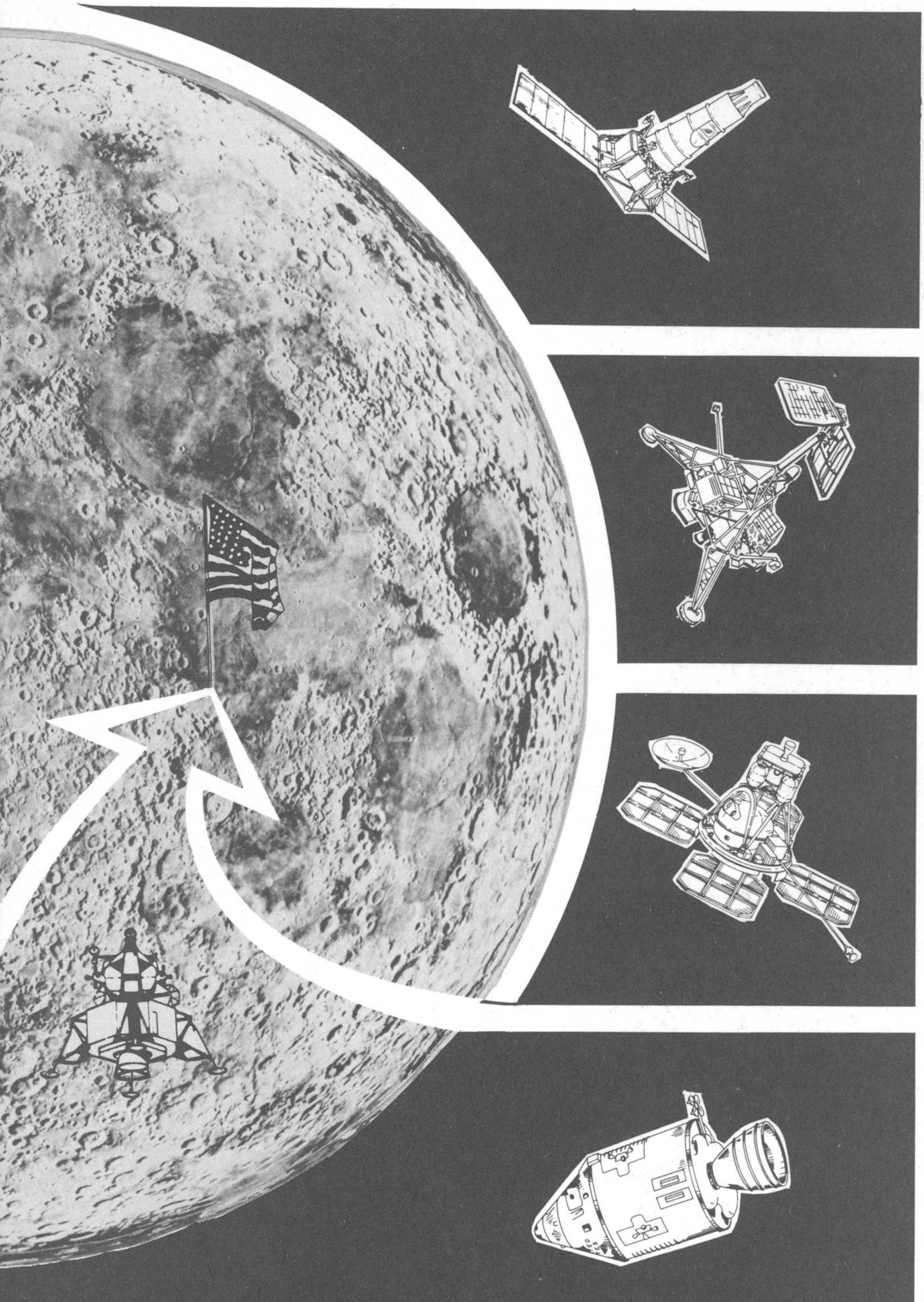
STEPS TO THE MOON



STEPS to the MOON

On July 20, 1969, man walked on the surface of the Moon and began a new chapter of his studies that will eventually disclose the geologic nature of the Earth's nearest neighbor. Although he has finally reached the Moon and sampled its substance, much work and study remain before he will know the full scientific significance of the first landing. This booklet briefly summarizes the steps man has taken to understand the Moon and what he thinks he has learned to date as a result of his centuries-long speculations and studies.

EARLY VIEWS

Astronomers of early science looked through telescopes at the dark and bright areas of the Moon and thought they were seas and continents. The dark areas—the seas—they called *maria* (singular, *mare* pronounced MAH-rey) the Latin word for sea. The light areas—the continents—they called *terrae* (singular, *terra* pronounced TER-uh) the Latin work for Earth.

In 1651, Giovanni B. Riccioli, a Jesuit priest, made a comprehensive map of the Moon and named its features with words borrowed from Latin. With poetic license, he chose names such as Sea of Tranquility, Sea of Clouds, and Sea of Rains for areas he thought were bodies of water. The large craters he named after famous men, such as Copernicus, Tycho, Kepler, and Plato. The lunar mountain ranges were named by Hevelius, a German astronomer, for those on Earth and included the Alps, the Apennines, and the Pyrenees. There have been several attempts to change some of the early names, especially those used to identify the maria, but to date they remain the same.

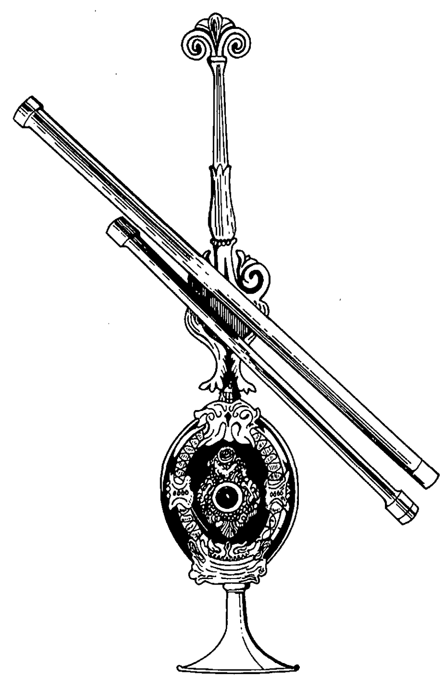
Today, names for lunar features are chosen by the Names Committee of the International Astronomical Union. Now that the far side of the Moon has been photographed in detail, many new names undoubtedly will be applied to the newly revealed lunar features.

CLOSER VIEWS

Primitive men, knowing only that the Moon was a strange but regular visitor to their night skies, incorporated its phases into their calendars as measurements of time. But they considered the Moon to be the handiwork of the gods, and its origin was shrouded in myths.

As truth replaced mythology, fact replaced mystery. Steadily, man's understanding of the Moon grew in proportion to his ability to develop instruments and methods for studying the Earth's nearest neighbor. There have been many contributions on this long road of progress. A few milestones stand out as tributes to human ingenuity.

Galileo, in 1609, was one of the first to use the telescope to study the celestial bodies. In addition to viewing the features on the surface of the Moon, he saw that Jupiter had moons and that various planets displayed moonlike phases. This last point supported the highly disputed Copernican theory that the Sun, not the Earth, was the center of the solar system.



Galileo devoted much time to developing and using crude telescopes. In 1610, he discovered that the Moon's surface was made up of mountains, valleys, plains, and a great number of cup-shaped depressions, or craters.

This telescopic photograph plainly shows the dark and bright areas of the Moon that early astronomers thought were seas and continents.

Note the ray patterns that extend from many craters. The largest system, stretching for hundreds of miles, radiates from the crater Tycho.

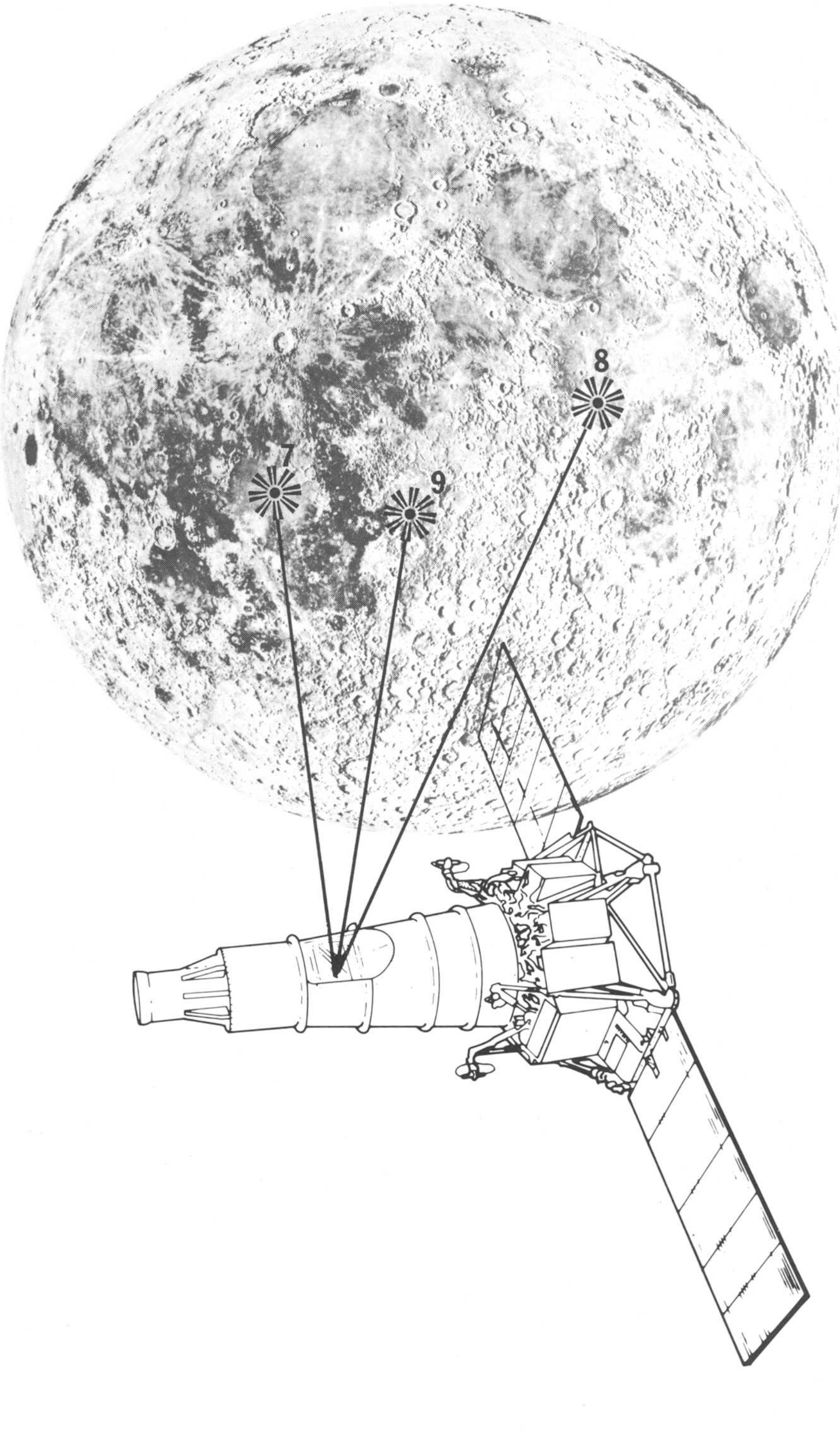
In 1864, a camera was mounted on a telescope and the first photographs of the Moon were obtained. Since then many new methods and devices for studying the Moon have been developed. Powerful telescopes, infrared photography, and the highly accurate measurements made with radar and laser beams have provided much information about the nature of the Moon's surface. With such modern equipment the Moon could be brought to within a viewing distance of 400 miles from the Earth. But until the space age, all methods of viewing and studying the Moon were earthbound, and lunar features less than 1,500 feet in diameter could not be clearly distinguished.

