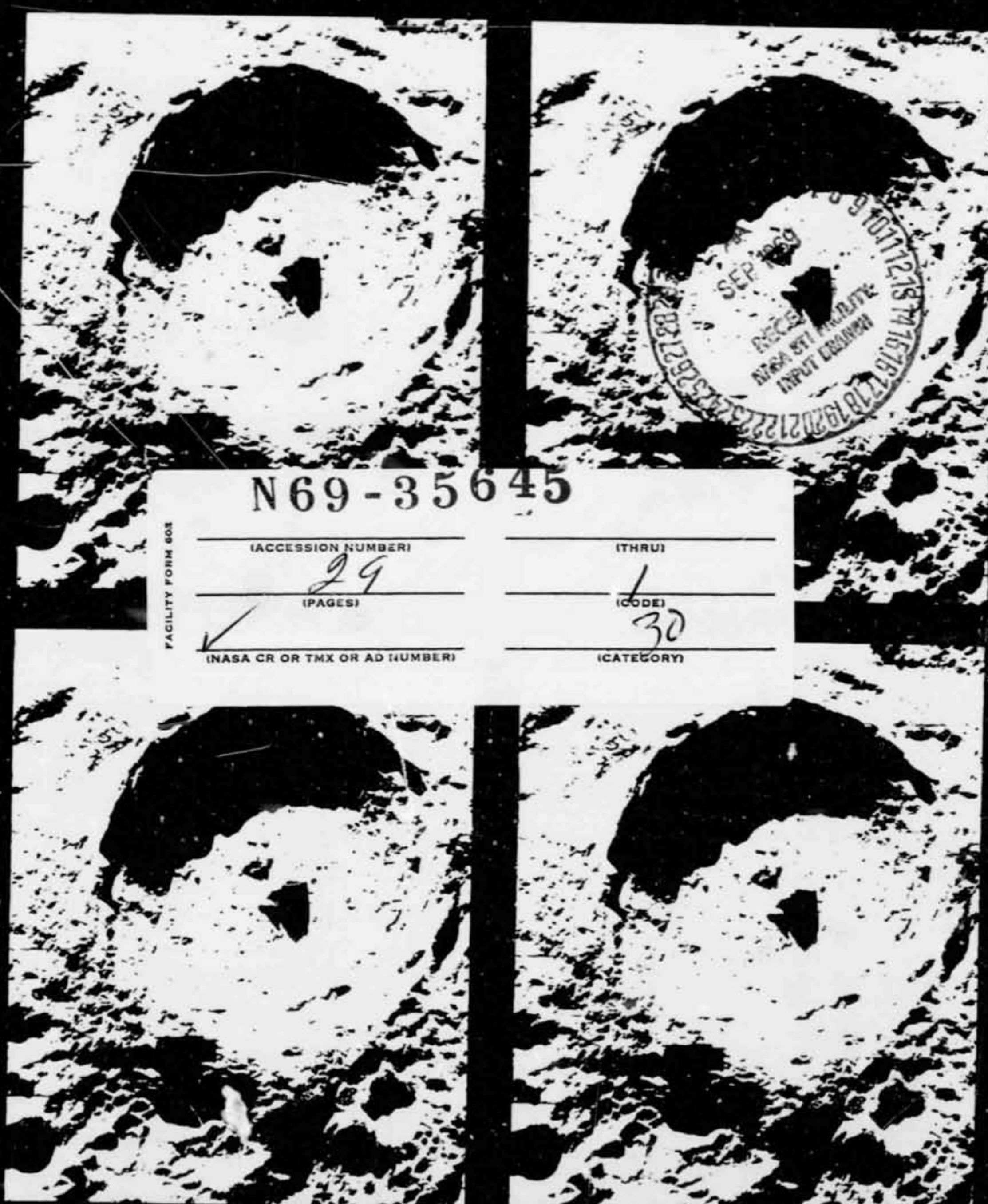
America In Space The First Decade

EXPLORING THE MOON AND PLANETS



National Aeronautics and Space Administration

America In Space: The First Decade

This is one of a series of booklets published on the occasion of the 10th Anniversary of the National Aeronautics and Space Administration. These publications are not intended to be comprehensive history, nor do they deal with all the facets of NASA's aeronautical and space activities. Rather they are overviews of some important activities, programs and events written for the layman in terms of the several science disciplines.

Each of these subjects is treated in more depth in other NASA publications and in scientific journals.

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EXPLORING THE MOON AND PLANETS

by William R. Corliss

National Aeronautics and Space Administration, Washington, D.C., 20546

Introduction

Ten years ago when the National Aeronautics and Space Administration was brought into being to explore space, it began immediately to give thought to exploring the Moon and the planets. From its beginning NASA has been interested in the scientific studies of these bodies. Since 1961 it has had the added responsibility of securing information concerning the Moon that would be needed for a manned expedition to the Moon. In the ten years of NASA's existence our knowledge of the Moon has increased immeasurably; we know the far side as well as the front. We have seen a portion of the surface of Mars from nearby. We have made measurements close to Venus. "Exploring the Moon and Planets" presents the findings made in the first ten years of the existence of NASA It is one of the avenues selected by the Agency to disseminate the knowledge that it has gained in its program in keeping with its responsibilities.

John E. Naugle
Associate Administrator for
Space Science and Applications

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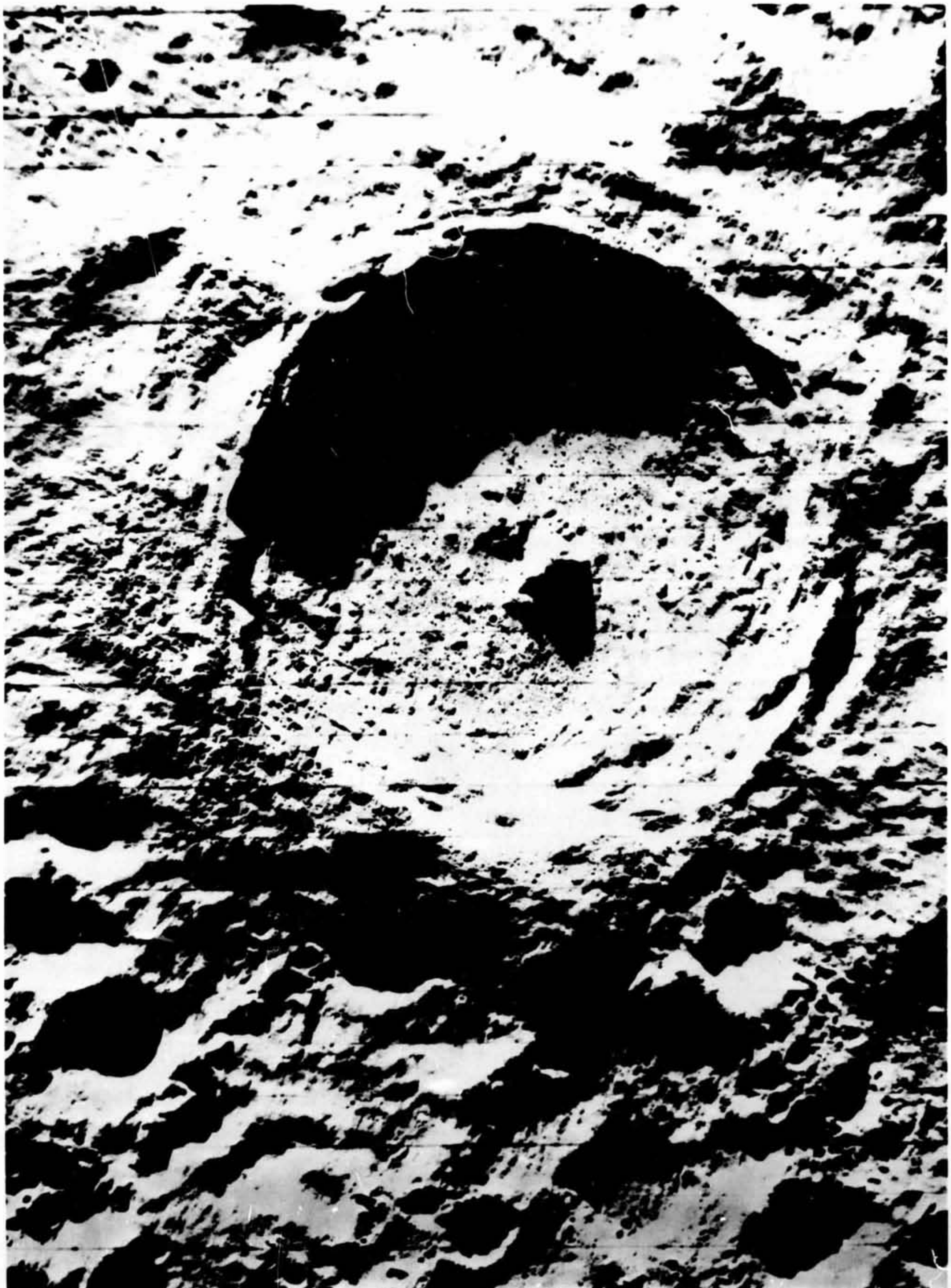


Exploring the Moon and Planets

An Earth Dweller's View

The positions of the planets at your birth fix your destiny—so said the ancient astrologers. Many people still believe this to be true. Others know for certain that sleeping in the moonlight courts lunacy.

Not content with superstitious speculations, scientists have watched and measured the motions of the Moon and planets for thousands of years. First, they used the naked eye; then, the telescope; and, more recently, spectroscopes and other modern instruments. Only a decade or so ago, astronomers were well satisfied with the apparent order they had found in the solar system. To be sure, the Earth's Moon was indecently large to be a satellite, and the axis of Uranus pointed the wrong way. But, by and large, only a few problems remained to be ironed out before the origin, evolution, and future of the Sun's little group of planets could be described with assurance.

Space probes and radar astronomy have changed all that. We know now that Mercury rotates with unconscionable rapidity; while its cloud-shrouded neighbor, Venus, turns hardly at all and the wrong way at that. Mars, which seemed an older version of Earth to scientists of 1900, has been found pock-marked with great craters. Frozen Jupiter has a magnetic field many times that of Earth and radiation belts to match. In just a decade, our comfortable view of the solar system has been shaken to its foundations. Solar system astronomy is in ferment.

The Moon Through the Telescope

The first thing man wanted to know about the Moon was where it was going to be and when. Eclipses, especially, were events of great religious concern. Even primitive man was able to discover a great deal of order in the Moon's motions. Visualize the precision of the huge circles of stone markers at Stonehenge. How many centuries did Stonehenge's builders watch the Moon and mark its progress before they discovered its lengthy eclipse cycle?

