SPECIAL WALL MAP SUPPLEMENT: THE EARTH'S MOON

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SEE "AUSTRALIA: THE TIMELESS LAND," TUESDAY, FEB. 18, ON CBS TV (page 300A)

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That orbèd maiden, with white fire laden, whom mortals call the Moon

By KENNETH F. WEAVER
Assistant Editor

GODDESS OF THE NIGHT they called her: Selene, Artemis, Cynthia, Luna. Men worshiped and feared her, believing that her mystical powers influenced life on earth. They closely marked her inconstant face, measured time by her waxing and waning. They sang of her splendor, named her "bright wanderer," "fair coquette of heaven," "sweet regent of the sky," "Mother Moon."

Once she was unreachably remote—the province of poets, of shepherds and nomads, of lonely astronomers and not-so-lonely lovers.

Today, in the twelfth year of the Space Age, earth's natural satellite has become the concern of everyman, and the object of the most intensive scientific and technological effort in history. Hundreds of thousands of people, and industrial firms by the thousands, have turned their energies toward realizing the goal of putting men on the moon.

Man has already probed at the moon with some 45 spacecraft bearing names like Luna and Zond, Ranger, Surveyor, and Orbiter. From afar we have poked and scratched its surface, hammered on its rocks, assayed its chemistry, measured its temperatures. We have tested it with radio waves, the exhaust of rocket engines, and magnets. We have photographed from close up all but the merest smidgen of its tortured face. (See the eight-color wall map, *The Earth's Moon,* a special supplement to this issue.)

And now, as this is written, a few chosen men, astronauts and cosmonauts, train with monastic zeal for the fantastic attempt that will bring alive the tales of Jules Verne and H. G. Wells.

Before long we may have at least partial answers to riddles that have always haunted men: Where did the moon come from? Of what is it made? Is it really cold and dead? And does life exist there? The moon may even prove to be the Rosetta stone of the solar system, the key that will help us understand the early history of the earth and her sister planets.

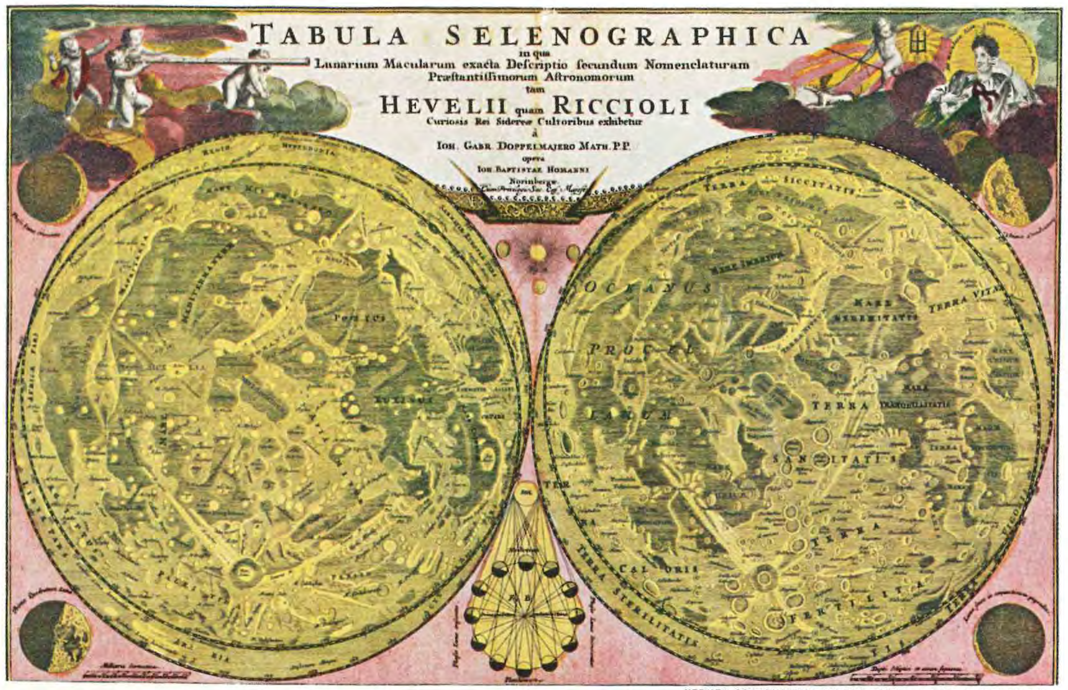
EKTACHROME MADE NEAR MUNICH, WEST GERMANY, BY HERMANN EISENBEISS, PHOTO RESEARCHERS © N.G.S.
TITLE QUOTE FROM "THE CLOUD," BY PERCY BYSSHE SHELLEY