DETAILED VIEWS

The Nation's effort to land men on the Moon added to the need for a better understanding of the nature of the lunar surface. Unmanned spacecraft, sent to the Moon to photograph its surface at close range, transmitted close-up pictures and features never before seen.

On July 31, 1964, Ranger VII made a successful flight to the Moon. It crashed on Oceanus Procellarum (Ocean of Storms), but during the final few minutes of flight, its television cameras transmitted thousands of pictures back to Earth. Lunar features as small as 3 feet in diameter could be clearly seen.

Rangers VII, VIII, and IX made successful hard landings on the Moon, and their television cameras returned thousands of pictures of various parts of the Moon's surface.



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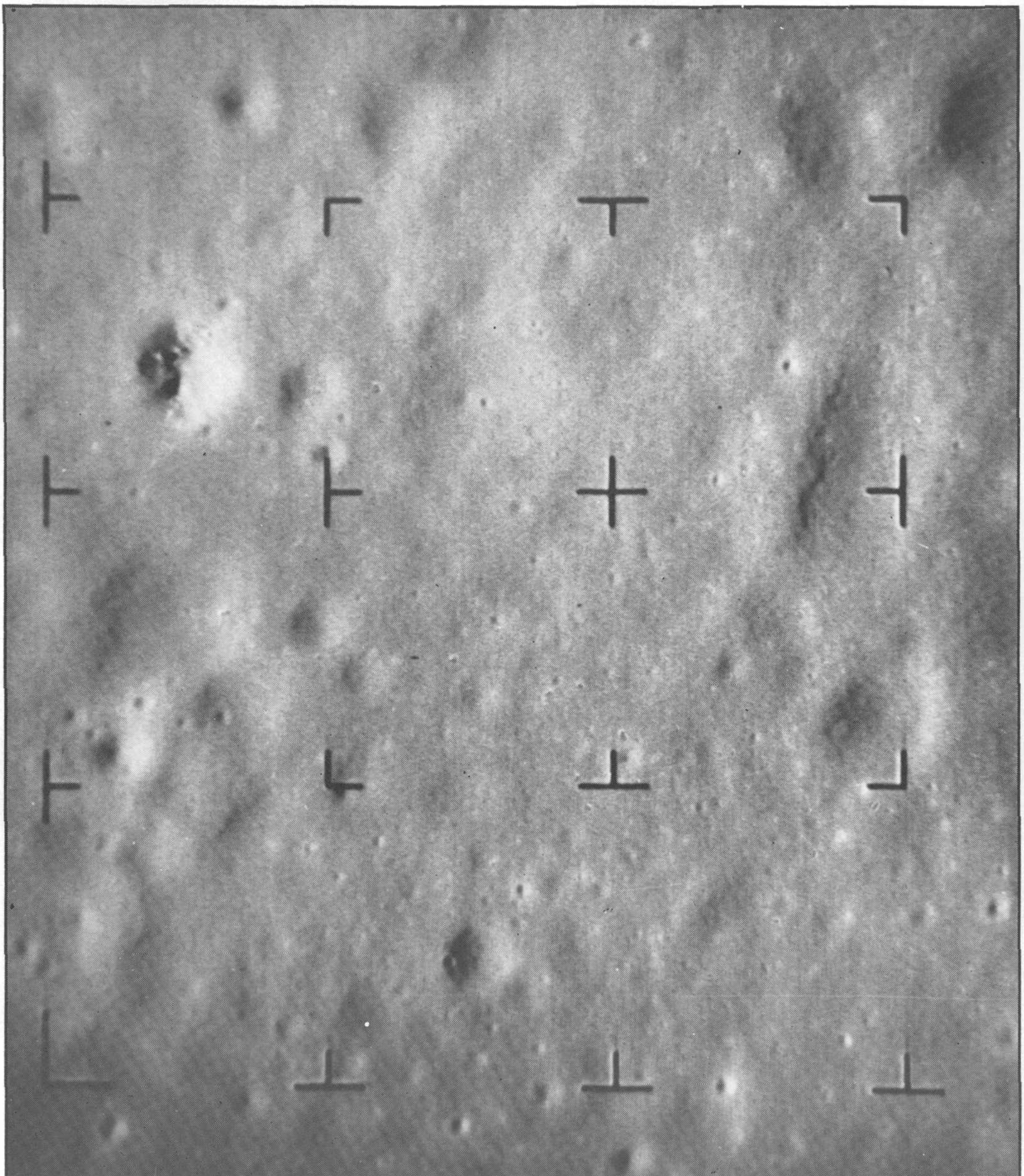
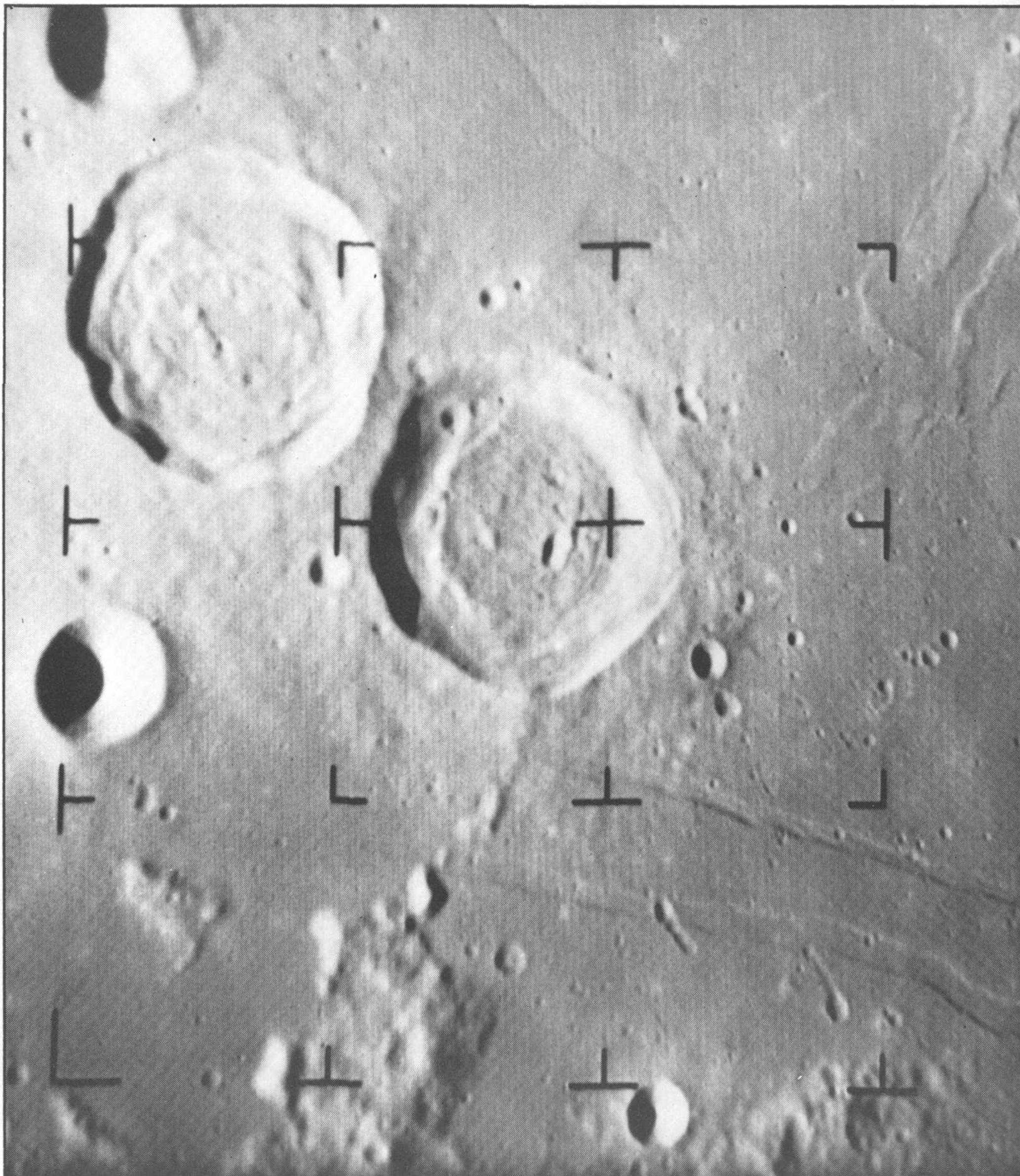


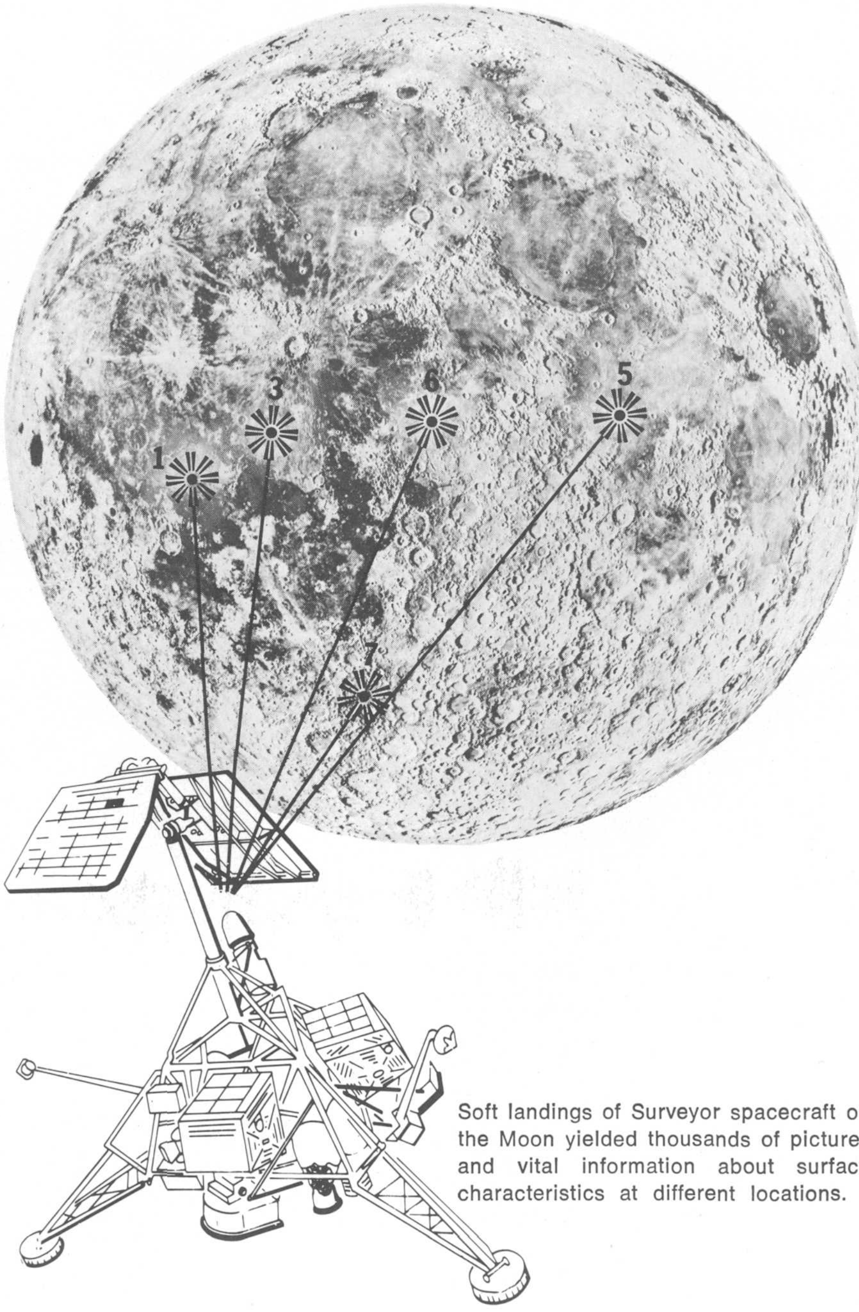
One of the last pictures to be transmitted by Ranger VII shows that the older craters have been battered into rounded shapes by the constant rain of cosmic debris. Rocks can be seen at the upper left lying in a crater that is approximately 820 feet in diameter.