Today, we are more interested in knowing where the Moon came from and what it's made of. Surprisingly, just by watching it through the telescope we can

1 *Some lunar local hot spots. Dots indicate hot spots; shaded areas, widespread thermal anomalies.*

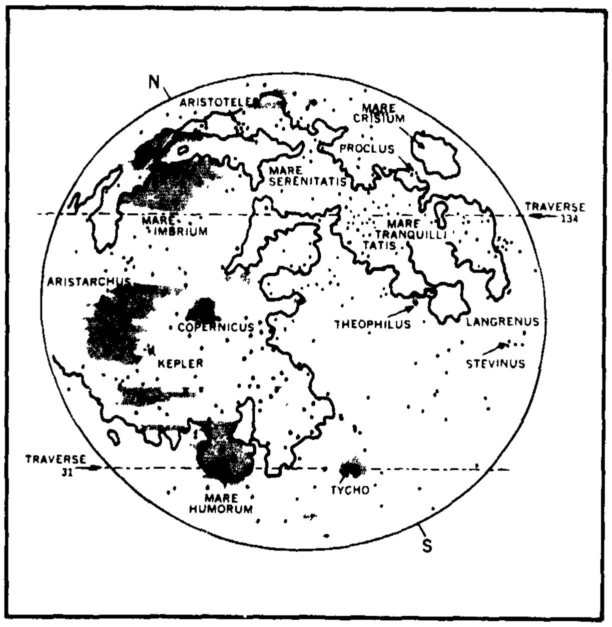
narrow down the range of possible answers. First, the Moon is big as natural satellites go—the Earth being only 80 times heavier. It is also quite close—about a quarter million miles away. Astronomers, in fact, tend to think of the Earth-Moon corporation as a double-planet. The two spheres revolve like a lop-sided dumbbell about their common center of mass, located some 3000 miles from the Earth's center toward the Moon. No other solar system planet can claim such an out-sized moon.

The Moon is so big and so close that its gravitation pulls our atmosphere, our oceans, and even the Earth's rocky mantle out of shape, although only slightly in the latter instance. The energy absorbed by the friction of these tides comes ultimately from the motion of the Earth and Moon. As a result, the Earth's day increases about 33 seconds per century and the Moon is slowing down in its orbit. As the Moon slows down, it slowly recedes from the Earth. Here is where we get some insight into the past history of the Earth-Moon system. Working the tidal friction theory backwards, scientists such as Gordon J. F. MacDonald arrive at the conclusion that the Moon would have receded to its present distance in 1.3 billion years. However, the Earth's age is apparently some 4.5 billion years, inferring that the Earth-Moon partnership may not have been created when the Earth was born.

Well, then, whence the Moon? Perhaps the Moon was once an asteroid that wandered in from the belt between Mars and Jupiter and was somehow gravitationally snared by the Earth. (One can imagine the terrestrial geologic upheavals accompanying such a union.) Or, as George H. Darwin, Charles' son, calculated around 1880: The Earth might have spun off a glob of Moon stuff eons ago when it was rotating much faster on its axis. Some believe that the Pacific Ocean basin is the scar left by this planetary fission.

Another intriguing observation: knowing the Earth's mass and the Moon's distance, astronomers can infer the Moon's mass and measure its diameter through the telescope. The average density of the Moon is only around 3.4, much less than the Earth's average of 5.5; yet it is close to the density of the lighter rock forming the Earth's crust. The advantage of the lunar probe is now obvious; it can analyze directly the composition of the surface of the Moon and see if it resembles that of the crust of the Earth.

The most obvious feature of the Moon through the telescope—even good binoculars—is its cratered surface. For the first half of this century, just about everyone believed that lunar craters were meteor craters. The Moon was supposed to be a cold, dead world "where nothing ever happened," so, the craters could not be of volcanic origin. Besides, the Earth, too, is pock-marked by huge craters. Photos



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from aircraft (and more lately satellites) have revealed many well-weathered craters right here on Earth, particularly in Canada and the Carolinas. It could be that both sets of craters were born during and after the Moon's birth pangs or its cataclysmic capture.

But is the Moon really dead? On the night of April 18, 1787, the great German-English astronomer William Herschel saw a red area near the crater Aristarchus glowing like "slowly burning charcoal thinly covered with ashes." Over the centuries, many Moon watchers have seen flashes of light and glowing red spots. Some old craters even seem to have disappeared. Despite the imperious pronouncement that the Moon was dead, over 400 "transient lunar events" have been recorded over the past five centuries. Apparently, the Moon's pulse still beats—though perhaps weakly.

Astronomers can also watch the Moon through our atmosphere's infrared window.* During the lunar eclipse of March 13, 1960, for example, Richard W. Shorthill and his associates noticed that the infrared temperatures of the floors of some of the lunar craters did not fall as rapidly as the rest of the shadowed surface. More recently, infrared maps of the Moon have revealed many hot spots. The erratic visual red spots seen by Herschel and many others since may be lava flows or some other surface manifestation of lunar volcanic activity. Nonthermal explanations also exist; areas of the Moon might glow when stimulated by Sunlight—or possibly the solar wind.

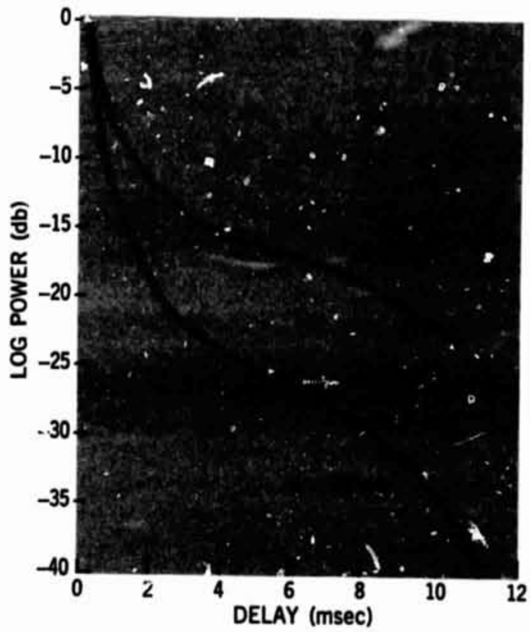
The telescope has obviously been a powerful tool in learning about the Moon. But there is a limit to what we can do with Earth-based tools. A well-equipped scientist-astronaut on the spot could best find out what is really transpiring on the Moon. First, though, there is an active lunar experiment we can carry out from Earth.

Radar Astronomy Of the Moon

The only kind of experiment we can perform on the Moon across a quarter million miles poses its questions electromagnetically. To do this, we aim a radar transmitter at the Moon, send out short pulses of radio waves, and wait for the echoes to arrive some 2½ seconds later. In radar parlance, the echo gives us the Moon's radar signature, which can be most revealing to the radar graphologist. For example, a smeared echo that is strong in the beginning and then trails off in a few microseconds reveals that the radar signal is being reflected from a rough

**Our atmosphere blocks out most radiation from space; the "windows" are open to visible, some infrared and most radio frequencies.*

2 *Radar echoes at 3.6 cm from the Moon are not as sharp as they are at 68 cm. The higher echo tail at 3.6 cm indicates that rough terrain around the aiming point is also contributing to the signal.*



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spherical surface. A perfectly smooth Moon would yield a sharp echo with no trailing edge. This is equivalent to shining a flashlight on a highly polished ball (say, a Christmas tree ornament) and seeing only a bright reflection from the center of the ball.

The first lunar radar echos were obtained just after World War II; but it was not until 1960 that radars were powerful enough to make a study of surface detail. When the Moon is illuminated with radar waves longer than 10 centimeters (4 inches) its surface appears rather smooth. 3.6 centimeter waves, however, show strong echoes from rough spots on the lunar surface. Lunar roughness, then, is small scale roughness—something like sand and gravel rather than boulder fields. However, because the echoes at long wave-lengths are not perfectly crisp and sharp, we know that some larger rubble also exists. Larger features, such as the lunar mountains, can be mapped by timing the echoes in the same way that aircraft radars see the terrain below them.

Radar makes use of another technique. When a radar wave hits the lunar surface, the strength of the echo depends upon a factor called the dielectric constant of the surface. Metals are superb reflectors; solid rock, not so good. By measuring the power in the returning echo, radar astronomers find that the Moon's surface has a dielectric constant only about half that of solid rock. In fact, lunar echoes resemble those from dry, sandy soil here on the Earth. Thus, even before the Surveyor space probes landed on the Moon, radar probing from Earth had provided a surprising amount of information about the lunar surface.

Some Hard Landings And Near Misses

The next step in the exploration of the Moon, beyond the telescope and the radar, is to go there; first by proxy with an unmanned instrument carrier and, soon, with man himself. Unmanned space probes have led the way; they are simpler, smaller, and the information they send back about the Moon is essential to any manned venture.

Summary of NASA's Lunar And Planetary Programs

Program	Number of Flights	Launch Dates	Target	Type of Missio..
Pioneer	5	58–59	Moon	Flyby
Ranger (phase 1)	5	51–62	Moon	Hard landers
Ranger (phase 2)	4	64–65	Moon	Hard landers
Lunar Orbiter	5	66–67	Moon	Orbiters
Surveyor	7	66–68	Moon	Soft landers
Apollo	–	68+	Moon	Manned landers
Mariner II	1	62	Venus	Flyby
Mariner IV	1	64	Mars	Flyby
Mariner V	1	67	Venus	Flyby

In order of marksmanship and technical sophistication required, the feasible space probe missions are: (1) a near miss or flyby; (2) a hard landing or unbraked impact; (3) a swing around the Moon, coming back toward Earth; (4) an orbit around the Moon; and (5) a soft landing. As mission difficulty increases so does the scientific potential of the probe.

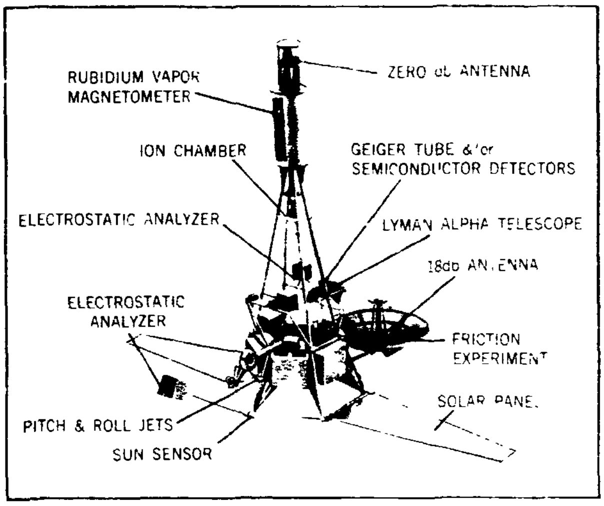
Both the United States and Russia were interested in the Moon early in their space programs. The U.S. Pioneer space probes flew toward the Moon; they were instrumented to explore space between the Earth and Moon (called cislunar space). The only Pioneer instrument that might have provided insight about the Moon itself was a magnetometer. The Pioneer that came closest to the Moon was Pioneer IV (launched March 3, 1959), which passed 37,300 miles from the Moon on its way into orbit about the Sun. Those early Pioneers contributed greatly to our understanding of the Earth's Van Allen Region and the solar wind.