> Late, late yestreen
> I saw the new moone,
> Wi' the auld moone
> in hir arme, And I feir,
> I feir, my deir master,
> That we will cum to
> harme.
>
> "BALLAD OF SIR PATRICK SPENS"

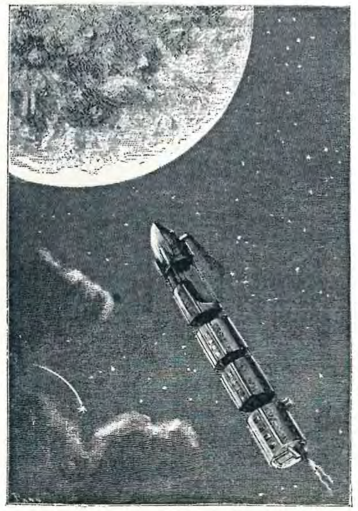
The moon has inspired more superstition than any other celestial body. It has long been regarded with foreboding, as an omen of evil, especially when it eclipses the sun, or when its dark orb, faintly lit by earthshine, lies cradled in a silver crescent.

And even the full moon has held its terrors. From the remotest times it has been supposed that sleeping in full moonlight can cause blindness or madness. The very word "lunatic" derives from the Latin for moon.

Some farmers to this day believe that the moon affects the weather, and that crops should be planted according to the moon's phases. "Sowe peasen and beans in the wane of the moone; Who soweth them sooner, he soweth too soone," goes the old saw.



YERKES OBSERVATORY (UPPER RIGHT); LIBRARY OF CONGRESS



Early portraits of earth's heavenly companion bear names that still survive. In 1647 Johannes Hevelius, on the first true moon map, called the dark areas *maria* (plural of the Latin *mare,* sea), reflecting a belief that these vast plains were water. Four years later Giovanni Riccioli renamed the maria and christened craters for famous men, as is still done. Their pioneering work still found currency in the early 1700's, when J. G. Doppelmayr of Nürnberg, Germany, published this re-rendering of the Hevelius (left, above) and Riccioli maps.

Moon express, a coal-burning train speeds toward its destination. Though illustrating Jules Verne's 1865 classic, *From the Earth to the Moon,* it bears little relation to the cannon-shell spacecraft in the French author's text. Amazingly prophetic, he described a three-man lunar capsule blasted into space by a giant gun near Tampa, Florida—only 120 miles west of today's Cape Kennedy.

Could the moon, with all its supposed influences on earthly life, have inhabitants of its own? Johannes Kepler, famed German astronomer of the early 17th century, thought so. He believed that the craters on the moon were artificial—that they had been made by whatever creatures lived there. And in 1835, a front-page story in the *New York Sun* told in detail how Sir John Herschel, son of Britain's Court Astronomer, had built a monstrous telescope 24 feet in diameter, and how he had seen through it lunarian men with wings like bats. An excited public learned later that it was all a journalist's hoax.

But less than a century ago, William H. Pickering, the respected American selenographer, saw with his telescope variable spots in certain of the moon's craters that seemed to darken after the beginning of the lunar day and then wane just before the sun set, 14 earth days later. He speculated that these could be some low form of vegetation. He even thought he saw melting snow that could have provided water.

Once I asked Dr. Eugene Shoemaker, then head of the Center of Astrogeology of the U. S. Geological Survey and one of the major experimenters in the Surveyor program (page 213), if there is the remotest chance of finding life on the moon. He burst out laughing.

"Well, of course there are the lunar elephants! We'll see those!" he said.

He referred to a pompous 17th-century Englishman, Sir Paul Neal, who announced that he had discovered an elephant on the moon. The announcement created a tremendous stir until—according to the story—people found that all he had seen was a mouse that had crept into his telescope.