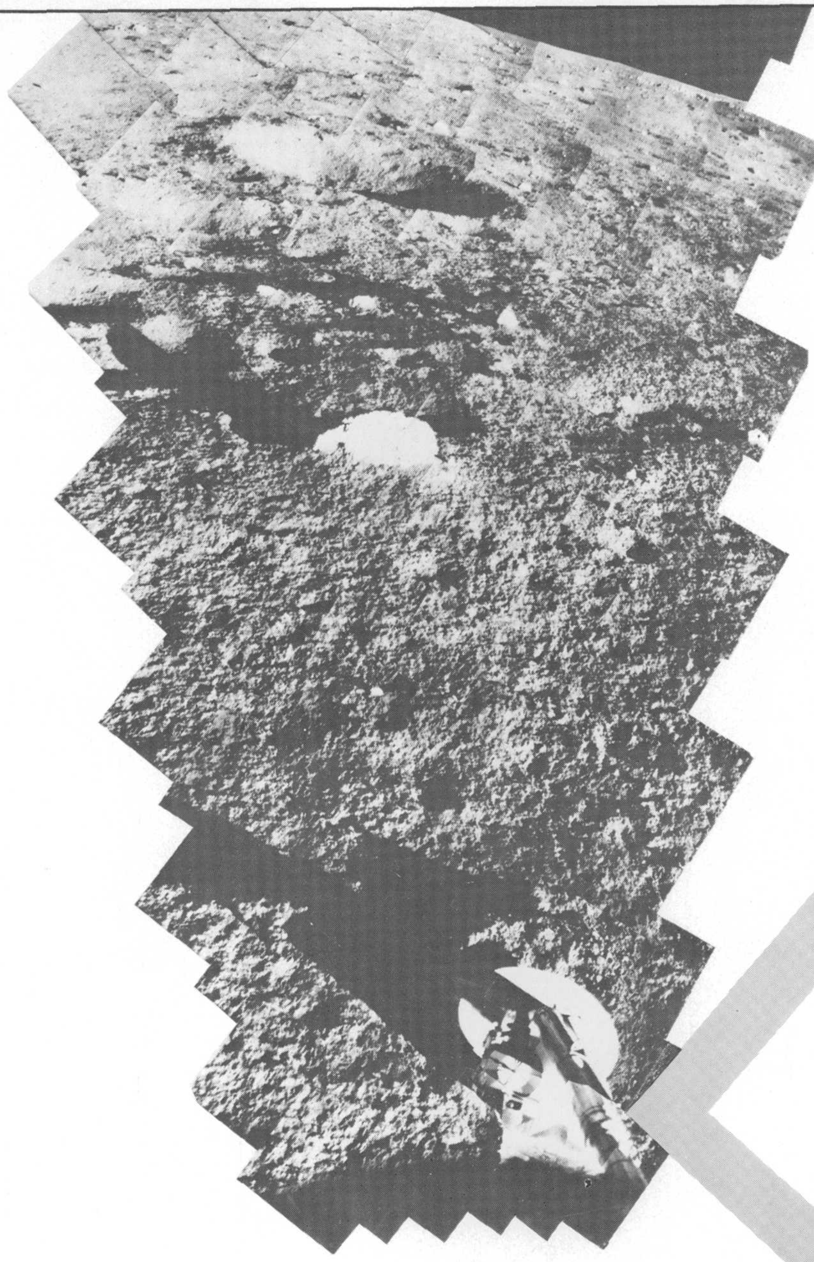
Some craters appear to be twins. These two, Ritter on the left and Sabine, each about 19 miles in diameter, are almost identical in size and shape. There is no overlap of rim material from one to the other and they appear to be of the same age and origin. These two are on the western edge of Mare Tranquillitatus (Sea of Tranquility) and were photographed by Ranger VIII.

As Ranger IX approached its point of impact within the crater Alphonsus, it transmitted this picture. The hummocky terrain is part of the rim of Alphonsus; the large fracture is in the crater floor. The length of the fracture seen in this picture is about 28 miles.

On July 2, 1966, Surveyor I soft-landed on the Moon about 35 miles north of the crater Flamsteed. Shortly after landing, its television camera began transmitting photographs of the scene about the spacecraft from the horizon down to its footpads. Pits and grains that measured fractions of an inch in diameter were easily seen in the televised photographs.



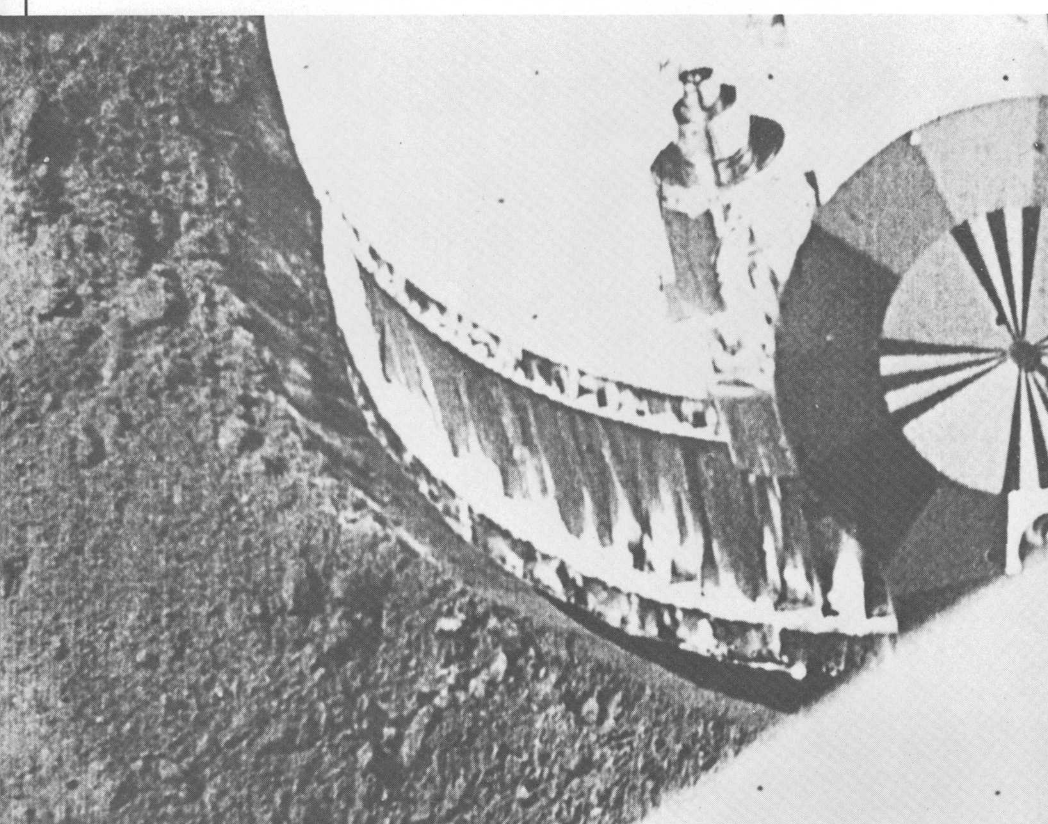
Soft landings of Surveyor spacecraft on the Moon yielded thousands of pictures and vital information about surface characteristics at different locations.



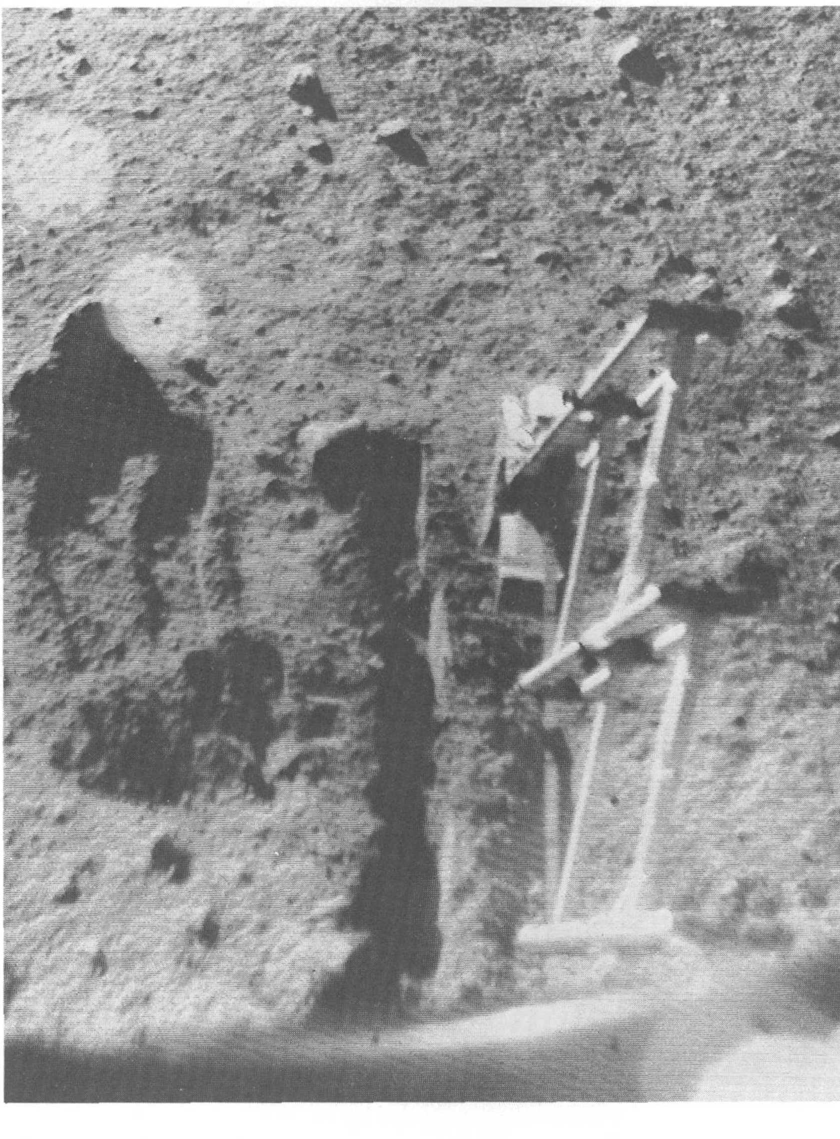
A photomosaic of pictures taken by the television camera aboard Surveyor I. At the bottom of this picture is one of the landing pads, which is about 1 foot in diameter. About 15 feet from the landing pad is a rock that measures about 1 foot in length. Beyond it is a smooth crater approximately 9 feet in diameter. Rock fragments generally litter the moonscape. The horizon is less than 2½ miles away.

The primary purpose of the Surveyor missions was to obtain pictures of sites tentatively selected for future manned landings, but other information was also obtained. Estimates of the strength of surface materials at the landing sites were made from data on the forces exerted on the landing gear during touchdown. Soil samplers dug small trenches. Delicate instruments analyzed the chemistry of the lunar "soil." Thermal measurements were made and magnetic properties were evaluated.