Russia's Luna 1 was launched on January 2, 1959 and passed within 3728 miles of the Moon. Luna 2 scored a direct hit a few months later. A magnetometer on Luna 2 indicated that the Moon possesses a very weak magnetic field. Luna 3 did even better; launched on October 4, 1959, it was temporarily captured by the Moon's gravitational field on October 6, swung around the Moon, and headed back toward Earth, where it went into orbit. While swinging around the Moon, Luna 3 took 40 minutes of pictures on 35-mm film. When the film was automatically developed and its images relayed back to Earth, the world had the first photographs of the Moon's back side, although the pictures did not have high resolution.

The United States undertook its first lunar exploration in the Ranger Program. Originally, the first Ranger spacecraft, the Block I models, were to fly by the Moon, making measurements of micrometeoroids and radiation in the space near the Moon like the Pioneers. Toward the end of the program, Block II Rangers were to drop packages of instruments onto the lunar surface. Rangers I and II, the two Block I spacecraft, were launched in the latter half of 1961. Neither was injected successfully into a Moon-bound trajectory.

3 *Photograph of a Block I Ranger.*

4 *Picture taken by Ranger IX from 258 miles, showing the crater Alphonsus*



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During 1962, the three Rangers in Block II departed from Earth satisfactorily. But, because of launch vehicle problems, Rangers III and V missed the Moon (only by 450 miles in the case of Ranger V). Ranger IV landed on the back side of the Moon, but its instrument package was destroyed when a timer failed to fire a retrorocket.

Block III was created when President Kennedy declared that landing a man on the moon by 1970 was a national goal. The mission of Rangers VI through IX was to obtain close-up pictures of the Moon's surface during approach to a hard landing in support of the man-on-the-Moon goal.

On January 30, 1964, Ranger VI left the launch pad for the Moon. Everything looked great up to a few seconds before impact on the Moon, but no pictures arrived back at Earth. It was later discovered that the television camera had been accidentally turned on while the probe was ascending through the Earth's atmosphere. Electrical arcing had occurred, damaging the camera. The remainder of the Ranger program was outstandingly successful. Rangers VII, VIII, and IX returned over 17,000 excellent photographs of the lunar surface in 1964 and 1965.

With visual resolution a thousand times those of the best Earth-based telescopes, scientists hoped that the Ranger pictures might settle some of the lunar controversies. Details less than two feet across could be seen. But the photos could not tell what the Moon was made of, nor was obvious volcanic activity seen. What science did gain was a tremendous mass of detailed terrain information, plus a few new perplexities.

In the Ranger pictures, countless craters of all sizes dominate the lunar maria (dark areas) that look so smooth through the telescope. The smaller the crater diameter, the more there are. Most of the craters smaller than 1000 feet in diameter have smoothly rounded rims, giving them a windblown appearance, which is quite contrary to the impression given by the larger, much sharper craters seen through the telescope.

The smaller lunar craters are nonuniformly distributed. Many seem to be secondary craters occupying the bright "rays" we see around large craters through the telescope. Presumably, these swarms of secondary craters are formed by debris or ejecta thrown out from the primary crater when it was formed.

The Ranger photos show few rocks and little rubble. Numerous collapse features, such as crevasses and crater slumpings, were photographed.

Ranger IX obtained some excellent close-ups of the prominent crater Alphonsus (diameter about 50 miles) and its surroundings. Many of the transient lunar events noted by earlier observers had occurred around the crater. Do the Ranger photos sustain the view that internal thermal activity still transpires in and around it? The answer is a fairly definite yes, although Alphonsus seems no different from many other large lunar craters. It boasts a striking central peak standing incongruously in the center of the relatively flat crater floor. Detailed Ranger photos show this peak to be nearly featureless and twice as bright as its surroundings—almost as if it were covered with snow. Snow is manifestly impossible on the cloudless, airless Moon.

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But thermal activity, such as the fumaroles seen at Yellowstone, might produce mineral frosting on Alphonsus' central peak. In addition, eight subcraters on the floor of Alphonsus are surrounded by dark halos and occur squarely on long cracks (rills). The thin blankets of dark material have partially filled the rills, indicating perhaps that debris or ash might have been ejected from the craters due to subterranean activity where the lunar crust was weakened by the crack.

The Rangers also radioed back some photos of systems of wrinkle ridges, where the surface seems to have been compressed horizontally. Wrinkle ridges are generally accepted as evidence of internal activity on the Earth.

Actually, many lunar craters seem to be due to impacts of meteoroids. However, the collision of a large meteoroid might so fracture the Moon's crust that it would set off secondary volcanic activity, causing the observed lava flows and eruptions of ash. It is in this sense that the Ranger photos do not resolve the crater controversy. Craters seem to be both meteoric and volcanic in origin.

The Ranger missions have given us many more facts that will eventually result in better hypotheses. And, of course, the Rangers assured the engineers designing the Apollo manned lunar landing craft that they would be able to find large, smooth areas on the lunar surface for landings.

Surveyor's View

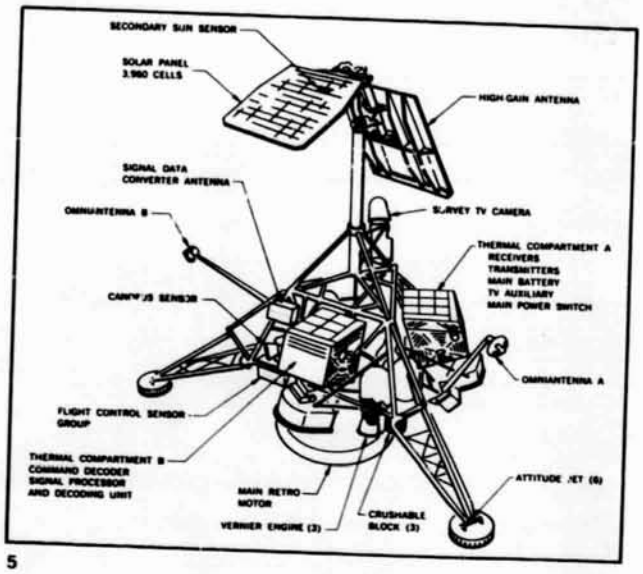
Seeing may be believing here on Earth, but we need something more revealing than photographs to understand the Moon. Just a simple lump of Moon stuff in a terrestrial laboratory would answer many of our questions, but this is still in the future. Today, we must make do with unmanned, unrecallable instrument carriers. Despite these limitations, there is a great deal we can learn over the quarter-million mile radio link between the Earth and a soft-landed lunar instrument package.

The U.S.S.R. tried to develop soft lunar landers in their Luna series. The first try at a soft lunar landing

5 *The Surveyor configuration.*

6 *General terrain seen by Surveyor I. Surveyors that landed in maria viewed similar expanses of flat, rubble-strewn lunar landscape.*

7 *Surveyor I photo showing footpad sinking into lunar surface.*



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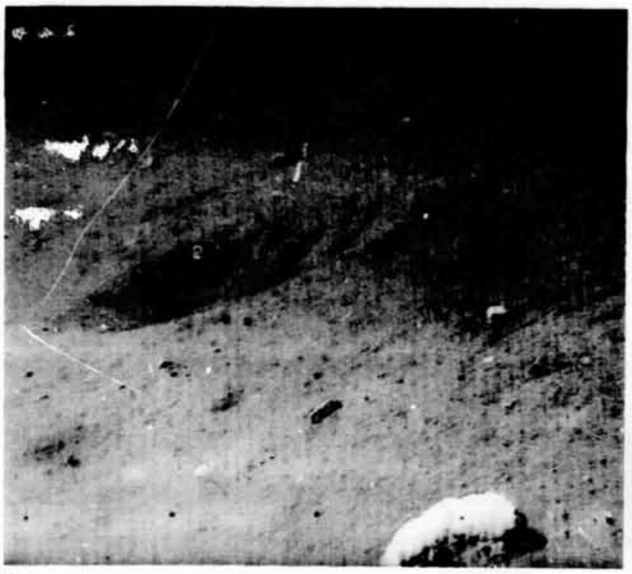
apparently was June 8, 1965, but Luna 6 missed the Moon completely. Later in 1965, two more Lunas (7 and 8) did hit the Moon, but much too hard (the retrorockets failed). Finally, on January 31, 1966, Luna 9 left a launch pad at Tyuratam and 79 hours later crashed on the lunar surface. But first it had ejected a 220-pound spherical capsule that braked itself to a soft landing on the western margin of Oceanus Procellarum. This vehicle then snapped 27 pictures with its single camera in three days.

The first major fact of the Luna 9 flight was that the spacecraft did not drown in a sea of loose Moon dust as some had predicted. The lunar surface apparently could serve as a safe landing platform for men. Luna 9's foundation was evidently not completely secure, because the spacecraft shifted twice while it was taking pictures possibly due to minor crumbling of the surface. The camera viewed an undulating landscape pockmarked with craters of various sizes and littered with fragments of material. Nearby, the lunar surface seemed to be porous, and some scientists immediately suggested that it was vesicular (frothy) lava—that is, a solid but foamy substance. The majority view inclined toward a weakly cohesive collection of fragmented material—something like sand with particles of many sizes.

Originally Surveyor's objectives were primarily scientific in character, but when the Apollo Program began to focus U.S. space efforts in 1961, the mission assumed some of Apollo's engineering tasks. While the Lunar Orbiters surveyed the lunar surface for suitable landing sites, the Surveyors soft-landed to determine the hazards of the lunar surface, particularly the characteristics of the soil, rock, or whatever the surface turned out to be. The first Surveyor left Cape Kennedy for the Moon on May 30, 1966, successfully soft landed, and transmitted over 11,000 fine photographs.

All around Surveyor I stretched a gently rolling surface studded with craters from an inch to a thousand feet in diameter. A sprinkling of fragments, large and small, covered the terrain. The spacecraft's footpads could be seen by the camera, and they had penetrated the surface an inch or so. The top part of the lunar surface, then, was definitely sandy and not solid lava. This was supported by firing a vernier engine to see if it would stir up dust. It did not.

One of the most interesting photos taken by Surveyor I shows a rock about a foot and a half long, with rounded contours and distinct porosity—much like the "bombs" that are sometimes spit out by terrestrial



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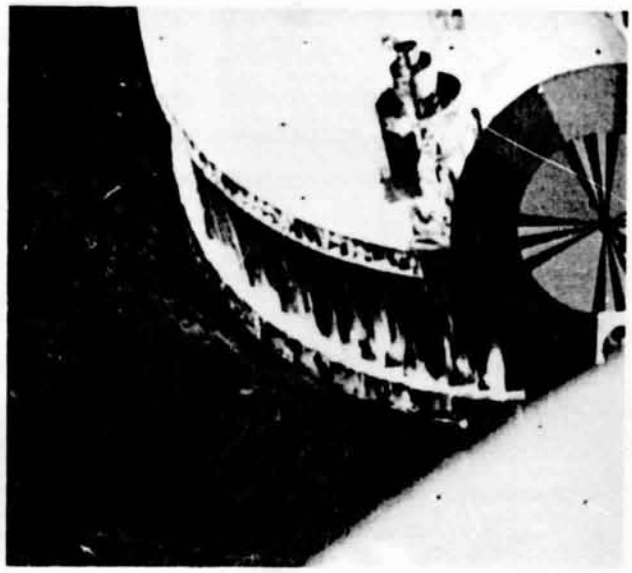

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volcanoes. Lunar geologists feel that it could also be a solidified glob of lunar material that was melted by and tossed there by the impact of a large meteoroid.