Dr. Shoemaker added that "the moon is the kind of place where you would put things to sterilize them." Lacking atmosphere, it feels the full brunt of solar radiation, including deadly ultraviolet, X-rays, and gamma rays. No surface water exists to sustain life—on that scientists agree. Midday temperatures at the equator are hotter than boiling water; with the coming of the lunar night they plummet some 500° F. And the moon exists in an almost total vacuum (although it must be noted that some earthly spores have proved able to survive without oxygen or atmospheric pressure). So it is not hard to accept Dr. Shoemaker's estimate that the chances of native life—even microscopic life—are no better than one in ten billion.

We may not be able to detect such life even if it is there. As Dr. Wilmot Hess, Director of Science at the Manned Spacecraft Center in Houston, points out, "The suit worn by the Apollo astronauts leaks at the rate of roughly 1,000 micro-organisms a minute. So biological analysis of the moon becomes difficult. How do you separate your bugs from moon bugs?"

But the National Aeronautics and Space Administration is taking no chances. When our astronauts return from their first moon landing, they and the samples they bring back will go into quarantine in special quarters in Houston—the astronauts for 21 days, the samples for a month or more. Even the Apollo Command Module, in which the astronauts have traveled home again, will be sealed in this Lunar Receiving Laboratory until experts are satisfied that no harmful lunar material exists to escape on earth.

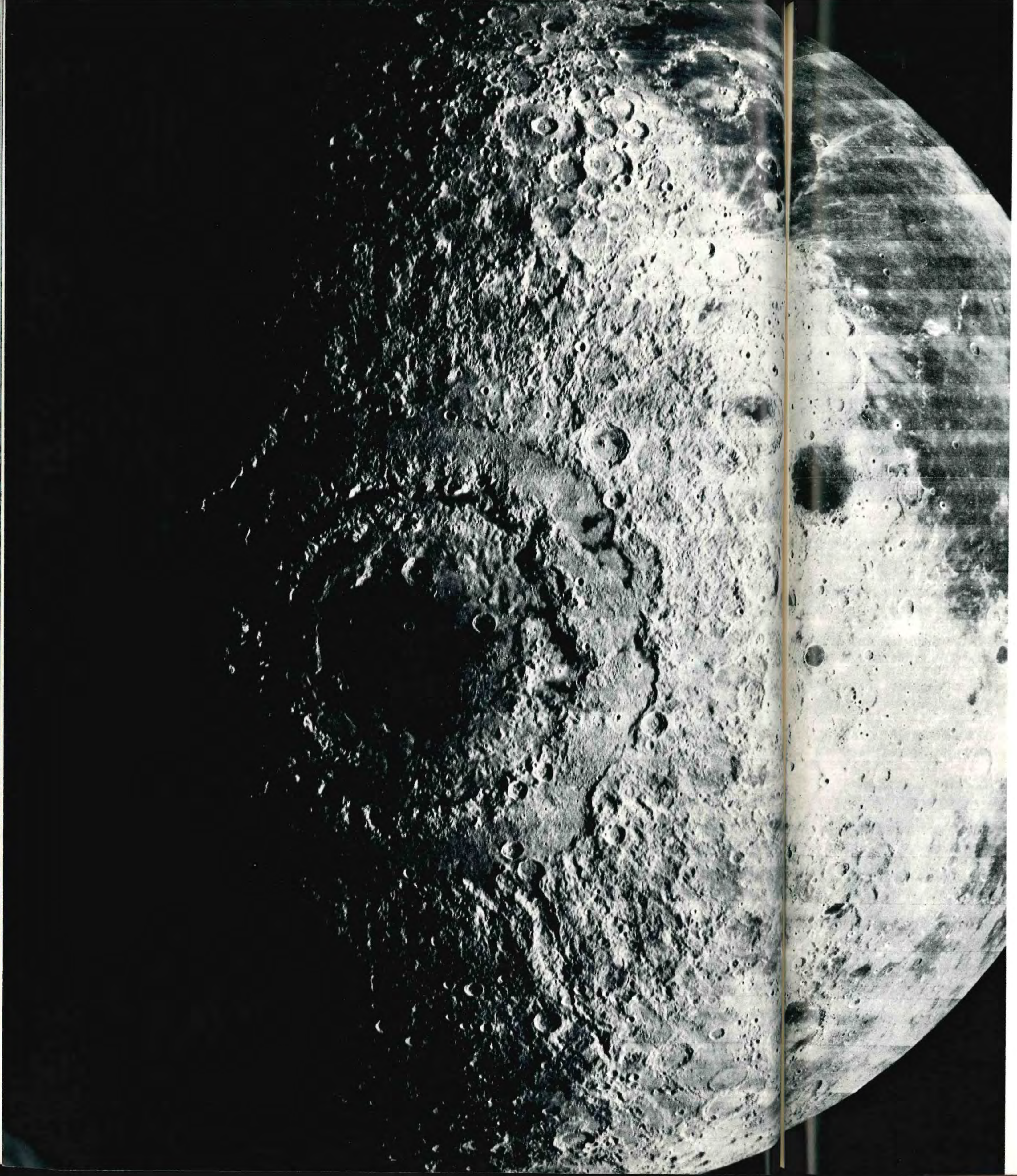
> The bent and broken
> moon, All batter'd,
> black, as from a
> thousand battles . . .
>
> JOAQUIN MILLER, "INA"