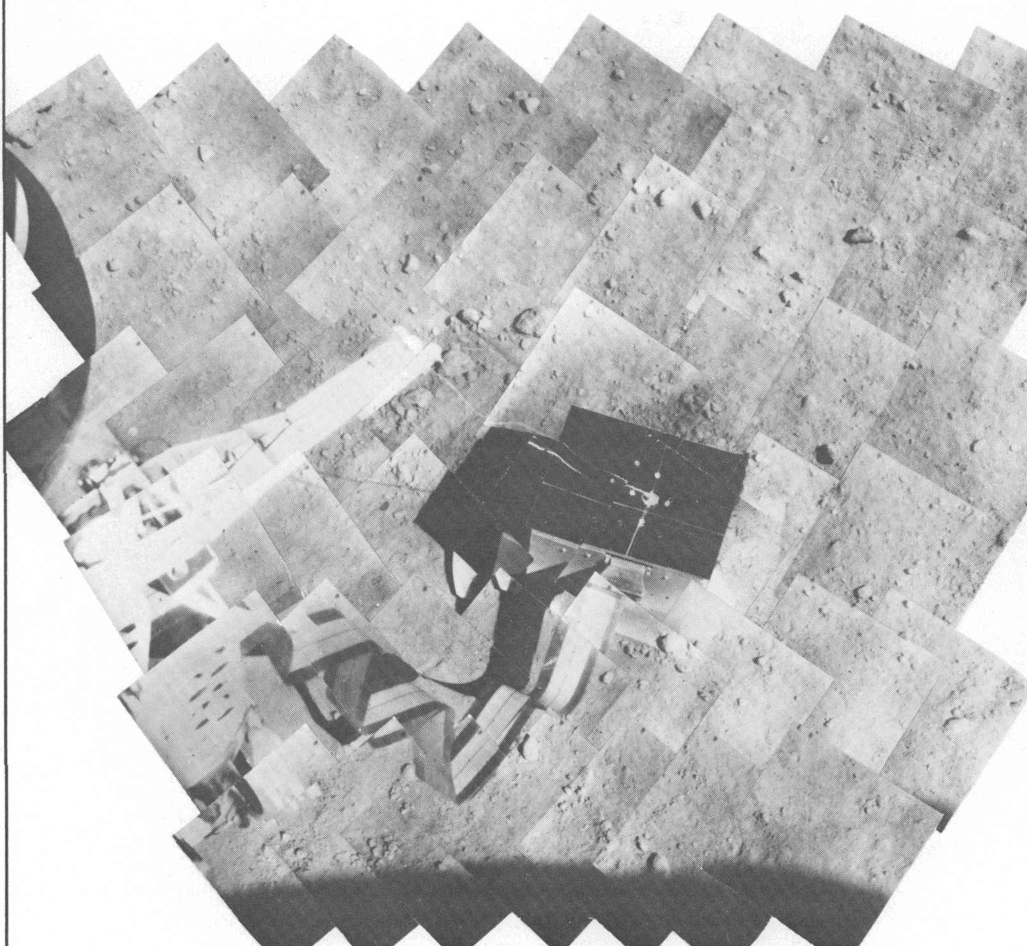
Close-up view of part of Surveyor I landing pad and color target. Among other scientific information, Surveyor I demonstrated that the lunar surface would support the landing of manned spacecraft.

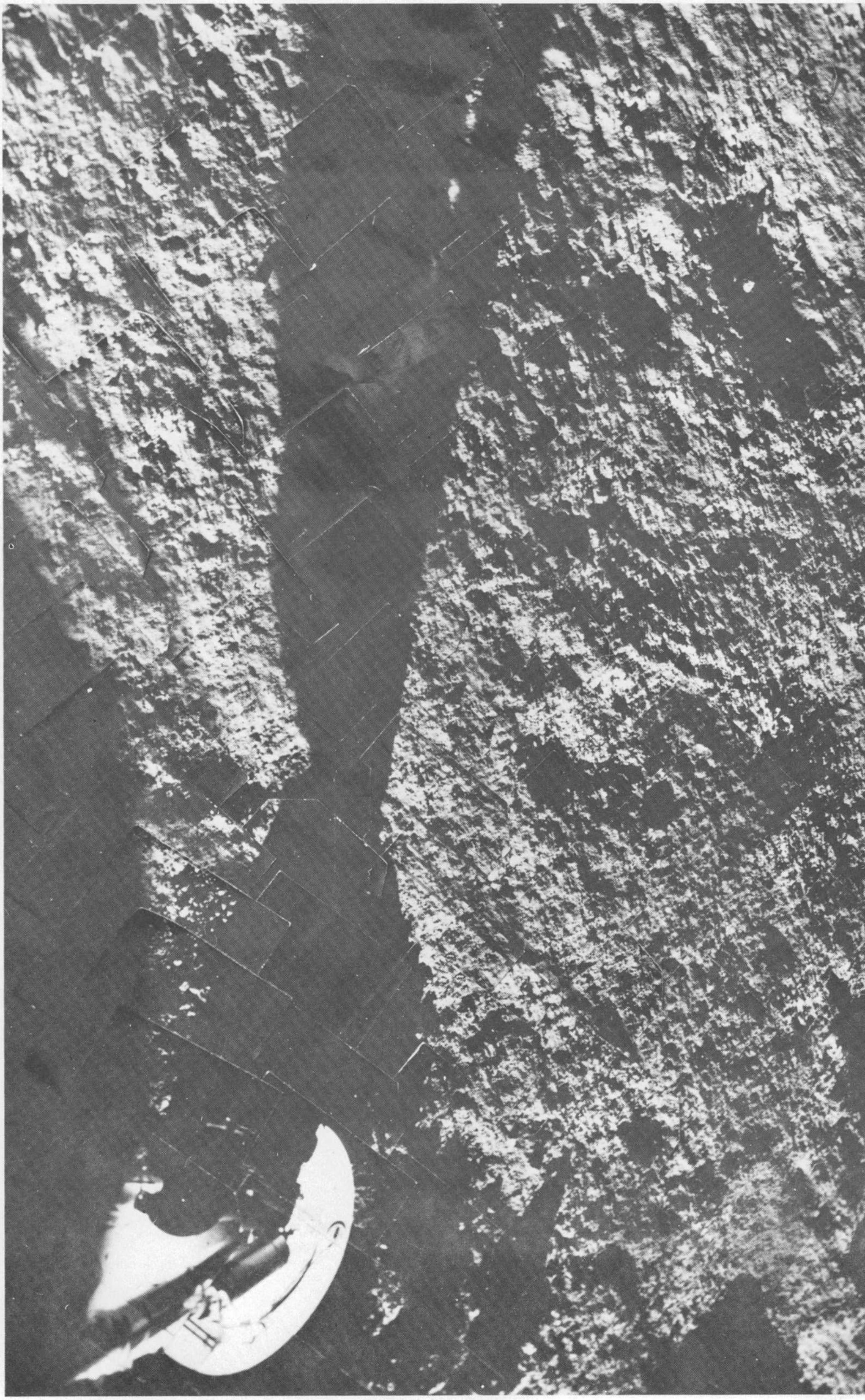


A view of the lunar "soil" showing the trenching tool of Surveyor VII in a raised position. The walls of the trenches did not crumble, indicating cohesion between particles. The trenching tools, pulling through the surface material, gave information about the physical properties of the soil.



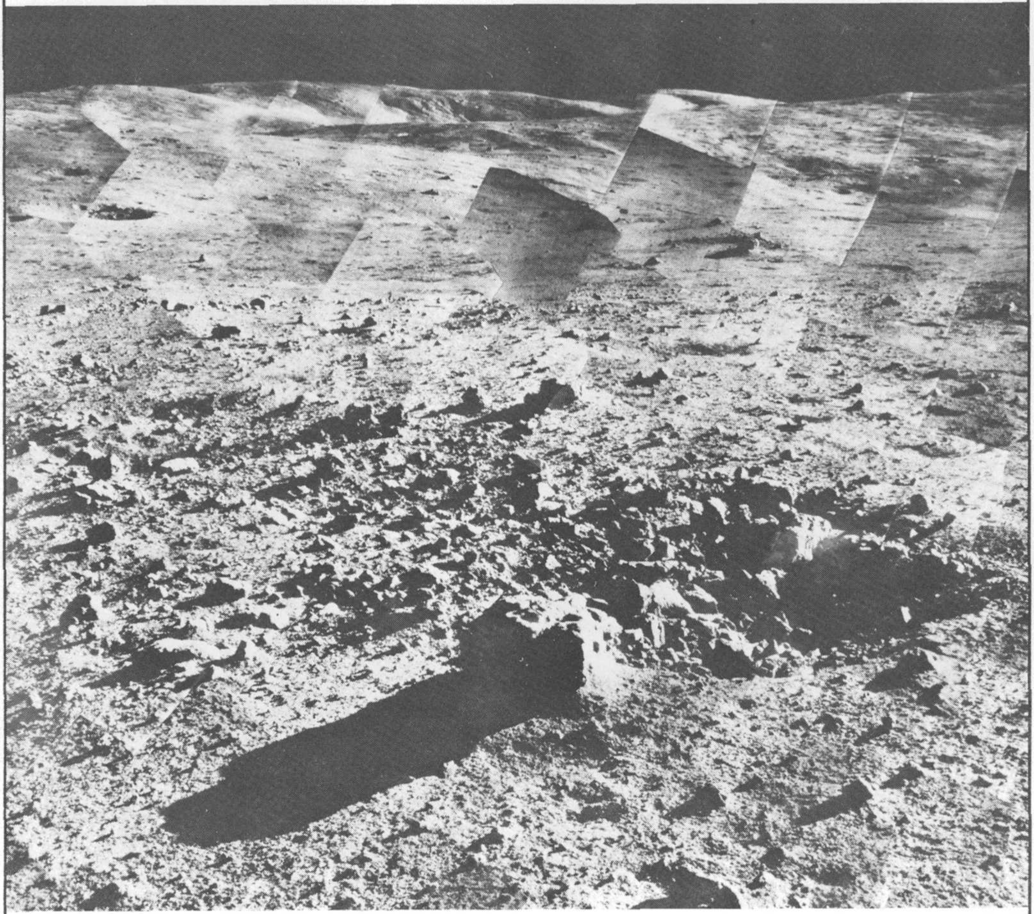
The alpha particle scattering instrument of Surveyor V on the Moon's surface. Similar instruments aboard Surveyors VI and VII analyzed the chemical composition of lunar material. At the landing sites of Surveyor V and VI, the composition of lunar material was similar to the composition of basalt—a common volcanic rock found on Earth. At the landing site of Surveyor VII, the composition of material was similar to "iron-poor" basalt. The rocks on the Moon, like those on the Earth, may have complex chemical characteristics that differ from one place to another.

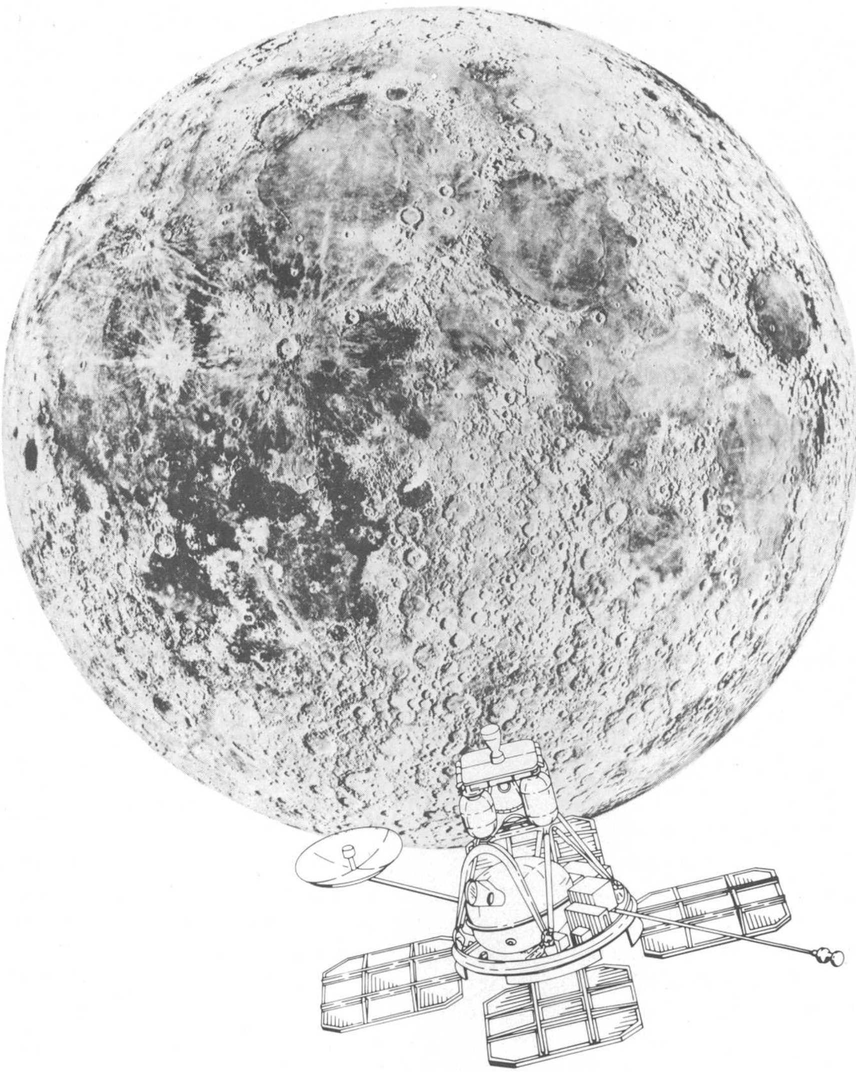




◀ The pits and small craters caused by an extensive bombardment of cosmic debris are plainly visible in this Surveyor VI view.

