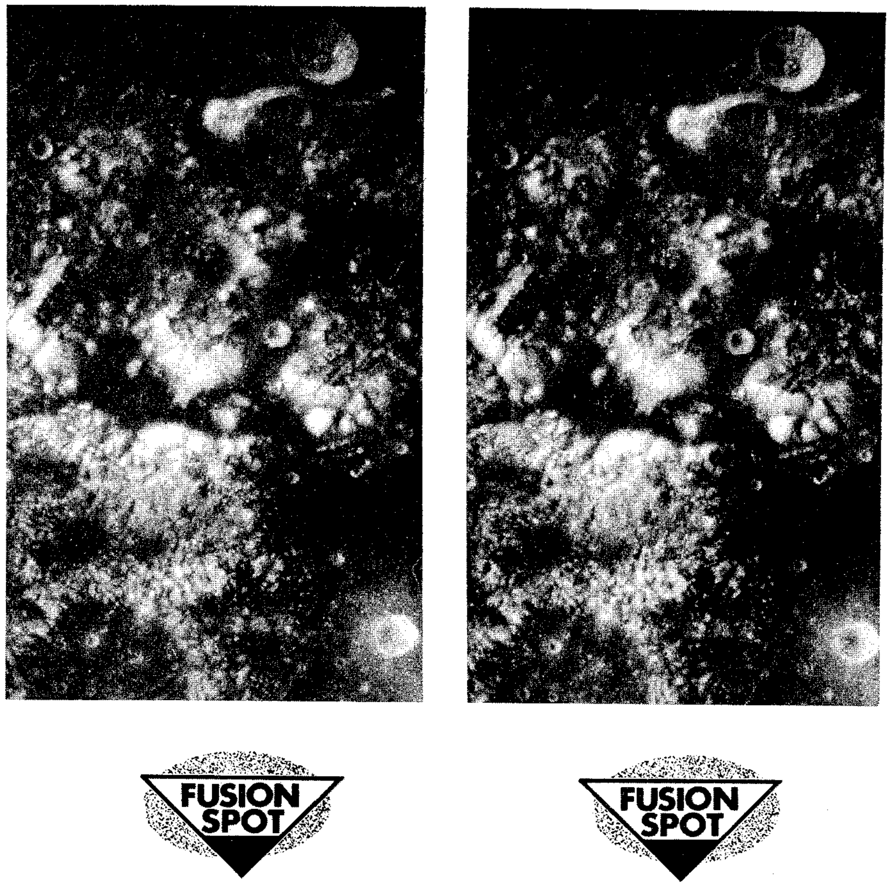

FIGURE 8.—Stereo Photographs of the Apollo 17 landing site. These photographs were selected by Leon J. Kosofsky and arranged by Earl E. Krause. Most people can train their eyes to focus on these photographs in such a way that they will see them in full three-dimensional vision. To help you train your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