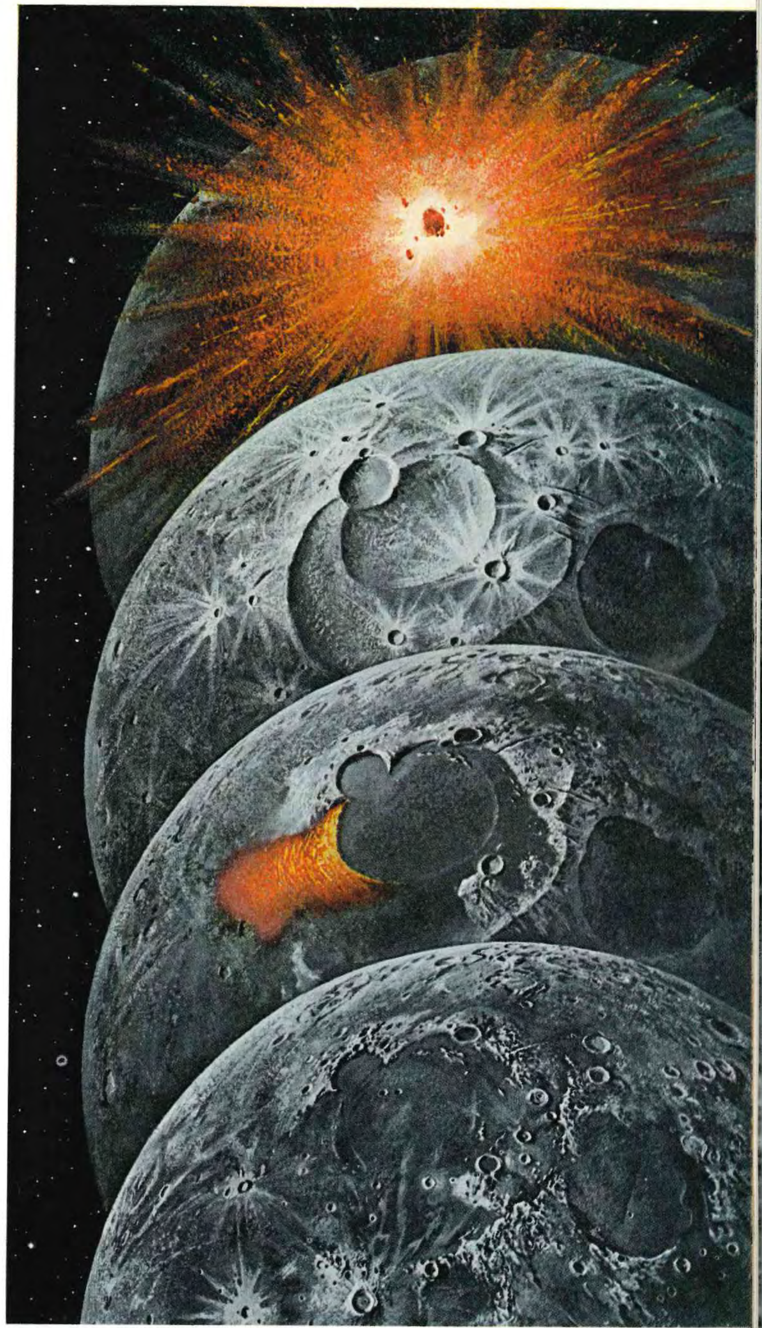
People once thought that the surface of the moon was smooth and crystalline, that like a mirror it reflected the continents and seas of earth.