At the landing site of Surveyor VII on the rim of Tycho, rock fragments of all sizes litter the landscape. The rock casting a long shadow is about 2 feet across and lies about 15 feet from the spacecraft.





The Lunar Orbiters were designed to obtain data from various orbital paths. They flew at different altitudes and provided picture coverage of almost the entire surface of the Moon. These photographs were the primary means of selecting landing sites for manned missions.

During the Surveyor program, five Lunar Orbiter spacecraft were launched. Their mission: to transmit pictures from various orbital paths around the Moon. Three were placed in equatorial orbits; two in polar orbits. Each was equipped with two cameras capable of taking high- and moderate-resolution photographs. These spacecraft provided photographic coverage of more than 99 percent of the Moon's surface, including the far side, which is never seen from the Earth. Mountains, valleys, details of craters, channels, fissures, depressions, and even the paths of boulders that had rolled downhill are among the features that were revealed.

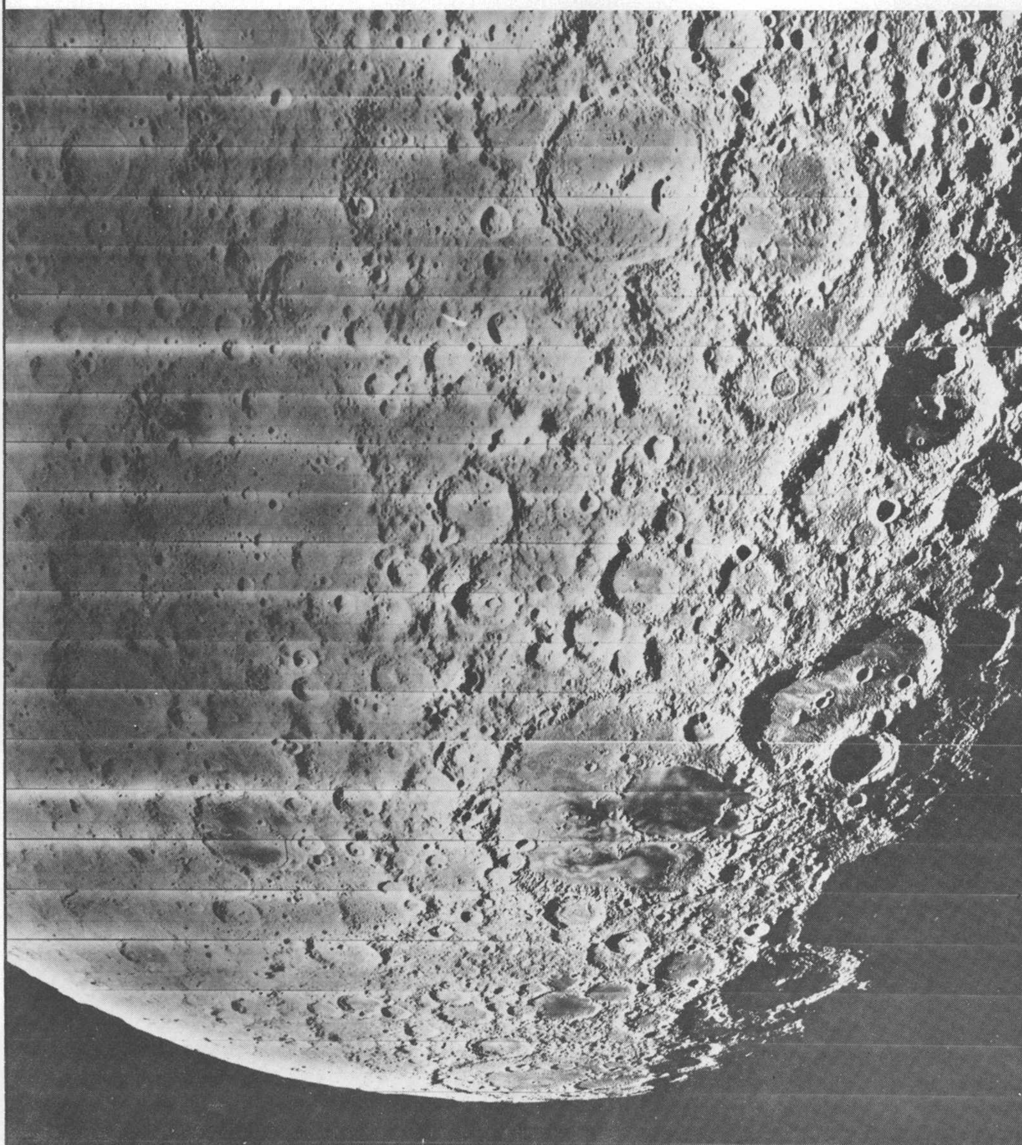
THE CRATERS

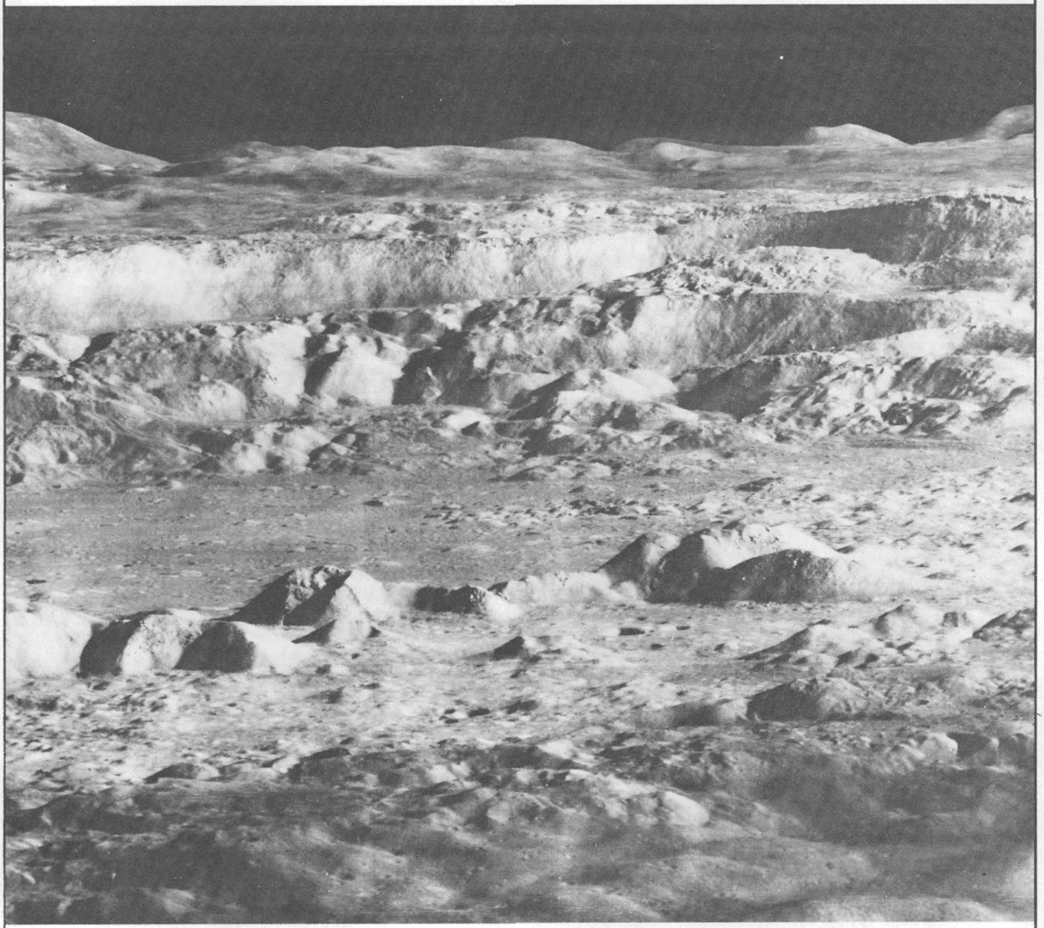
Spacecraft photography has verified that craters far outnumber any other type of feature on the Moon; thus the most active processes are the crater-forming ones. Today, scientists generally believe that most of the craters are of impact origin—that is, the craters were formed as a result of bombardment by cosmic debris—but that volcanic activity has also played an important part in forming many craters and in determining the nature of the Moon's surface.

Many impact craters can be classified as either primary or secondary. Primary craters are formed by the impact of cosmic debris that reaches the Moon from outer space. Secondary craters are formed by the impact of blocky material that is thrown out during the primary event. Large primary craters are commonly flat-floored and many display central peaks; small primary craters and the secondary craters usually have rounded cup-shaped floors.

Craters range in size from small pits, as seen for the first time in the Surveyor photographs, to the giants that measure hundreds of miles in diameter. Small craters are vastly more abundant than large ones, and a tally of craters in various size categories provides a rough measure of the rates of bombardment. Micrometeoroids frequently bombard the Moon, large meteorites strike less frequently, and perhaps once in hundreds of thousands or millions of years, a comet or asteroid collides with the Moon to form a giant crater.

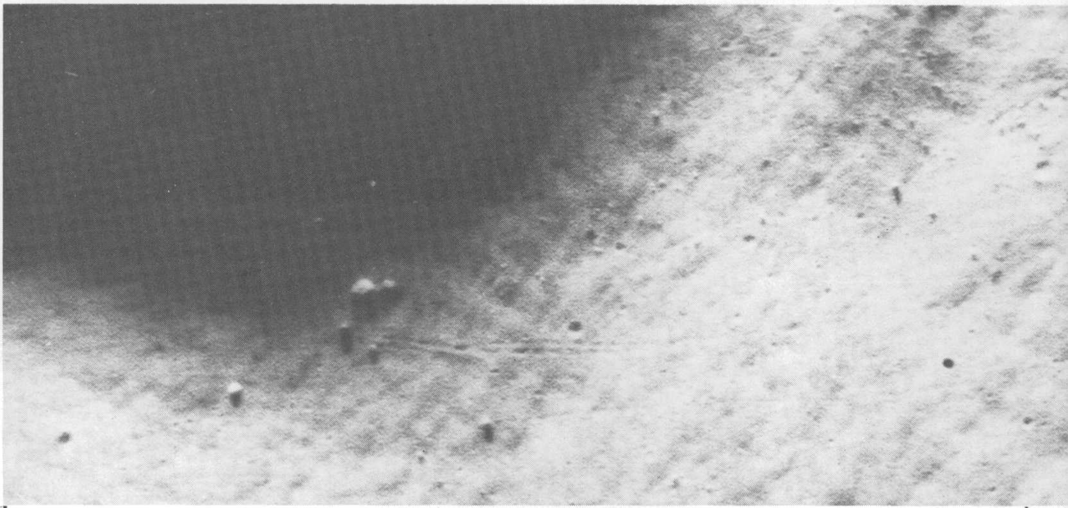
Detailed features of the far side of the Moon were revealed by photographs from Lunar Orbiters. The far side lacks large mare areas and is more heavily cratered than the near side.