Surveyor II was launched on September 20, 1966, but mid-course difficulties prevented a soft landing, and the Moon had one more crater added to its roster. On December 24, 1966 Luna 13 soft-landed on the Moon's surface. The Russians have reported receiving pictures similar to those of Luna 9, although the overall terrain was much smoother. Luna 13 carried a probe rod to measure the density of the upper layer of lunar material. A Geiger counter measured the amount of gamma rays coming from the soil. Evidently, the soil is slightly less dense than water on the top. The inference is that the Moon's surface has about the strength of terrestrial soil.

On April 20, 1967, Surveyor III bounced to a landing 390 miles from Surveyor I. The unplanned bounces had value, for the lander's camera was able to photograph the "footprint" made by one of its footpads at the next-to-last touchdown. These photos plus data from strain gages attached to the landing gear provided data on surface strength that showed that man could land and walk safely on the Moon.

When the 6315 Surveyor III pictures were studied, they revealed that the spacecraft had landed in a shallow crater 656 feet in diameter. Panorama views of the lunar surface were impossible. Camera problems, including glare caused by the tilt of the spacecraft caused difficulties in obtaining good pictures.

Surveyor III was not as passive as its predecessors. With a remotely controlled mechanical hand (called a surface sampler) it could do something besides look. By digging four trenches and by pressing and hitting the lunar surface, the surface sampler showed the lunar soil to be much like damp sand. The walls of the trenches did not cave in, nor was the soil hard to dig. A piece of rock picked up by the sample was not crushed or broken when subjected to a pressure of 100 pounds per square inch. In other words, the Moon's surface layer was moderately cohesive and the objects that looked like rocks were rocks.

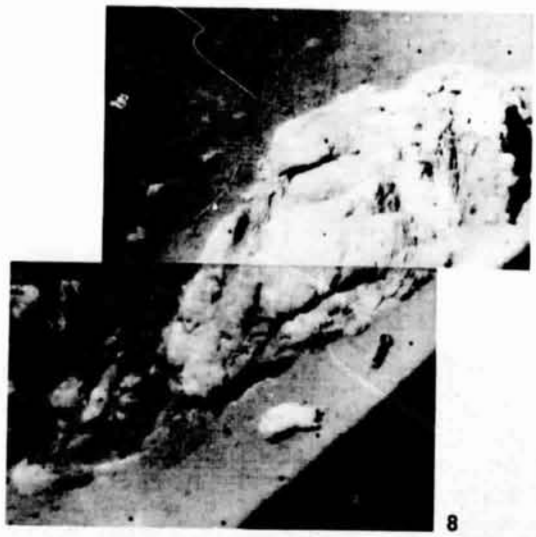
Close study of the bigger rocks scattered about Surveyor III give the impression that they are partially "submerged" in lunar material. There are no craters or depressions around them. Somehow, lunar material tends in time to fill in depressions. Yet, there is no accumulation of material around the rocks

8 *One of the lunar rocks photographed by Surveyor I. Rock may be of volcanic or meteoric origin.*

9 *Small area on lunar surface strewn with loose fragments scattered by Surveyor V as it landed in a small lunar crater on September 10, 1967.*

10 *The alpha-scattering experiment on the later Surveyors was lowered to the lunar surface by an escapement mechanism. It provided the first direct measurements of lunar composition.*

11 *Mosaic of pictures taken of surface sampler operations around the base of Surveyor VII in January 1968. Excavations were made to determine the nature of the lunar surface.*



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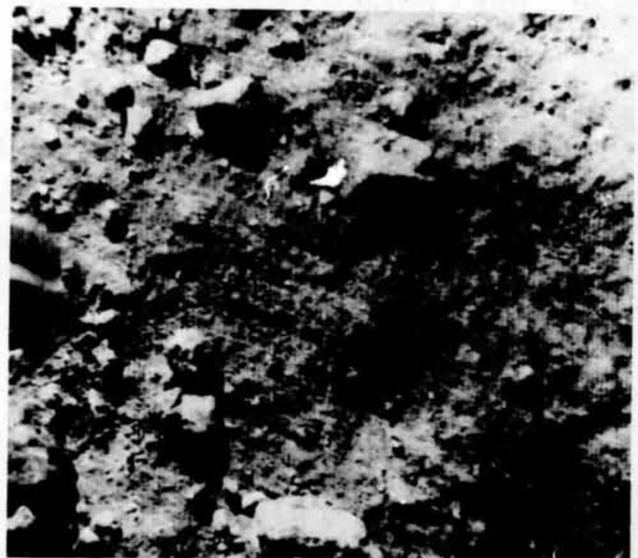

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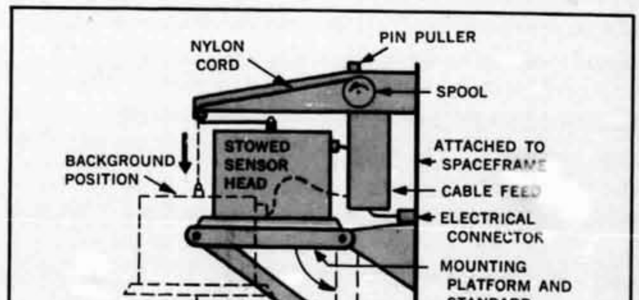

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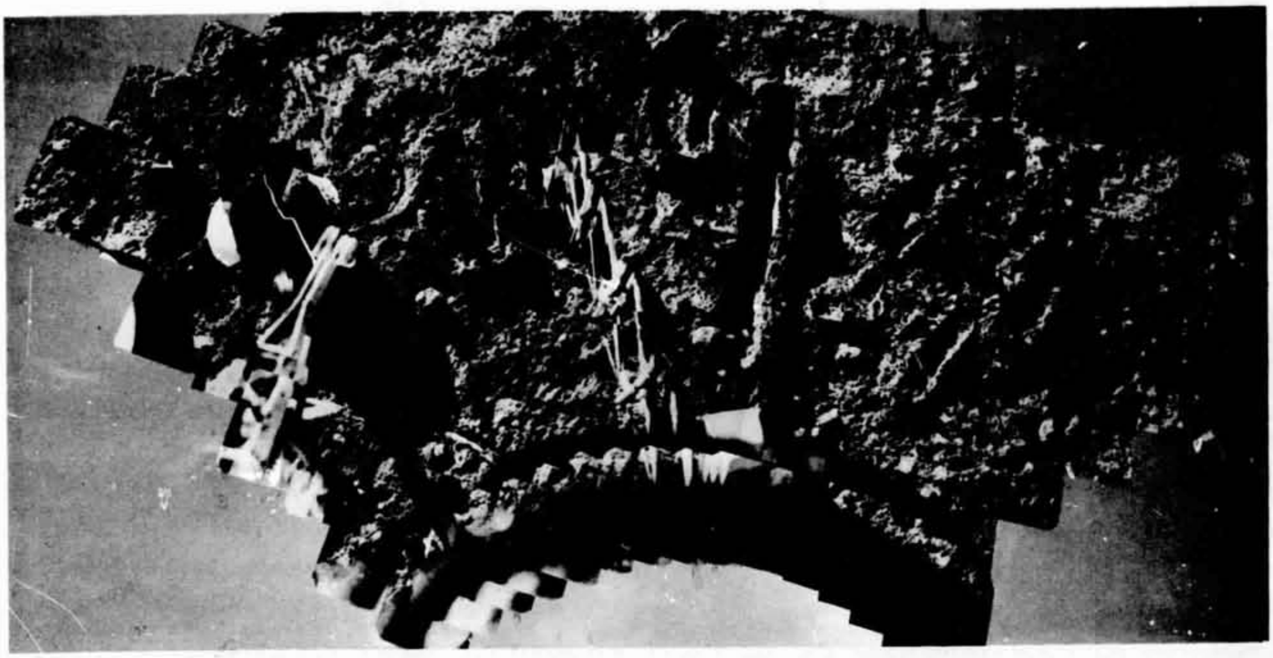
as there would be with windblown sand or snow on the Earth. Just what the nature of this gentle lunar "rain" is, no one knows.

Surveyor V, the next successful probe in the series, braked to a soft landing on the Mare Tranquillitatis on September 11, 1967. Although Surveyor V relayed over 18,000 excellent pictures with high scientific content on its first day, and more after two cold, lonely weeks in the lunar night, this spacecraft will be remembered for its alpha-scattering experiment. By shooting alpha particles (doubly ionized helium atoms) into the lunar surface material and measuring the energies of alphas that bounce back and the energies of protons created in nuclear reactions in the lunar material, man made his first chemical analysis of the Moon. Once the spacecraft had landed safely, a signal from the Earth fired two explosive "pin-pullers" that freed the sensor head of the alpha-scattering



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experiment. In a Rube Goldberg-like sequence, the sensor head swung free in the weak lunar gravitational field and was slowly lowered to the ground by an escapement mechanism. The curium-242 alpha source fired its subatomic bullets into the soil and counters measured the particles that flew back. Data from the counters were flashed back to Earth (1⅓ seconds transit time). Atoms that no number of photos could identify were catalogued. Essentially, the top layer of the lunar mare surface closely resembles terrestrial basalt, the rock underlying all oceans and continents.

A basaltic lunar surface gives scientists confidence that terrestrial geochemical processes also can be applied to the Moon. In other words, since the Earth and Moon may possess similar basaltic outer shells, the Moon may have evolved like the Earth. Although scientists are still wary of Darwin's theory about the Earth giving birth to the Moon, the apparent discovery of basalt-like material on the Moon tends to give this theory a credibility it has not had in decades.

Alpha-Scattering Experiment Analysis of the Lunar Surface at the Site of Surveyor V

ELEMENT	ATOMIC PERCENT*
Carbon	<3
Oxygen	58.0 ± 5
Sodium	<2
Magnesium	3.0 ± 3
Aluminum	6.5 ± 2
Silicon	18.5 ± 3
Atoms with atomic weight between 28 and 65	13.0 ± 3
Iron, cobalt, nickel	>3
Atoms with atomic weight above 65	<0.5

** Excluding hydrogen, helium, and lithium, which cannot be measured with this instrument.*

The success of Surveyor V was followed by that of Surveyor VI, which also settled down to a landing spot on a lunar mare. More basalt-like material was found in the new location.