Since Galileo's time, at least, we have known otherwise: The 14,650,000 square miles of moon are incredibly rough, a cosmic battlefield. Even a small telescope brings to view the startling, awesome moonscape which Galileo was first privileged to see, and which must have thrilled him beyond measure. It is a scene of unearthly wildness, of forbidding badlands, of desolate dark plains, of harsh shadows, set off by a sky of utter blackness.

The dusky regions, given the Latin name *maria* because 17th-century astronomers thought they were seas, form the whimsical figures that men of every age have fancied. There's the man in the moon, with Mare Imbrium as his right eye, Mare Serenitatis and Mare Tranquillitatis as his left eye, and

(Continued on page 214)



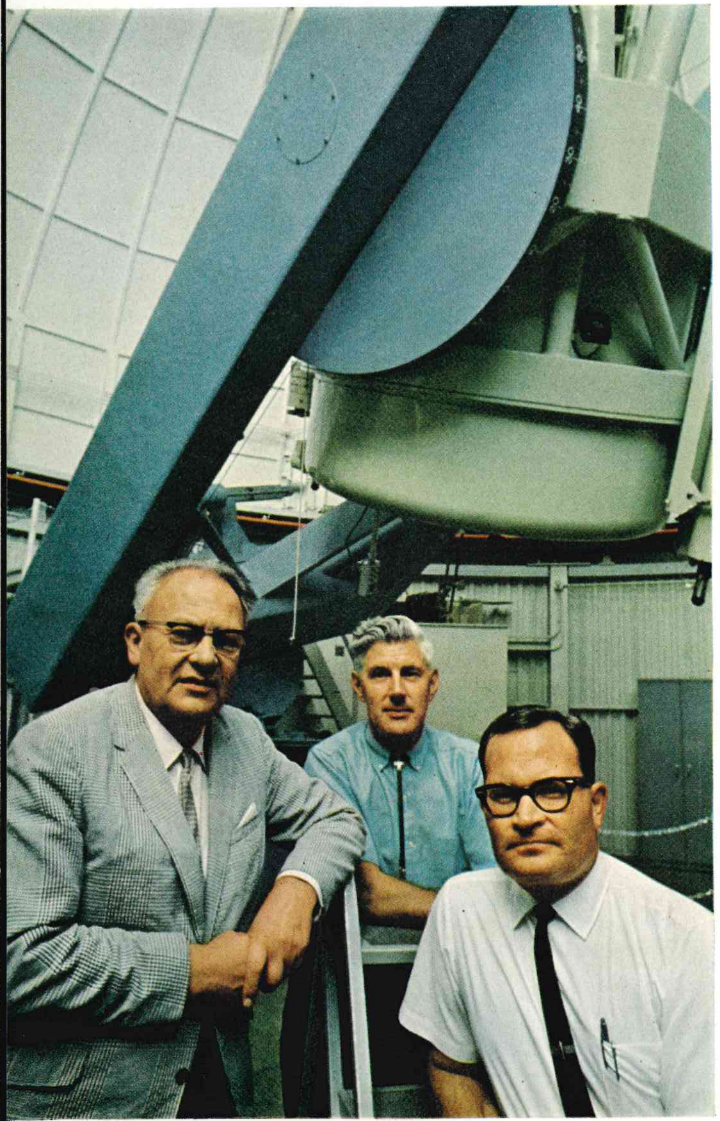


PHOTOGRAPH (LEFT) BY LUNAR ORBITER 4, NASA; PAINTING BY DAVIS MELTZER © N.G.S.