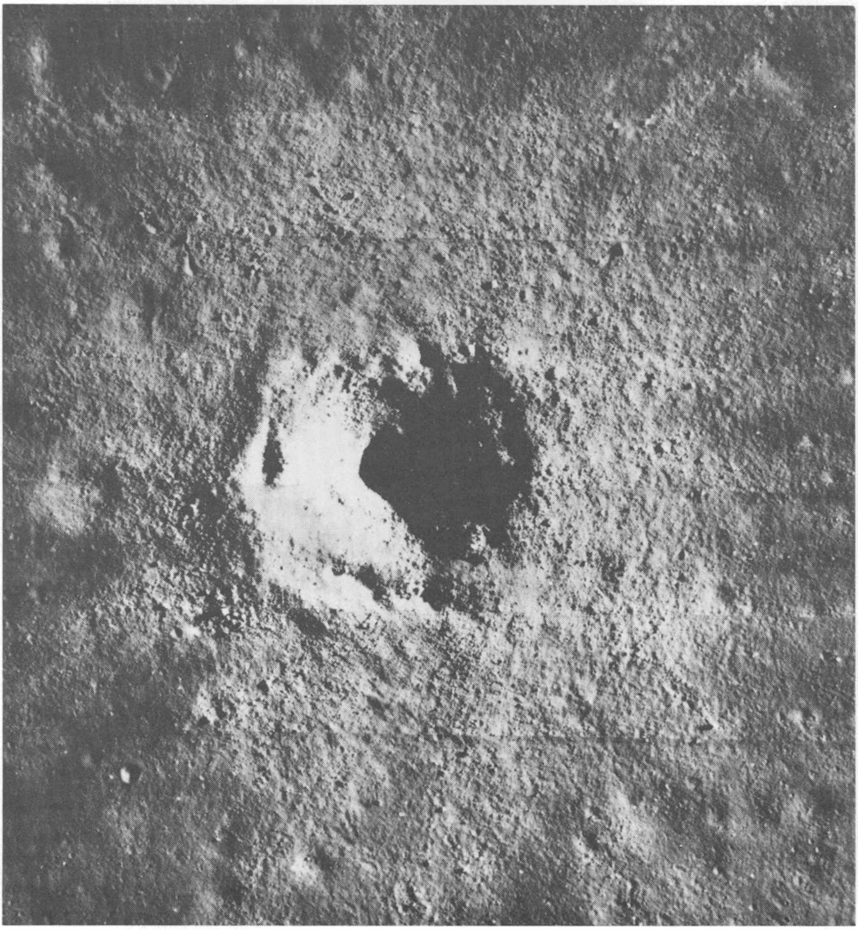


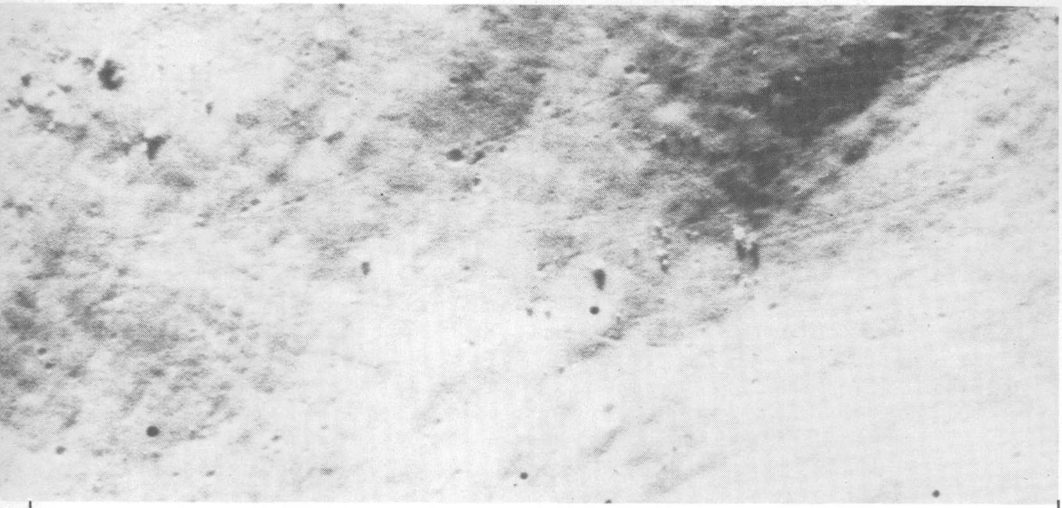


Lunar Orbiter II, from an altitude of 28.3 miles above the Moon, transmitted this spectacular picture of the crater Copernicus on November 23, 1966. Copernicus is about 60 miles in diameter and over 10,000 feet deep—*twice the depth of the Grand Canyon.* The step-terraced walls reduce the diameter of the floor to about 35 miles.

The central peaks, which are common in many large craters, rise from 1,000 to 3,000 feet. The hummocky hills on the near rim (foreground) were formed by material that was thrown out of the crater at the time of impact.







This close-up of the Moon's surface shows the trails of several boulders that have rolled downhill. At the right of the picture, boulders 20 feet across can be seen where they came to rest. They were probably dislodged by moonquakes, some of which may have been caused by nearby impacts.

This unnamed crater, about 1,500 feet in diameter, is the result of a relatively recent impact. The sharpness of detail attests to the youth of the crater. The rim material is much lighter in tone, shows ripples attributed to an outward surge of ejecta, and contains blocky fragments of the type of rock that lies beneath the surface.

Some of the large craters on the Moon resemble volcanic features called calderas on Earth, which are formed by the collapse of surface rock into the underlying magma chamber from which molten material was removed at the time of an eruption. Crater Lake in Oregon is a caldera. Other features on the Moon resemble those that characterize volcanic fields on the Earth, such as domes, cones, and surface flows.

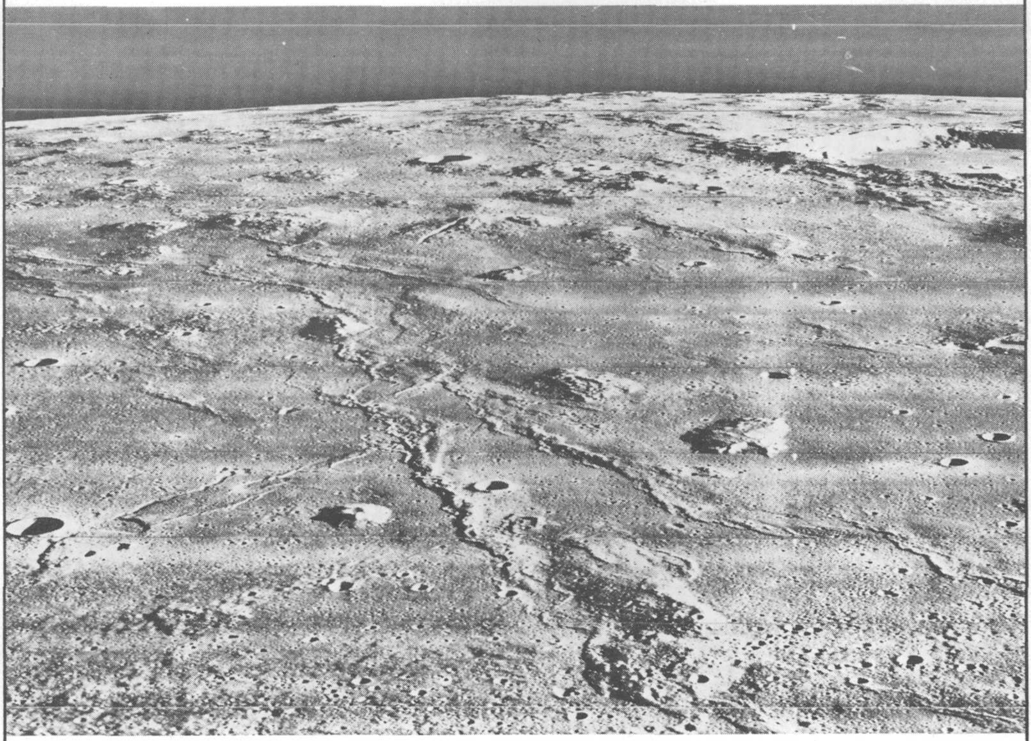
The possibility that volcanic activity occurs on the Moon is supported by many reports of the observation of red spots, white spots, and other transient phenomena. Infrared photographs, taken during lunar eclipse, show variations in surface temperature across the Moon. Even though differential absorption of sunlight may account for some of this variation, part of it may be the result of heat transmitted from below the surface.

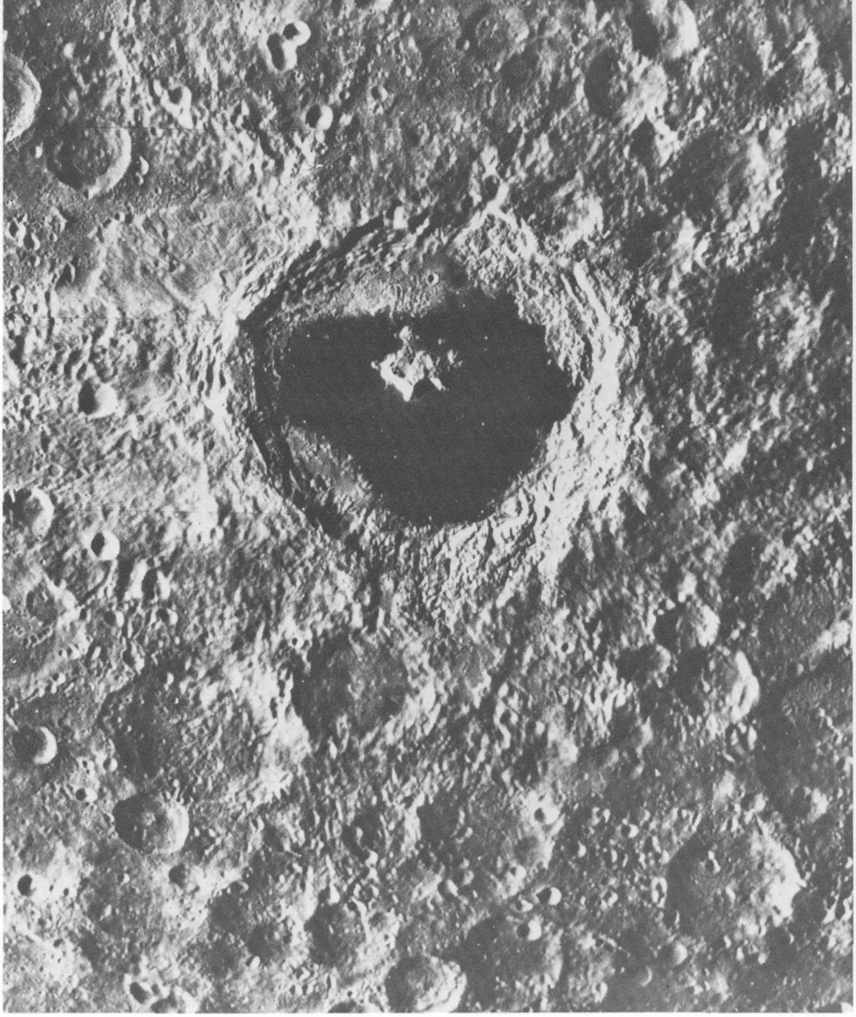
This picture, from the camera of Lunar Orbiter IV, shows a variety of geologic features. The larger crater near the bottom is Reiner, which is about 19 miles in diameter. Of probable impact origin, Reiner displays the characteristic pattern of ejected material surrounding the rim. There are many other impact craters in this photograph.

The domes at upper right, part of the Marius Hills complex, are believed to be of volcanic origin. They are similar in appearance to certain volcanic domes on Earth.