With many thousands of mare pictures in their hands, two basalt measurements, and safe landing spots for astronauts assured, scientists recommended that the last Surveyor be set down in the rugged lunar highlands. Lunar Orbiter photos had demonstrated dramatic differences between the two types of lunar terrain; i.e., highland craters are fewer and some of them are fresh.

Surveyor VII landed just north of the crater Tycho in the lunar highlands on January 9, 1968. It touched down only 1.2 miles from its aiming point, setting a new record in accuracy. On the first day, Surveyor VII radioed back over 21,000 photos of the surrounding highlands. Later, the surface sampler dug several trenches and also rescued the alpha-scattering instrument, which did not descend to the surface according to plan. The sampler was able to force it down to where it could make composition analyses.

Through the telescope, Tycho seems a very young crater. Few later craters are superimposed upon it. Its rays radiate outward from the 56-mile crater, crossing many older lunar features. The Surveyor VII camera saw rocks everywhere—many more than previous Surveyors had seen on the maria. A further indication of Tycho's relatively recent formation was the fact that only a few inches of debris covered the surface around the spacecraft.

Some of the rocks photographed showed elongated spots up to a centimeter across. These may be mineral crystals. In some rocks, the spots line up in the same direction, just as crystals do in some terrestrial rocks. In other lunar rocks, the Surveyor VII camera showed two sets of elongated spots aligned in two different directions. In terrestrial rocks, this kind of structure indicates that the original rocks were altered after they solidified. Alteration or metamorphosis of rocks around Tycho could have come from the energy released during the collision or eruption that formed Tycho.

The alpha-scattering experiment on Surveyor VII made analyses of lunar highland material at three locations. The analyses showed that the material around the spacecraft contained lower percentages of the heavier elements, such as iron, than the mare materials. Neither mare nor highland materials are similar to the bulk of the meteorites picked up on the Earth's surface, inferring that meteorites probably do not originate on the Moon as some have supposed. The composition of the Moon also differs substantially from that of the solar atmosphere, indicating that the Moon, if indeed it was formed from solar material originally, has since undergone considerable chemical evolution.

Cameras In Lunar Orbit

For wide-scale, close-up mapping of the lunar surface, a lunar satellite is a must. The Rangers and Surveyors covered too small an area to give scientists a feel for the whole lunar surface. With this in mind, NASA's Jet Propulsion Laboratory (JPL), which built the Rangers, began studying picture-taking lunar satellites in 1959 as part of the Surveyor Program. Because JPL was too busy with the Rangers and the Surveyor soft landers, NASA transferred the Lunar Orbiter project to its Langley Research Center in 1962. The basic objective of Langley's Orbiter was to survey the Moon for possible Apollo landing sites. The program was extremely successful; the first three spacecraft obtained hundreds of superb photographs showing many places where astronauts could land safely. As a result of the success of the first three spacecraft, the objective of the remaining two flights was changed to that of obtaining high resolution photography of features on the entire front side of the Moon.

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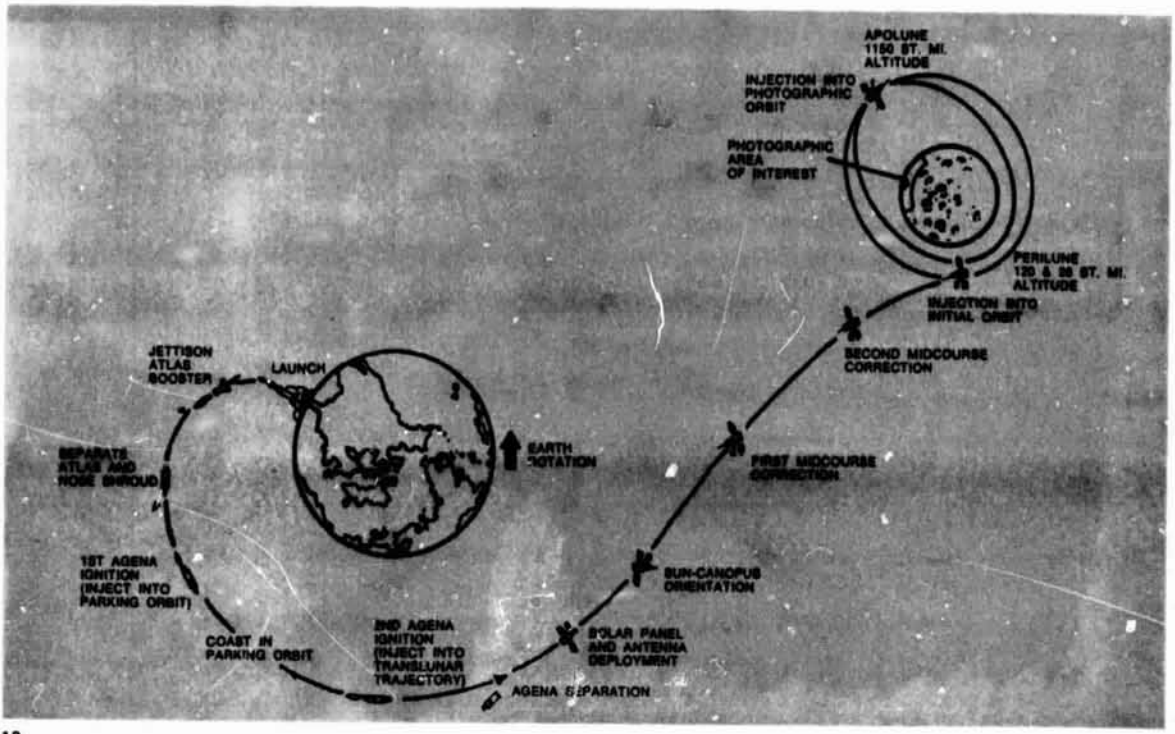
12 *Lunar Orbiter took this photo as it was approaching the crater Copernicus. Crater is about 60 miles across and two miles deep.*



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The Lunar Orbiters overwhelmed scientists with sharp, clear photographs showing hundreds of thousands of square miles of the lunar surface in great detail. It will take years to analyze this bonanza completely.

The Lunar Orbiter pictures show that the Moon's surface is peppered with craters of every size, expanding the rather narrow views of the Rangers to the whole Moon. Apart from the craters, three general types of terrain remain: level, gently rolling, and rough. Most of the level ground occupies the dark plains of the lunar maria (seas). The gently rolling and rough countryside is found in the lunar highlands, where one finds a complex system of mountain ranges and intervening basins. In general, the maria seem concentrated on the side facing Earth—a puzzle to those who believe they were created by random meteor collisions.

When the entire collection of Lunar Orbiter pictures is viewed, it becomes apparent that lunar craters are not distributed randomly over the surface. There are obvious clusters. As noted in the Ranger photos, the bright rays of large craters show many small craters; which are often elliptical and oriented in the direction of the ray, like a school of fish. Population densities of craters between 30 and 60 feet in diameter vary from a high of 1700 per square mile to a low of 250. This nonrandomness could be due either to secondary craters created by ejecta from large craters or to internal volcanic action acting along lines of weaknesses in the Moon's basic structure. Probably both classes of events have occurred and may still occur.

As Lunar Orbiters flew over the Moon's highland areas found far fewer craters—a factor of 2 to 3 less than on the maria. This fact in itself cries for explanation. An even more striking aspect of the highland areas is the presence of narrow, roughly parallel ridges and troughs, a kind of washboard effect, with 10 to 30 feet between the crests. In some places the furrows are parallel to the general contours of the land; elsewhere this is not so. Sometimes the furrow-ridge systems intersect, giving a knurled appearance to the lunar surface. Probably these furrows are the result of subsurface activity associated with the lunar equivalent of Earthly mountain building.

A fascinating discovery from the Orbiter photography has been the detection of a few of what appear to be rare fresh craters, with all the marks of having been blasted out just yesterday. These fresh craters are sharp and distinct. Furthermore, sharp angular blocks are prominent on the floors and external slopes of the craters; some blocks have been blasted clear out beyond the crater in a ray-like pattern. Lunar specialists want to know what these blocks are made of. Are they from a debris-covered layer of lava or basalt? Or, are they just dust and debris welded together by pressure?

13 *Typical flight profile for a Lunar Orbiter. The flight to the Moon takes about 90 hours*

The fact that fresh craters exist in the company of old craters infers the existence of some sort of weathering process on the Moon. Since the Moon has no weather as we know it, perhaps a steady rain of micrometeoroids knocks the fresh edges off craters in time. Only the fresh craters display angular, block-like rubble; will astronauts find similar blocks buried around old crater sites? If so, how did they get buried? And by what? Quite obviously, our closer look at the Moon raises questions we never thought of while looking through telescopes.

Some of the Moon's hot spots have been identified with fresh craters. It seems as if the impact of a meteoroid, or possibly a subsurface explosion, blasted off a layer of thermal insulation while making the crater. Fresh craters appear hotter than the surroundings because we see exposed the uninsulated, hot rock surface of the Moon. If this view is correct, we can imagine that today's hot spots will slowly be covered by dust—or whatever comprises lunar precipitation—and fade from our infrared pictures. After some millions of years, fresh craters may take on that worn, windblown look of the mare craters

The subject of lunar craters is not as far removed from Earthly concerns as we might like to think. There are enough fresh craters on the Moon to tell us that large meteoroids are still colliding with the Moon (assuming they are meteoroid craters of course). If large meteoroids collide with the Moon, they can also hit the Earth. Is Meteor Crater, in Arizona, a fresh terrestrial crater corresponding in time to those fresh craters we see on the Moon? Perhaps the Earth and Moon survived the same celestial cannonades and the Moon can give us hints about the Earth's past and future.

An intriguing feature from the Orbiter photographs: several of the pictures provide strong indications that material has flowed down the sides of some craters. There is clear evidence of what terrestrial geologists call "mass wasting"—that is, dirt, rock, or something flowing down hill. On Earth, both lava and water-saturated soil flow down hill. We might expect lava on the Moon—but water? Unlikely as it may seem, some scientists feel that ice may still survive under the insulating dust that seems to cover most of the Moon. Lunar mass wasting might occur as dust-covered ice moves glacier-like down slopes.

The Planets

Beyond the Moon, eight planets and numberless planetoids and asteroids ply their elliptical paths around the Sun. The planets, in particular, attract us. Through the telescopic eyepiece, they seem to float tantalizingly in space—so near yet so far. Though we know now that these distant worlds are inhospitable to our form of life, they are our closest neighbors in a universe that otherwise seems very empty. Perhaps they harbor life forms adapted to their extreme environments; or we may find remnants or precursors of life.