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

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

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

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

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

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

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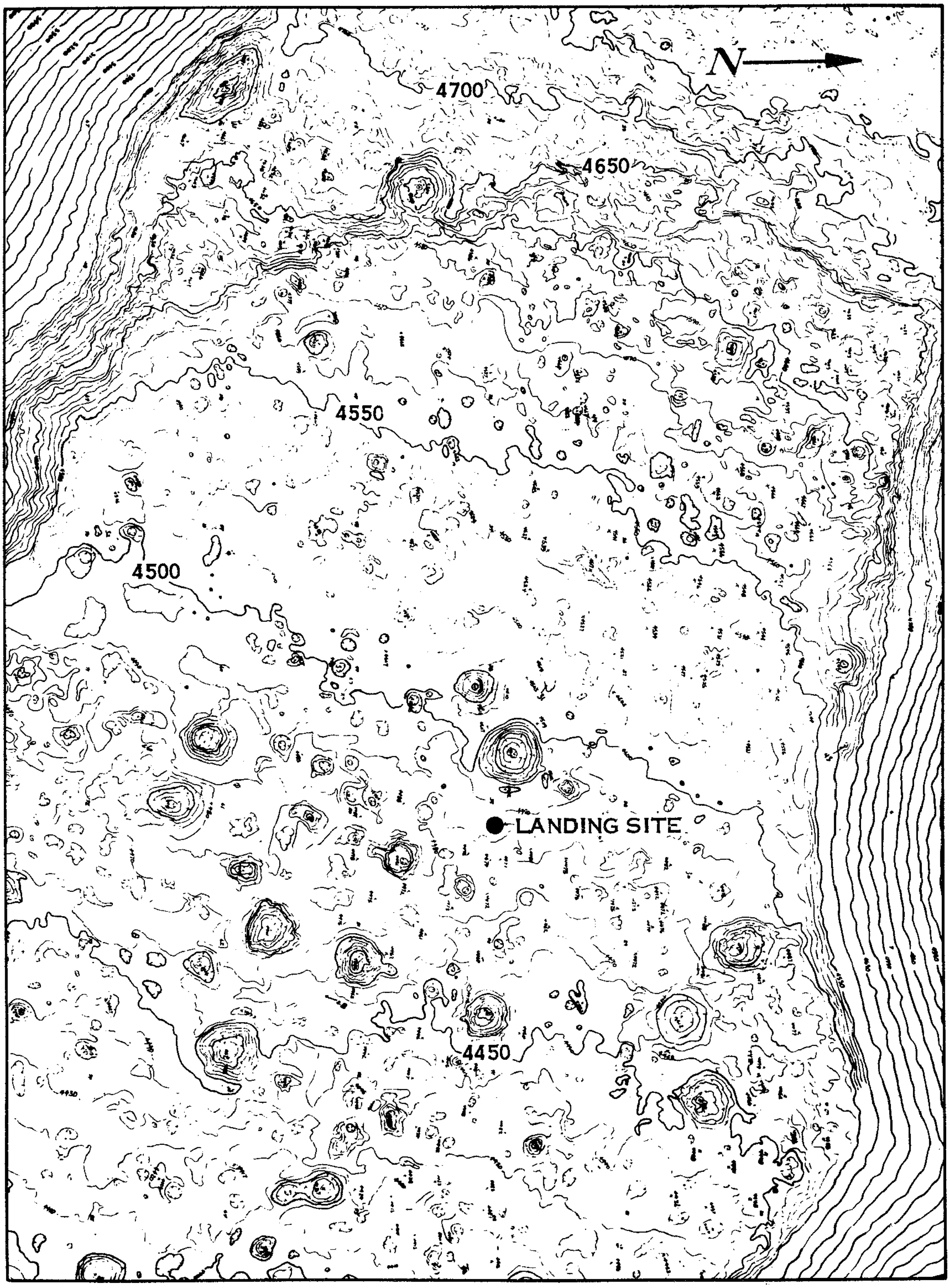

FIGURE 9.—Topographic map of the Taurus-Littrow region. This map shows the elevations of the surface of the Moon in the vicinity of the Apollo 17 landing site. The lines, called contours, connect points of equal elevation. Thus the line that is labeled 4550 indicates that the elevation of all points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

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

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

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

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

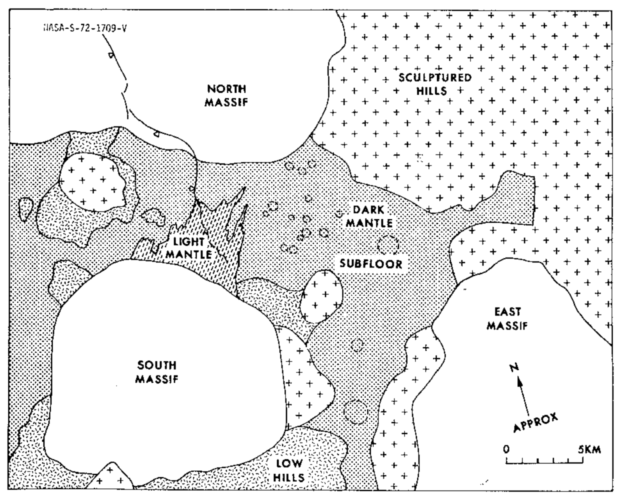

FIGURE 10.—Geologic map of Apollo 17 area. The different patterns are used to show the aerial distribution of different kinds of rock on the Moon. From a study of the relations of the various materials to each other, we *think* that the LIGHT MANTLE material is the youngest, the DARK MANTLE material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

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

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

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

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

SURFACE FEATURES

Several major surface features of special interest occur at the Apollo 17 site. These include a thin regolith; several faults; a long, steep, east-facing cliff (geologically, scarp) and several craters. All of these features are readily apparent in the photographs of the region. They are especially clear in

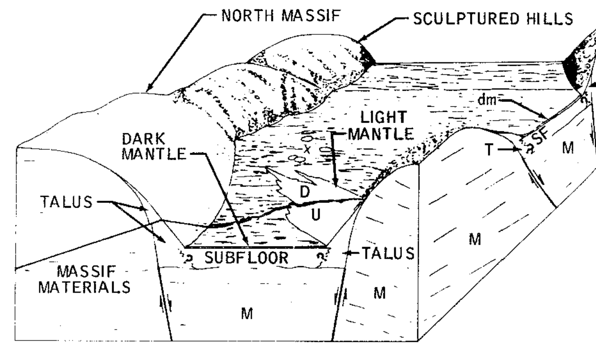

FIGURE 11.—Schematic view of Taurus-Littrow. Visualize, if you will, a large section of the Moon's material sawed out, lifted by a gigantic crane, and placed on a huge tabletop for us to view. From our photographic observations, previous study of lunar rocks, and our experiences in studying geology on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

the stereo photographs. The description of the geologic features of the landing site is perhaps easier to visualize with the aid of a block diagram. Shown in figure 11 is a large chunk of the Moon as it would appear if lifted out of the Moon so that we could view it.