Meandering channels, called sinuous rilles, are readily apparent. Like the white feathery streaks, they have not yet been satisfactorily explained.

An oblique view of the Marius Hills region. At the far right is the large crater, Marius. Scarps, which are probably the leading edges of lava flows, are very conspicuous in this picture.





This large crater, Tsiolkovsky, is 155 miles in diameter. It is on the far side of the Moon and was photographed by Lunar Orbiter I.

Some craters on the Moon that appear to have been formed by impacts are partly flooded by volcanic materials. Fractures in the floors of these craters may have served as vents from which molten material flowed. In some places, this material can be seen as "ponds" that settled only in lower levels; in others, the flooding continued until the entire crater floor was covered.

THE MARIA

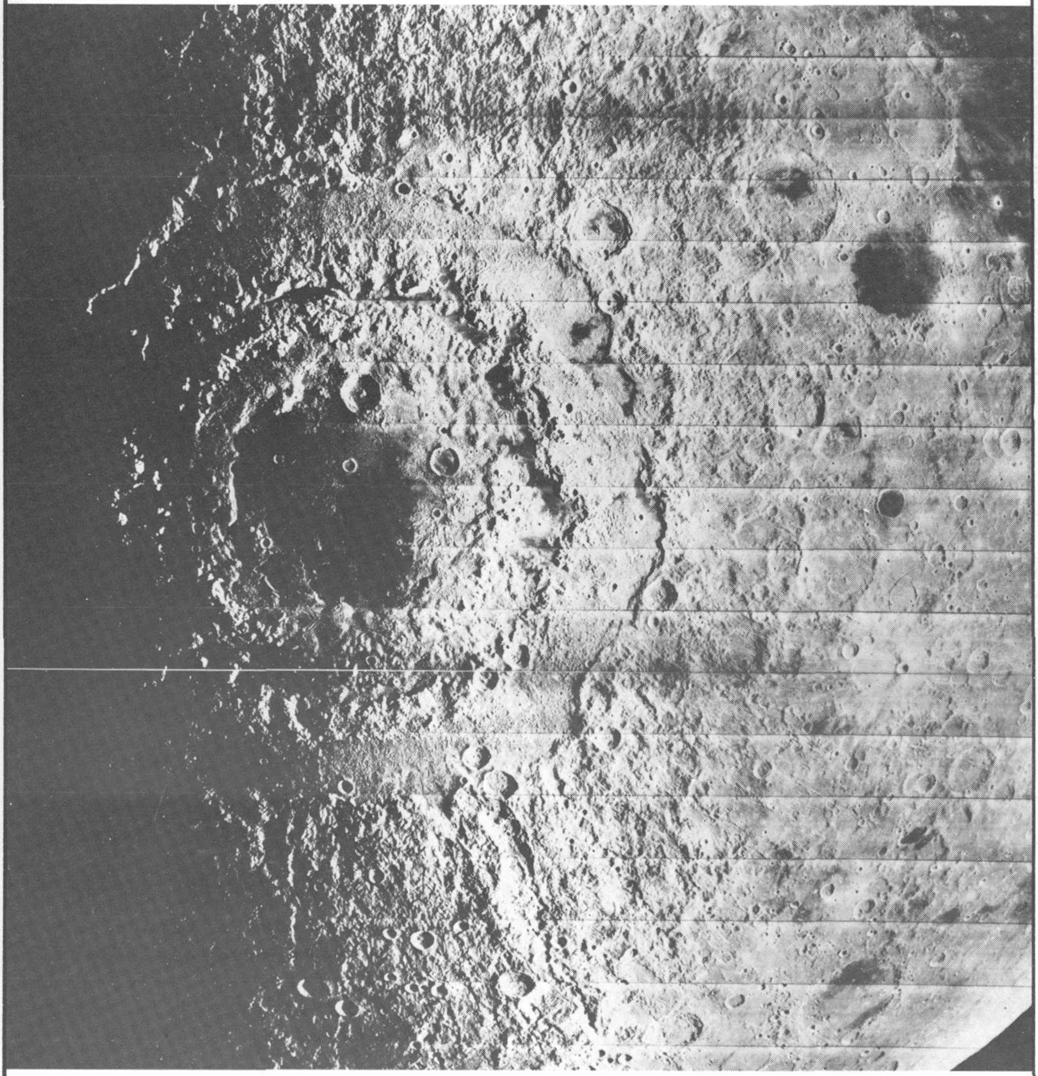
The broad, circular mare basins may also have been formed by impacts, but the impacts were of much greater magnitude than those that formed the craters Tycho, Copernicus, and Kepler. Mare Imbrium (Sea of Rains), for example, is about 750 miles in diameter. Along its southern perimeter are the semicircular Carpathian and Apennine mountain ranges, whose inner slopes drop sharply to the mare floor. The ridges and valleys of the outer slopes extend for many miles and their alinements are radial from a point within the mare, suggesting that they were formed by a tremendous surge of material caused by an impact of huge proportions. The mare material flooded the basin at a much later date, as shown by the presence of craters sandwiched between basin deposits and mare deposits.

Evidence of another mare-size impact was revealed in detail by Lunar Orbiter IV. Mare Orientale (Sea of The East), which is flanked by the Cordillera Mountains, can barely be seen from the Earth because of the extreme angle of view. Spacecraft photography, however, provided a full view and revealed an astonishing bull's-eye structure about 600 miles in diameter. The inner basin, or primary impact point, is surrounded by circular troughs that are partially filled with mare material. The surrounding ridges and valleys, like those around Mare Imbrium, extend radially from a point within the inner basin.

Other large circular basins on the Moon, such as Mare Humorum (Sea of Moisture) and Mare Crisium (Sea of Crises), may also have been formed by giant impacts and later flooded by mare material.

Mare Imbrium, the large, round basin in this telescopic photograph, is about 750 miles in diameter. This feature appears to be the result of a giant impact that formed the bordering ring of mountains. The bright-rayed crater at lower left is Copernicus.

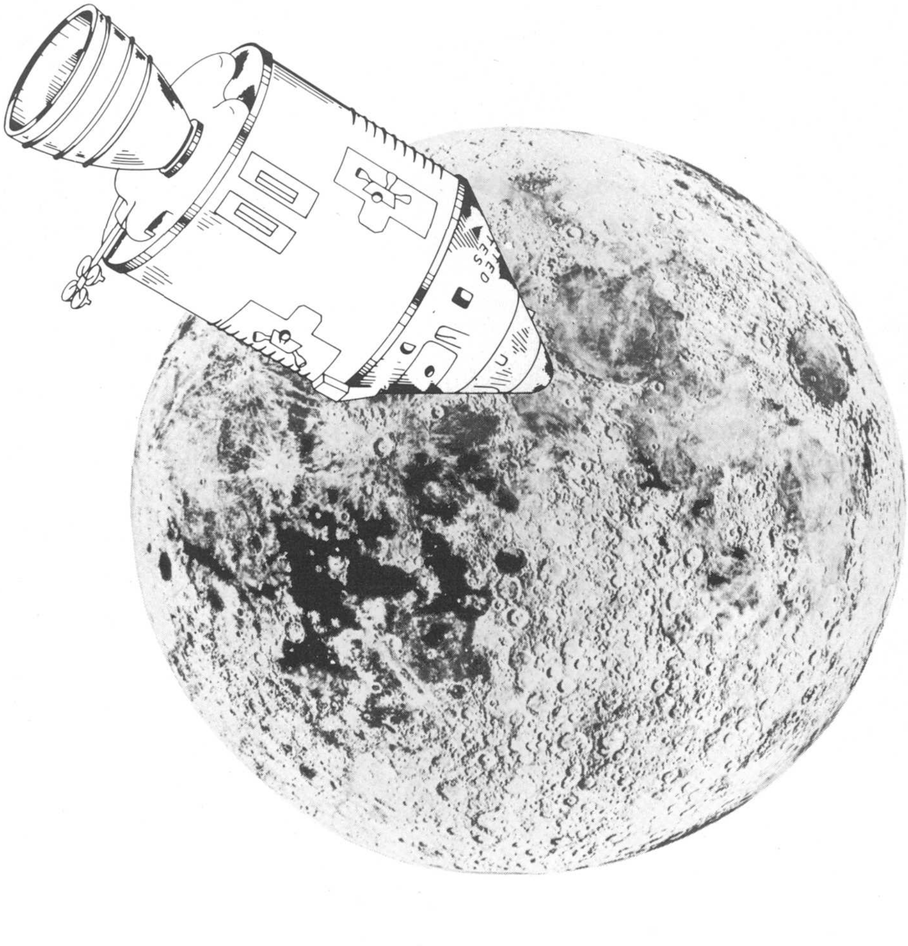
Mare Orientale basin, about 600 miles in diameter, is the result of another impact of huge proportions. The inner basin was the "bull's-eye," and the concentric troughs resulted from the collision. Radiating from the outer ring are ridges and valleys thought to be formed by a surge of material from the impact.

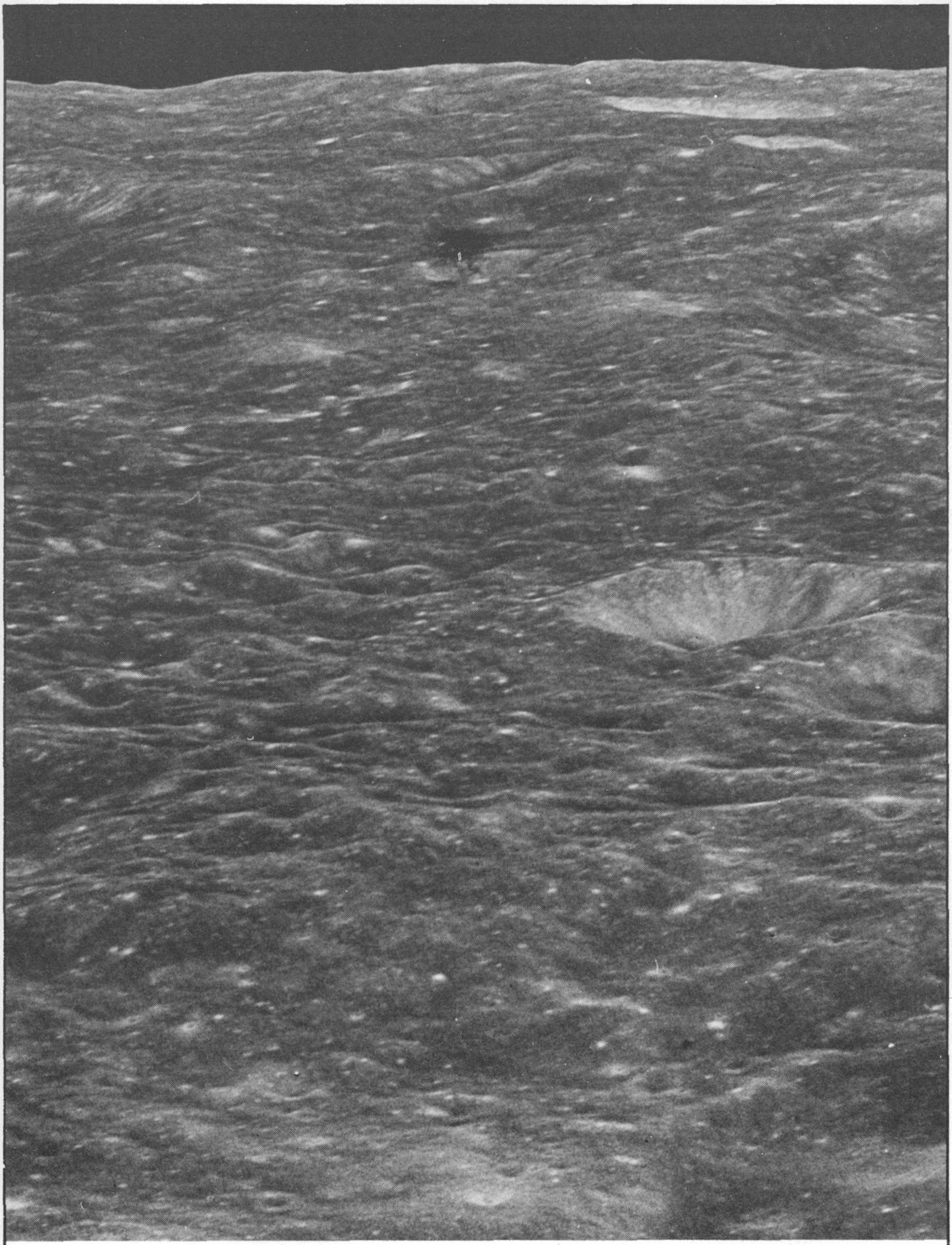


THE CLOSEST VIEW—MAN ON THE MOON

On January 10, 1968, the unmanned phase of lunar exploration carried out in the Surveyor program was climaxed by the landing of Surveyor VII on the rim of the crater Tycho. The stage was now set for manned flight—which had advanced through the Earth-orbiting Mercury, Gemini, and Apollo series—to try for landing on the Moon.