Mars has always been a favorite target of the astronomer's telescopes. Rich surface detail swims frustratingly in and out of the observer's ken. Some astronomers see a Martian surface covered with a gridwork of artificial-looking lines; others see nothing or a few smudges at best. Most agree, however, that a peculiar wave of darkening sweeps toward the equator following the shrinking of the polar caps in the Martian springs. Clouds are also observed, indicating the presence of an atmosphere. In fact, Mars looked so obviously inhabitable to early observers, especially Boston's Percival Lowell, that they scarcely doubted that it was inhabited. Modern telescopic studies reveal a much less inviting planet—a frigid spheroid where temperatures at the equator barely get above freezing during the hottest summers, and a thin atmosphere, mostly carbon dioxide, only one-fortieth the pressure at the Earth's surface.

Mars is a little too far away for today's radar to be of much use in probing its surface. It is the planet Venus that yields to radar interrogation. This is fortunate because Venus is so shrouded by clouds so heavy that astronomers never catch even fleeting glimpses of anything below. By choosing the proper frequency, radio pulses can be reflected directly from Venus' solid surface. Venus also emits radio waves that help us diagnose its atmospheric structure and temperature; however, these radiations are subject to wildly varying interpretations.

Beneath all the clouds, Venus is about the size of the Earth, but since we cannot see the surface, we cannot guess its topography nor even deduce from visual data alone how fast it rotates on its axis. The Irish planetologist, Patrick Moore, once counted all the guesses of the rotational period of Venus made from 1666 to 1961 and came up with 85, ranging from about 22 hours to 225 days.

Radar offers a way to determine the rate of rotation of a planet even if the surface cannot be seen. If a pulsed radar signal of a given frequency is transmitted toward a planet, the echo will be spread out both in time and in frequency. The first part of the echo was reflected back from the nearest part of the planet and the tail of the echo from more distant parts of the planet. The spread in frequency is a Doppler effect produced by the relative motions of the planet and the Earth, including the rotation of the planet. If, for a given portion of the tail of the echo, the spread in frequency of the echo is plotted for various positions of the planet in its orbit, both the direction and rate of rotation of the planet can be calculated.

The first radar contacts with Venus were made in 1961. These echoes were too weak to determine the planet's rotation. More powerful radar systems were used during subsequent years By watching the shape of the echo signal, radar astronomers decided that Venus rotates on its axis only once every 240 to 250 days and that it rotates the wrong way; that is, its rotation is retrograde, opposite to the rotations of all the other planets. The exact rate of rotation has been determined by another use of radar. Today's radar is good enough to distinguish rough spots on the planet's disk. It is assumed that these rough spots are true surface features, such as mountains, and not atmospheric phenomena. By watching the movement of these features over long periods of time, the rate of rotation of Venus is known to within an hour or so.

* *A micron is one millionth of a meter.*

The temperature of Venus' unseen surface is also a subject of controversy. The temperature of a planet can be deduced from the electromagnetic radiation it emits. In the case of Mars, surface temperature is easy to measure because we can look directly at the surface with an infrared detector. The temperature of the invisible surface of Venus can be inferred in two ways: (1) by direct measurement of surface radiation in the microwave region of the spectrum which may pass through the cloud cover unaltered; and (2) by measuring the temperature of the top of the cloud layer and making assumptions about how temperatures vary below. The first supposed temperature measurements of Venus' surface were made in 1924 in the 8-13 micron* infrared band which represents a spectral window in the Earth's atmosphere. The result was a chilly –28°F. But the clouds of Venus are apparently not transparent in the infrared, and the –28°F turned out to be only the temperature of the atmosphere far above the surface. When temperature measurements were made in the microwave region in 1956, a startling 8[illegible]0°F was measured. More microwave measurements confirmed a hot rather than cold Venus. Visions of a life-sustaining planet vanished as scientists pictured a baked surface, possibly spotted with lakes of liquid metal.

Venus did not stay hot for long. In thick atmosphere continuously stirred and activated by the Sun, nonthermal radiation is quite possible in the microwave portion of the radio spectrum; glow discharges and similar electrical activity might radiate microwaves that would make Venus appear hotter than it is. Some experimenters measuring Venus' radio emissions in 1966 estimated that 30% of the radio energy they received was probably nonthermal. This viewpoint brought the surface temperatures of Venus down so far that seas of ordinary water and even polar ice could exist. Today, however, most observers of Venus feel that nonthermal microwave radiation is negligible. The temperature question is still not settled.

Flying By Venus

Why fly by Venus instead of going straight in through its atmosphere for a hard or soft landing? Surveyor-type soft landings have been out of the question until recently because operational booster rockets were not

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14 *Mariner II, a Venus probe.*

large enough to propel a heavy soft lander to Venus. Hard landings are possible, but the high temperatures create a big question mark.

During a flyby, the space probe spends hours in the vicinity of the planet. During flight, mission controllers on Earth fire the probe's midcourse motor by remote control so that its trajectory takes the spacecraft around back of the planet. In this way, radio signals from its transmitters are temporarily cut off (occulted) by the solid planet and its atmospheric layer. By measuring how the transmitter's radio waves interact with the atmosphere, scientists can infer the atmosphere's density, height, and degree of ionization. Magnetometers and radiation detectors on a flyby probe can look for a magnetosphere and radiation belts. Further, the planet's disk can be scanned by radio and optical instruments. The cloud cover of Venus prevents visual surface photography, but microwave and infrared pictures of the planet can tell us something about its atmosphere—much more than we can learn with the same instruments from the Earth tens of millions of miles away.

The U.S. interplanetary program has resided at the Jet Propulsion Laboratory in Pasadena ever since NASA assumed responsibility for nonmilitary space activities in 1958. The JPL planetary probe program was called Mariner. Early plans called for launching a probe to Venus and another to Mars in the 1962-1964 period when both planets would be in favorable positions relative to the Earth. The first good Venus firing window extended 56 days between July and September 1962. JPL prepared two probes, based to some degree on its Ranger technology. The first, Mariner I, was launched July 22, 1962, but had to be destroyed by the Cape Kennedy safety officer when it veered off course. Mariner II was successfully launched toward Venus on August 27, 1962. 109 days later, and 36,000,000 miles from the Earth, Mariner II passed within 21,598 miles of Venus.

Mariner II weighed only 447 pounds, including a rocket for midcourse corrections, a power supply, controls, transmitter, and so on. It also carried a microwave radiometer,* an infrared radiometer, a

** A radiometer measures the intensity of electromagnetic radiation within a narrow bandwidth.*

15 *The trajectory of Mariner V. (See page 22 for details of the encounter with Venus.)*

magnetometer, radiation counters, a micrometeoroid detector, and a solar wind detector for measurements of interplanetary space on its way to Venus.

The magnetometer on Mariner II found that the magnetic field of Venus was zero or at most very small. Neither were any untoward concentrations of radiation and solar plasma discovered. And Venus did not seem to be surrounded by a micrometeorite or dust cloud like the Earth.

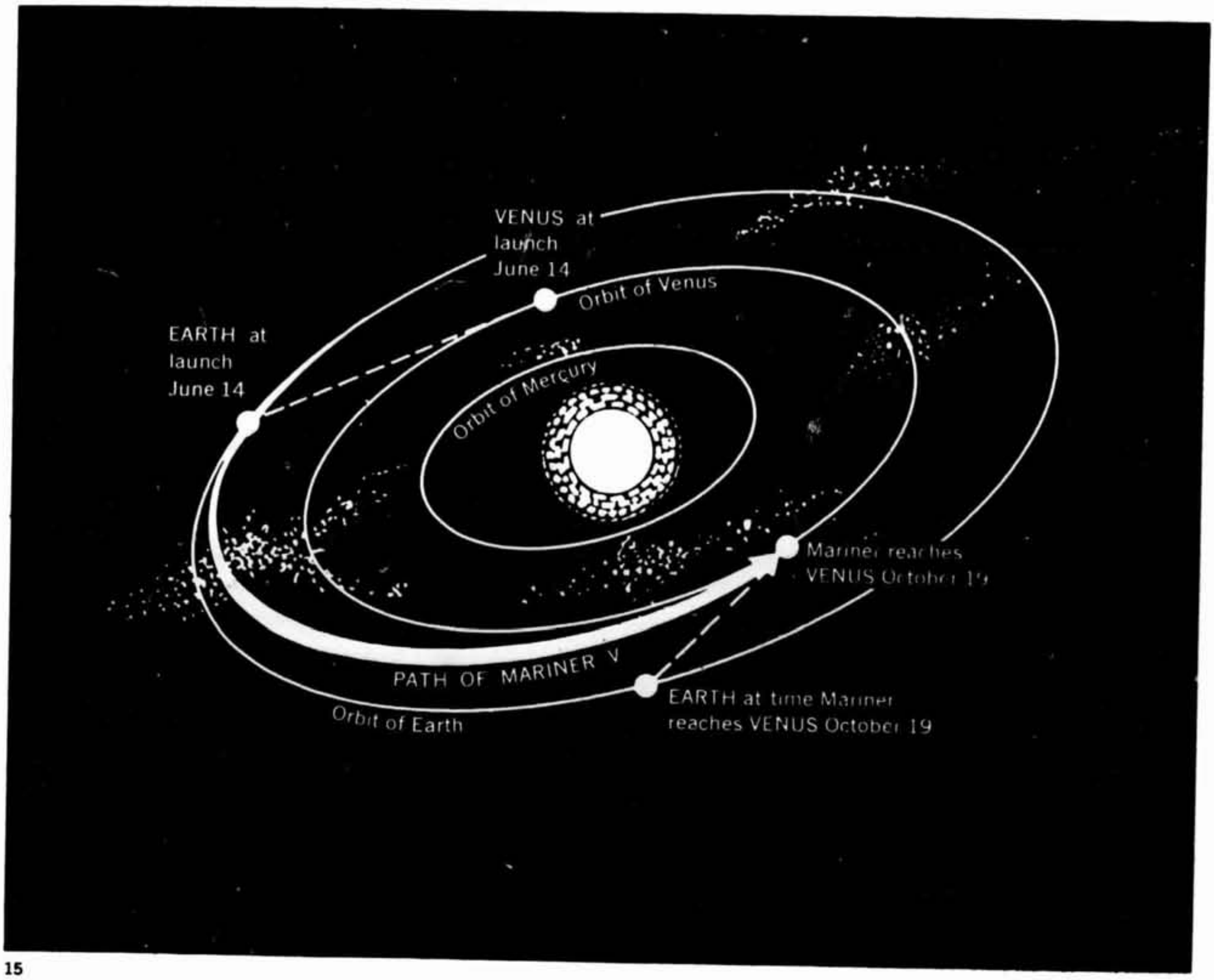
The nearness of Mariner II to Venus allowed its two radiometers to scan the disk of Venus, covering both the night and day areas. As the radiometer's field of view moved toward the edge of the planet, it saw less and less planet and more and more atmosphere. The atmospheric edge of the planetary disk is called its "limb." Thus, Mariner II radiometers could measure the fine structure of the planetary disk, something impossible for Earth-based radiometers.