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

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

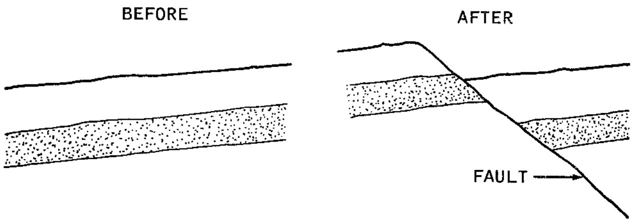

FIGURE 12.—Fault. The geological term fault is used for any surface on which movement has occurred. Although layered rocks are shown in this illustration, faults also occur in rocks that have no layering. The rock may move in any direction; in this example the rocks on the right hand side of the fault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

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

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

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

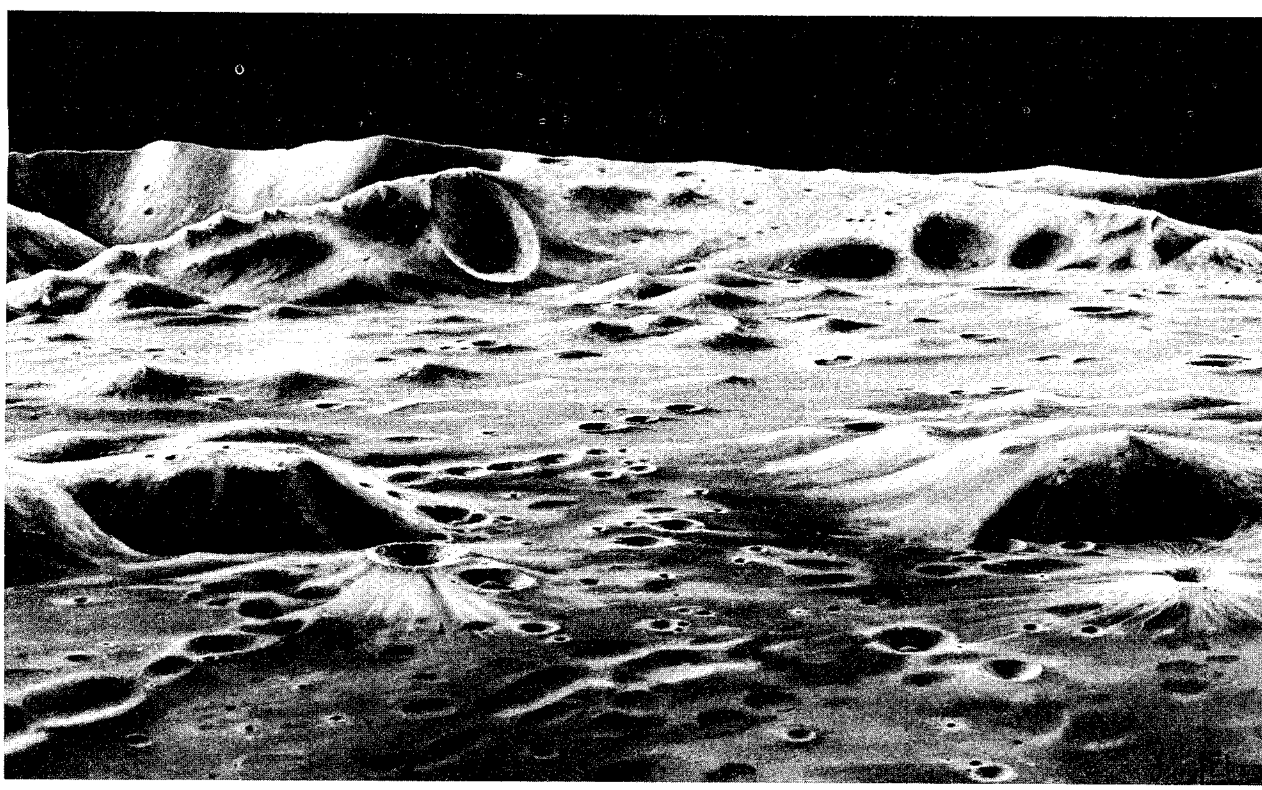

FIGURE 13.—The descartes region, landing site of Apollo 16. We are looking due east and downward at an angle of about 10°. The bright rayed crater in the lower right hand corner is South Ray. The one slightly to the left of center and in the foreground is North Ray Crater. The LM landed roughly midway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

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

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

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

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

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

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

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

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