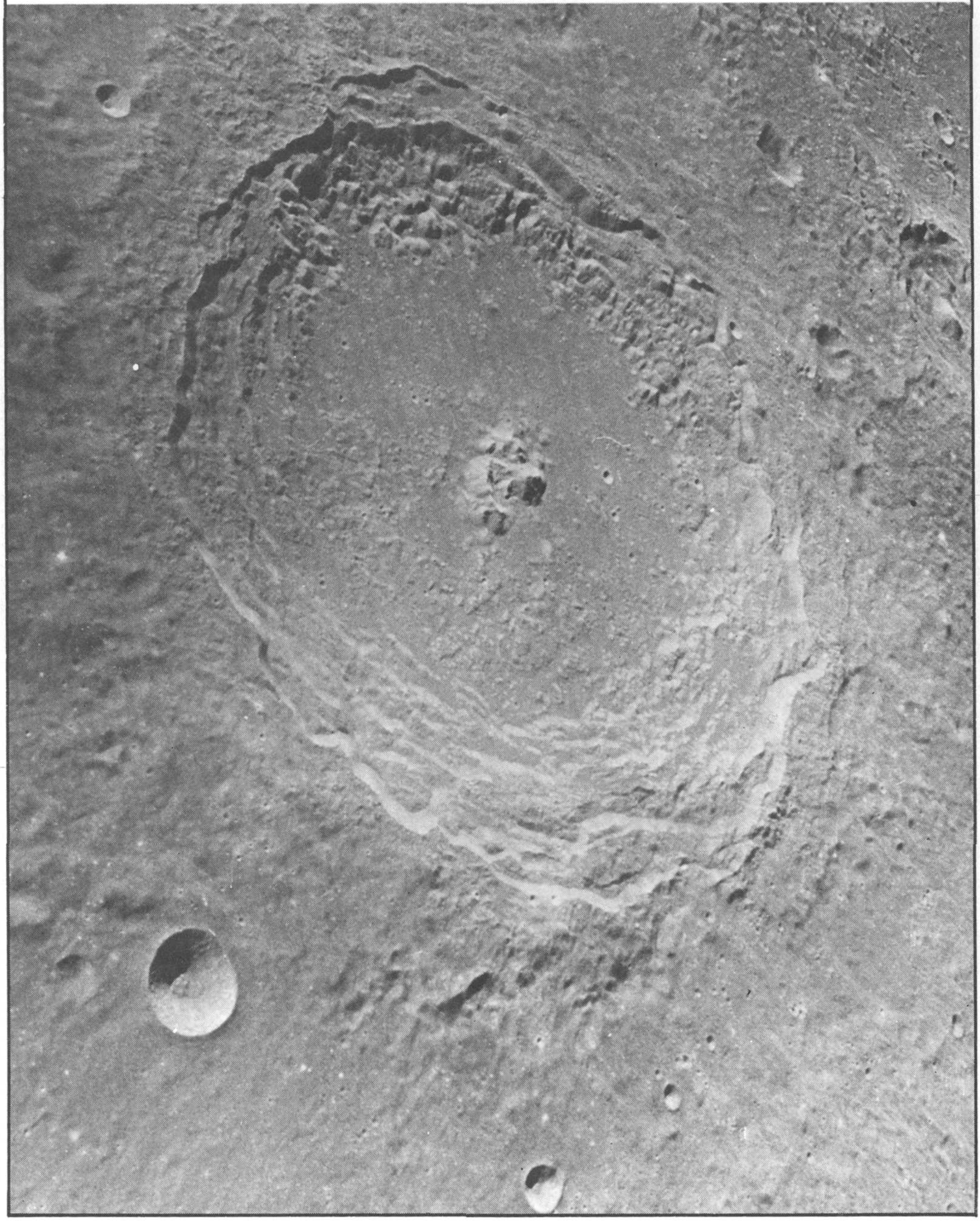
On December 21, 1968, Apollo 8 was launched on lunar trajectory and, on Christmas Eve, carried the first men into orbit around the Moon. The crew took hundreds of pictures through the spacecraft windows and described the lunar scene about 70 miles below.





The Apollo 8 crew reported the presence of many small, fresh impact craters. Such craters are common in this view.

Langrenus, 80 miles in diameter, was photographed during the Apollo 8 mission. This view shows the central peaks and the step-terraced walls.



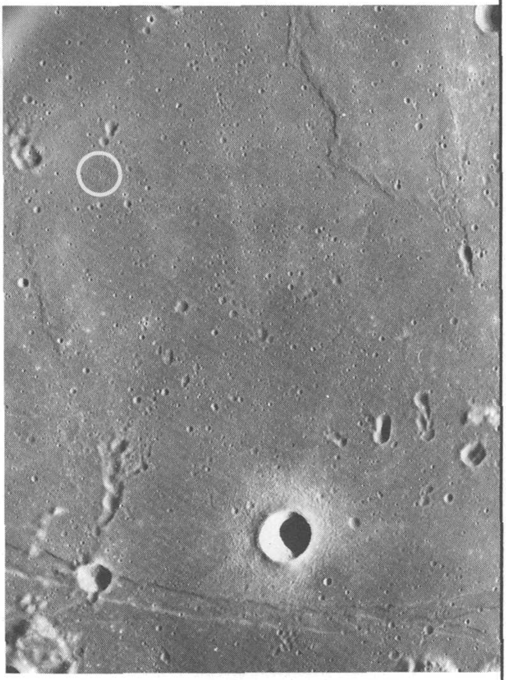
Apollo 9, in Earth orbit, tested the rendezvous, docking, and flight characteristics of the Lunar Module (LM), which was to carry men to the surface of the Moon.

On April 22, 1969, Apollo 10 tested the LM in lunar orbit, flying the LM to within 10 miles of the Moon's surface.

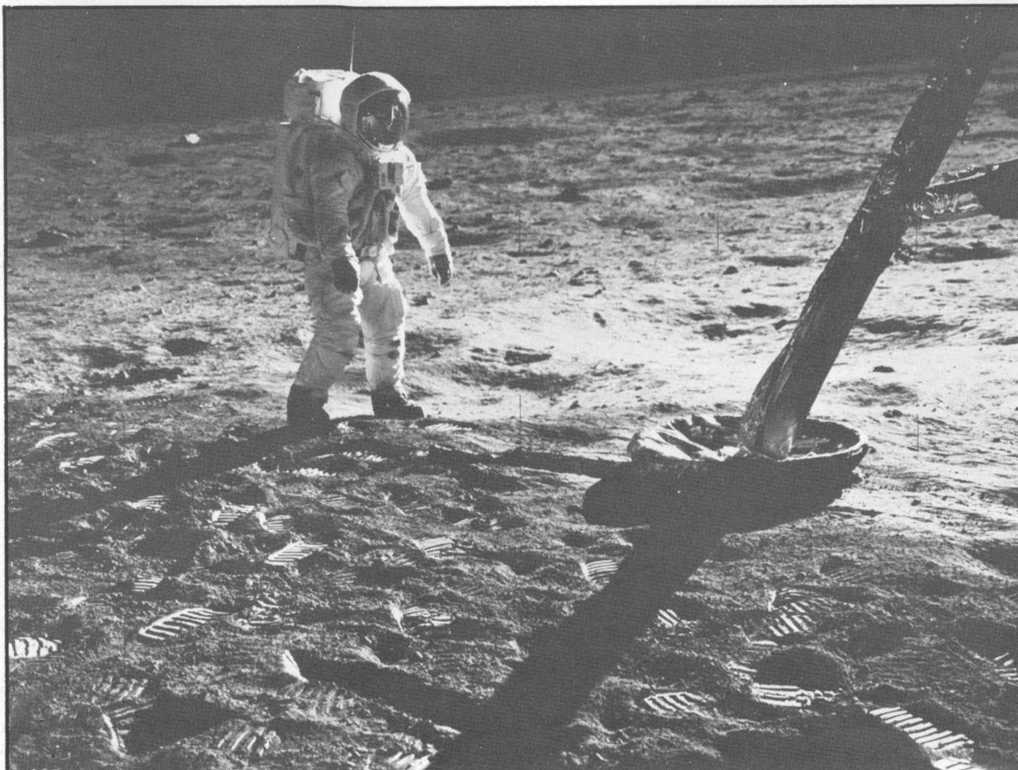
On July 16, 1969, Apollo 11 was launched; and on July 20, while millions of people around the world witnessed the event on television, the long-sought dream came true: man set foot upon the Moon.

Man has crossed the threshold of space, and the technology he has developed to reach and explore the Moon can be applied to exploration of the more distant planets. Man now has within his grasp the capability to study in greater detail the entire solar system and thereby to gain a better understanding of his home—the Earth.

Footsteps to touchdown. These two craters, photographed by Apollo 10, are Messier (on the right) and Messier A, which are near the route that Apollo 11 followed to land on the Moon.



This Apollo 10 photograph shows the landing site selected for Apollo 11 (circle). The largest crater is Moltke.



Footprints on the Sea of Tranquility. Apollo 11 astronaut "Buzz" Aldrin walks on the Moon near a footpad of Eagle.

MOON FACTS

Circumference	6,785 miles
Diameter	2,160 miles
Surface area	14,600,000 square miles
Mass	81,000 trillion tons
Gravity	1/6th that of the Earth
Mean distance (between centers) from Earth	238,857 miles
Average orbital velocity	2,287 miles per hour
Orbital distance traveled	1,500,000 miles
Period of revolution and rotation ..	27 days, 7 hr., 43 min., 11.5 sec.

Temperature variation

Lunar "noon" (Full Moon)	243° F.
Lunar "midnight" (New Moon)	−279° F.

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Various sensing devices mounted in spacecraft probe the Earth for information that will enable man to make the best use of our planet's assets.

The Geological Survey, U. S. Department of the Interior, conducts a wide-ranging program of field and laboratory research on geologic processes and environments. A new field of space research, which combines the principles and methods of the geological sciences with those of the astronomical sciences, is called "astrogeology."

The Survey has two primary programs in the field of astrogeology: to conduct basic research on the nature and geologic history of the Moon, and to undertake scientific studies in support of space exploration programs. The Survey programs are undertaken on behalf of the National Aeronautics and Space Administration (NASA).

The Survey's research in astrogeology is undertaken by a staff of scientists at its Center of Astrogeology in Flagstaff, Arizona, and selected research projects are conducted in the Survey's regional office at Menlo Park, California, and at the Geological Survey National Center in Reston, Virginia.

(From material provided by Alvin E. Dale)

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Telescopic photograph of the Moon (p. 5)—Lick Observatory, Mt. Hamilton, California. Mare Imbrium (p. 28)—Mt. Wilson Observatory, California. All other photographs—National Aeronautics and Space Administration (NASA).

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