The microwave radiometer gave scientists their first close-up temperature readings. Eighteen readings were made at both 13.5 and 19 millimeters as the radiometer scanned the planet. According to the telemetry data, the surface of Venus was extremely hot—about 800°F, assuming, of course, no nonthermal radiation. As the radiometer scanned close to the edges of the planet, limb darkening was noticeable. This infers that the microwave radiation came mainly from the planet's surface rather than its atmosphere. (Limb brightening would have inferred the reverse situation.) Moreover, little change in temperature was noted as the scan crossed the dividing line (the so-called terminator) between dark and sunlit sides. The conclusion drawn from this was that strong convection within the atmosphere of Venus equalized temperatures between day and night sides.

Slight limb darkening was observed by the infrared radiometer, which measured radiation at 8.4 and 10.4 microns. Since carbon dioxide absorbs infrared radiation in the 10 micron region, scientists interpreted this result as indicating a small amount of carbon dioxide above the tops of the thick clouds of Venus. In summary, Mariner II results supported the hot Venus viewpoint.

Venus was untroubled by snooping probes from Earth for nearly five years. Then, within two days in October 1967, two probes flew past, carrying different complements of instruments. One was Mariner V (Mariners III and IV were Mars probes); the other was Venus 4 (Venera 4), a spacecraft launched by the U.S.S.R.

Venus 4 arrived a day before Mariner V. It carried a magnetometer that detected no measurable field in the neighborhood of Venus, a result that conflicted with Mariner V data. The primary contribution of the Soviet experiment was in the direct measurement of atmospheric temperature, pressure, and composition during the hour and a half descent of its parachute



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instrument capsule through about 15 miles of atmosphere.

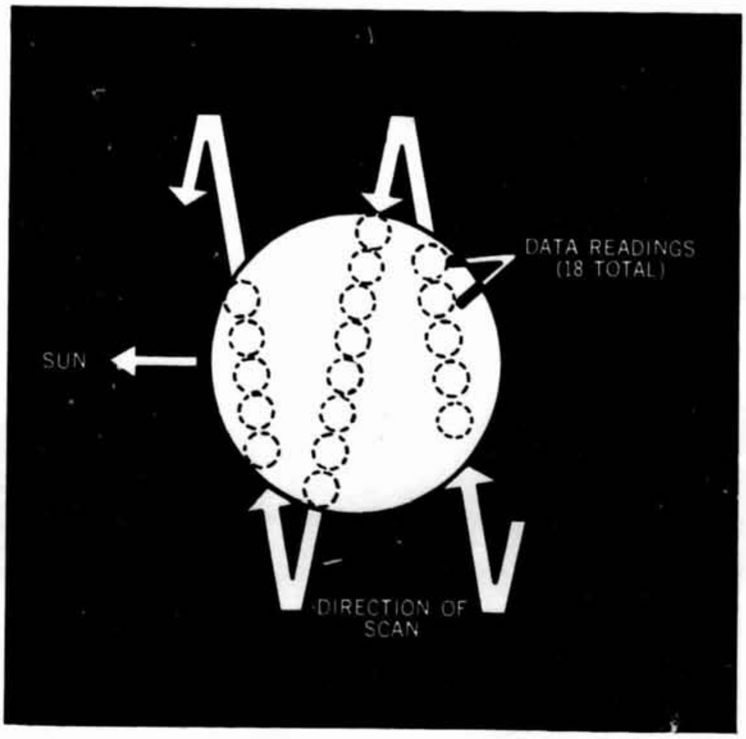
On October 19, 1967, Mariner V flew past Venus some 6300 miles from the planet's center. It carried a solar wind detector, radiation counters, an ultraviolet photometer, and two radio occultation experiments. The experiments of Mariner V were basically different from those of Venus 4, although we should expect agreement where the phenomena measured overlap. While the results do not all concur exactly they are generally not contradictory.

In summary, Mariner V, like Venus 4, found a hot planet with a thick atmosphere—mostly carbon dioxide (about 80%). It found an ionosphere, an induced magnetosphere, a "plasmapause," and a "superrefractive" atmosphere. Scientists are still analyzing the immense quantity of data telemetered back by Mariner V, and conclusions must be considered tentative. The Mariner V picture is drawn in terms of the electromagnetic effects observed from outside the Venusian atmosphere, while the Soviets made direct measurements of chemical and thermodynamic quantities in the atmosphere down to or near the surface. It is not really surprising that two rather different pictures are seen viewed through such different sets of instruments.

According to Mariner V, an intrinsic magnetic field of Venus exists but seems to be a thousand times smaller than the Earth's. Even with only a small magnetic

16 *The scanning platform on Mariner II made three passes at the disk of Venus with microwave and infrared radiometers.*

17 *Venus 4 measured pressure and temperature during its descent through the atmosphere of Venus.*



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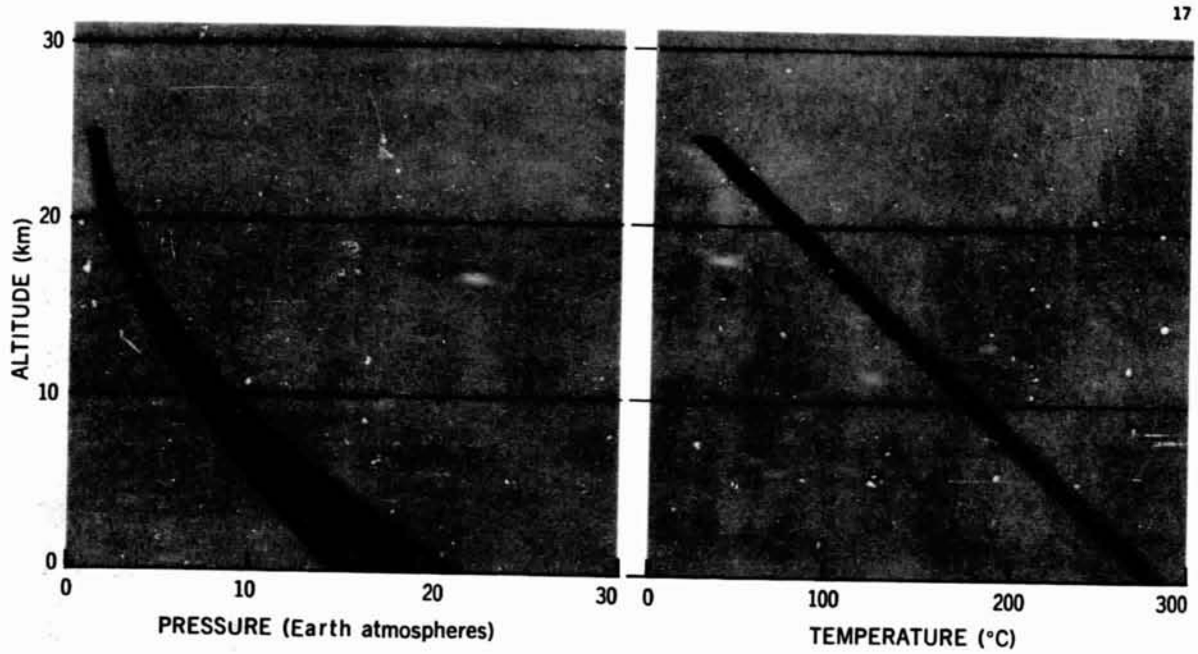
field, the solar wind seems to flow around Venus. The deflecting prow of Venus is its newly discovered, dense ionosphere. The outer surface of this prow is termed a plasmapause to distinguish it from the Earth's magnetopause, which deflects the solar wind for our planet. The plasma in the ionosphere inside the plasmapause is so good an electrical conductor that magnetic fields cannot penetrate it in either direction. It therefore traps internally generated lines of force and excludes those in interplanetary space.

The superrefractive atmosphere of Venus is bizarre. Venus' atmosphere is so thick that electromagnetic waves entering it from outside at certain angles are apparently trapped and cannot leave again, much as some terrestrial radio waves are trapped between the Earth's surface and ionosphere. The full physical implications of this radiation trap are not known as yet, although we can surmise that the horizon would seem to curve up to anyone standing on the surface of Venus.

There is no accepted view of Venus. The space probe data are too new. Add its retrograde rotation and we have a Venus that a 1958 scientist would have thought unlikely—as improbable, say, as a Mars pockmarked with craters like the Moon.

Where Are The Canals?

"The Planet Mars, a Second Earth" was the title of a book written by Jakob Schmick, a German scientist, as the Nineteenth Century drew to a close. The title reflects the thought of that era: Mars was assuredly an abode of life. When the American astronomer



Percival Lowell began publishing popular accounts of his studies of the Martian canals ("Mars and Its Canals," 1900), he merely reinforced current opinion. Many top astronomers, however, could not see any canals at all, much less the intricate, intelligently organized network that Lowell drew. Slowly, the Martian canals and the expectation of finding life on Mars faded into the background of World War I and other urgent matters. But, half a century later, when the first space probe was launched toward Mars bearing a camera, keen anticipation was felt by the pro-life and anti-life schools and those of the pro-canal and anti-canal persuasions. These controversies are still deeply ingrained in the fabric of today's speculations about Mars.

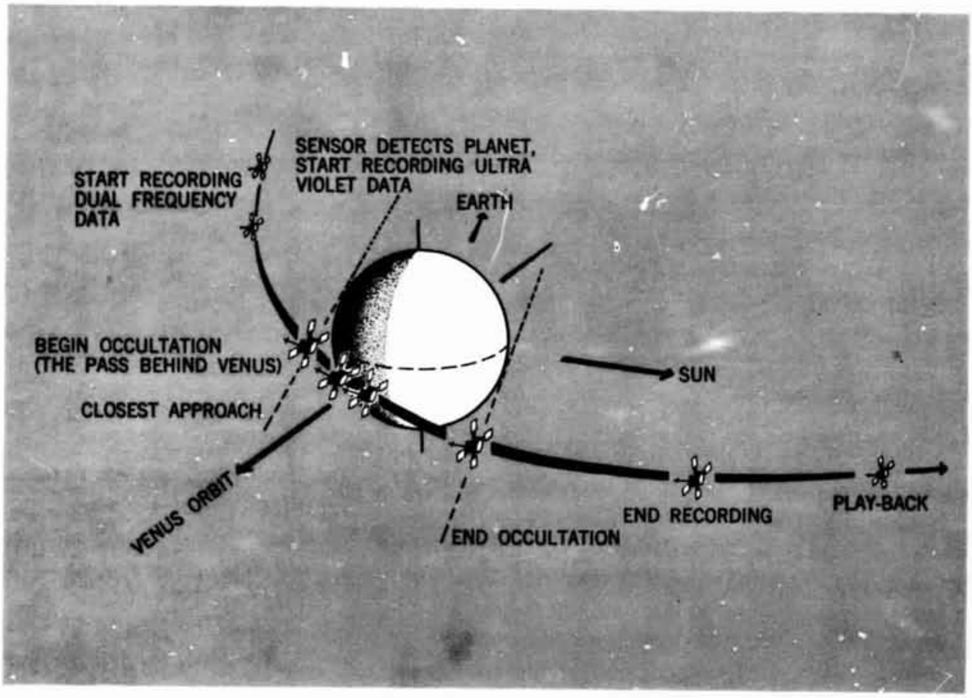
Mariner IV has been the only successful Mars probe, as contrasted with three for Venus. The innate perversity of machines seems to have been the problem rather than lack of trying. Mariner III, for example, was launched toward Mars on November 5, 1964, but the spacecraft's protective shroud could not be blown off after launch. Russia has made several tries, but only one, Zond 2, launched November 30, 1964, has been officially announced. Zond 2 failed to return any data on Mars.

The payload on Mariner IV was much like that of Mariner V, the Venus probe. The major difference was the addition of a television camera on the scanning platform. Close-up pictures were the primary goal; but radiation detectors, a magnetometer, a solar wind detector, and a micrometeoroid detector were also aboard. As the spacecraft passed behind Mars, occultation of its telemetry transmitter signal was observed on Earth, yielding information on the planet's atmosphere and ionosphere.

Mariner IV encountered Mars on July 15, 1965, after a flight of 307 days. The probe came within

18 *A typical planetary encounter,*
Mariner V flew past Venus on October 19, 1967, 127 days after launch. As it passed behind the planet, the probe's radio signals were modified in their passage through the planet's thick atmosphere. These changes permitted scientists to deduce the nature of the atmosphere and ionosphere of Venus.

19 *Mariner IV being prepared for a 350 million mile space voyage to the vicinity of Mars.*



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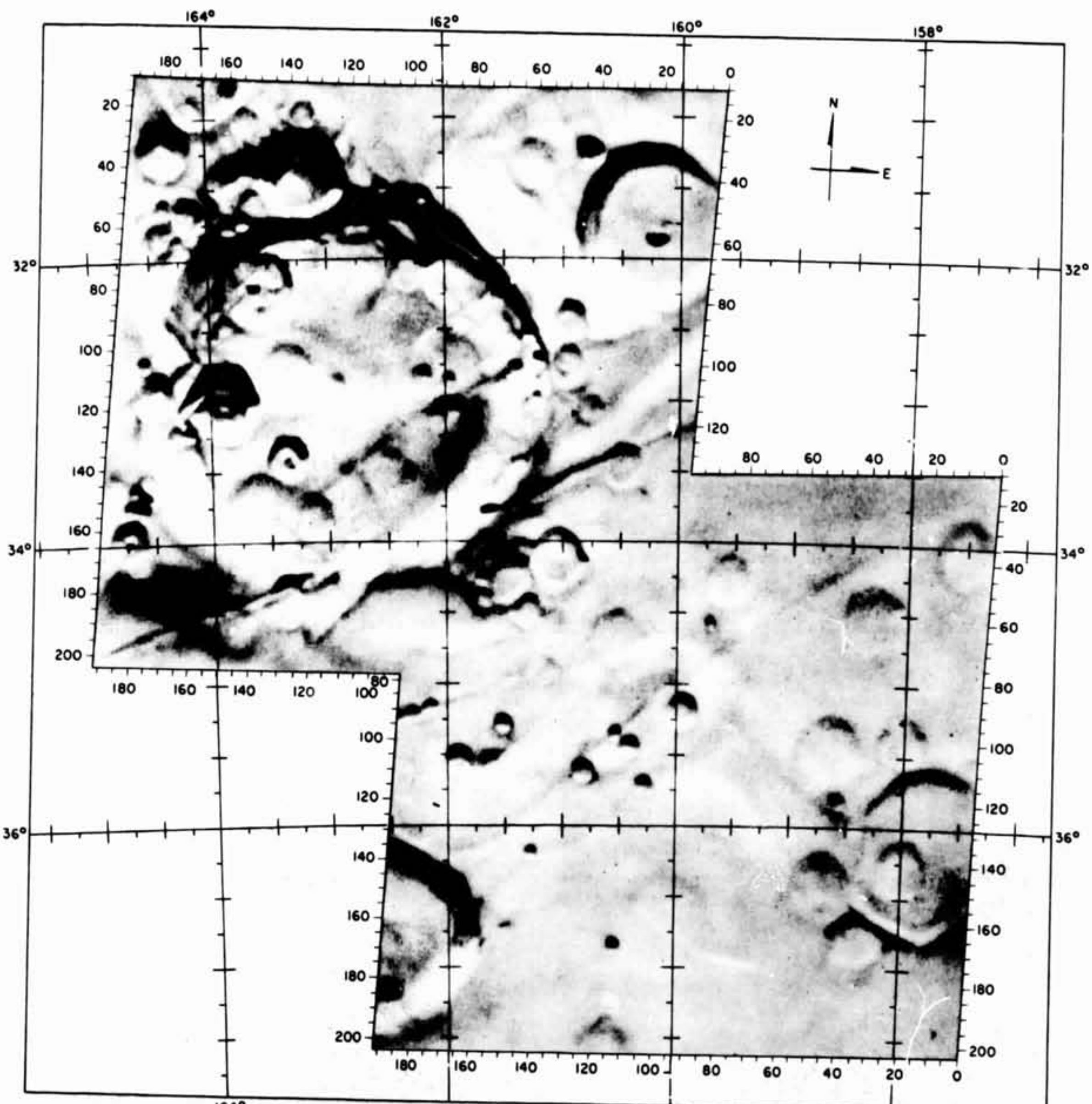
6200 miles of the planet and transmitted its findings back to Earth, by that time some 135,000,000 miles away.

The close-up photos of Mars looked as if they might have come from a Lunar Orbiter. They were fuzzier, to be sure, but the terrain surveyed strongly resembled that of the Moon. A few scientists, such as Ernst Opik and Clyde Tombaugh, had predicted a heavily cratered Mars as early as 1950; but most of the scientific world was taken by suprise. The 21 Mariner IV pictures clearly showed about 100 craters along the long narrow strip of the planet it surveyed. The craters seem remarkably Moon-like; some even have that peculiar little mountain in the center of the crater. From the small sample taken, Mars may have 10,000 craters with diameters between 3 and 75 miles. The Martian surface appears very old. The rate of weathering can be guessed by studying the craters, but estimates vary widely. Weathering is certainly faster than on the airless Moon, but undoubtedly much slower than on Earth, where most craters were all but obliterated by erosion long ago.

The big questions, of course, are: Where are those canals and are there any signs of life?



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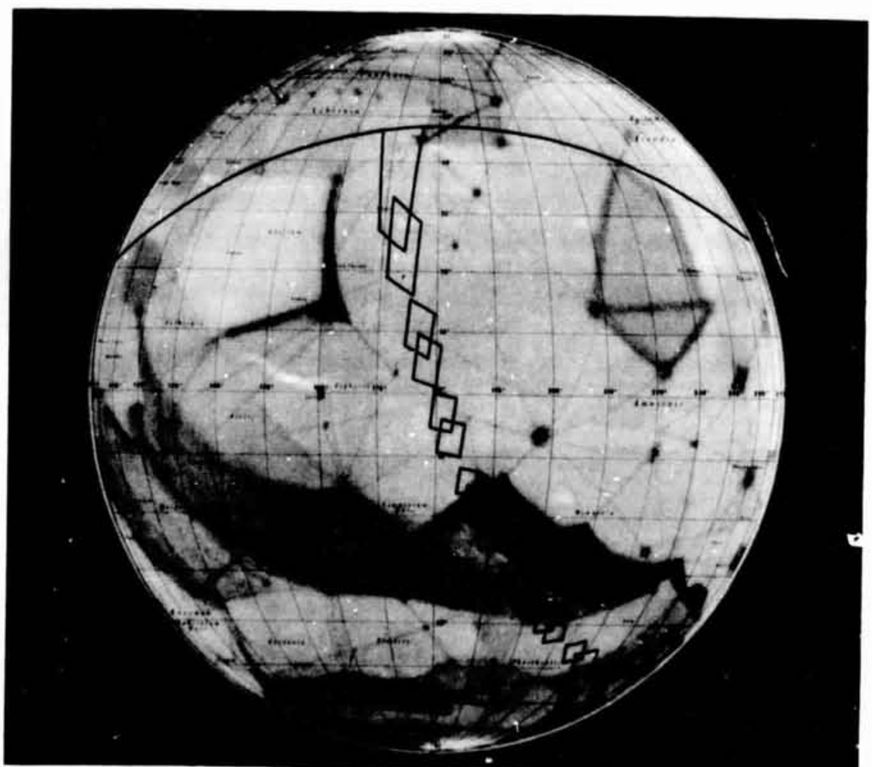
At first glance, the canal scoffers seemed about to have their victory. Canals are certainly not obvious. A more careful analysis—with an open mind, of course—reveals several linear features. Some astronomers have found straight-line features in the photos, which they can associate with canals seen from Earth. The linear features seen by Mariner IV may represent well-weathered and pock marked natural geological features—perhaps natural cracks in the planet's crust caused by meteoroid impacts.

As for life, we cannot see buildings, roads, forests, or any other features, suggesting any kind of life. But from 6200 miles, we shouldn't. Careful analysis of similar pictures taken from high Earth satellites—with better detail—show no conclusive signs of any kind of life on Earth.

The other experiments on Mariner IV discovered some important features of the planet. Mars has no

20 *Airbrush drawing of Mariner IV photos 11 and 12, showing the heavily cratered Martian surface. Careful analysis and interpretation of photo 11 (top) reveals many more craters than revealed in a cursory examination of the original photo. A strong linear feature is also shown approximately in the location of a Martian canal. These linear features are probably due to natural geological processes, such as those that form rift valleys on the Earth.*

21 *The pictures of Mars transmitted from Mariner IV showed the areas indicated on this map. Sequence was from top to bottom; photos on page 24 are part of this sequence.*



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significant magnetic field of its own and no radiation belts. The atmosphere is even thinner than that deduced from terrestrial observations: 4 to 7 millibars, mostly carbon dioxide and argon. (Atmospheric pressure on Earth is about 1000 millibars.) Sunlight acting on the thin film of atmosphere hugging the planet does not create an ionosphere on the Sun side. Apparently, the solar wind slams directly into the atmosphere, creating a bow shock wave as it does with the Earth's magnetopause and Venus' ionosphere.

More than ever, Mars seems hostile to life. But not completely so. Some form of life could conceivably hang onto existence on that desolate cratered surface. At some period in its early history, Mars may have had an atmosphere more conducive to life. Traces of such life may be found there by future probes.

Additional Reading

For titles of books and teaching aids related to the subjects discussed in this booklet, see NASA's educational publication EP-48, Aerospace Bibliography, Fourth Edition.

Information concerning other educational publications of the National Aeronautics and Space Administration may be obtained from the Educational Programs Division, Code FE, Office of Public Affairs, NASA, Washington, D. C., 20546.