Cataclysm shapes a ravaged face: a four-stage re-creation of the possible genesis of Mare Imbrium, largest of the moon's circular "seas." Striking with the energy of millions of H-bombs, a massive comet nucleus or an asteroid splashes molten rock and debris across the moon and into space. Two vast basins form: a central crater from the impact, and an encircling depression caused by gradual slumping. Later, lava wells from a molten interior—time and again. Finally, perhaps 500 million years after impact, Imbrium's lava sea lies cold and pitted by meteorites, a stage shown also by huge Mare Orientale (left). The craters indicate how two forces—impact and volcanism—are believed to have molded the moon's features.

Colossal bull's-eye, Mare Orientale sits in a series of rings 600 miles across, with 15,000-foot peaks. At upper right spreads dark Oceanus Procellarum, right temple of the "man in the moon."

DONALD E. GAULT, right, and William L. Quaide, experts on craters, adjust rods that register contours of a man-made crater at NASA's Ames Research Center near San Francisco. An aeronautical engineer, Mr. Gault has developed a gun that hurls projectiles up to 28,000 feet a second to simulate meteorites, aiding study of crater formation.



KODACHROMES BY JAMES L. STANFIELD (LEFT) AND JAMES E. RUSSELL; EKTACHROME (LOWER LEFT) BY JACK FIELDS © N.G.S.

HAROLD MASURSKY analyzes a moonscape photographed by one of NASA's five Lunar Orbiter spacecraft, whose cameras surveyed potential landing spots for Apollo astronauts. Chief of the Branch of Astrogeologic Studies of the U. S. Geological Survey in Flagstaff, Arizona, Mr. Masursky headed the team responsible for interpreting the Orbiter pictures.

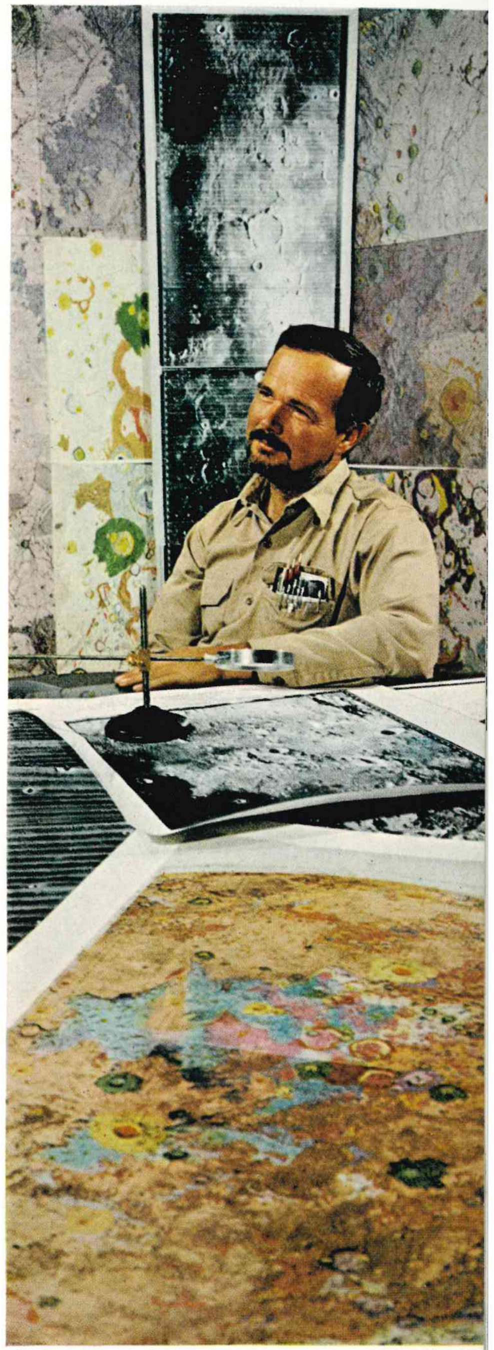
Moon men

GERARD P. KUIPER, left, a renowned astronomer who still keeps an eye to the telescope, heads the Lunar and Planetary Laboratory at the University of Arizona in Tucson. He was among the first to believe that the lunar surface would reveal a soil chemically similar to earth's basalt—a view confirmed by U. S. spacecraft. Here he stands before a telescope with two colleagues, Ewen Whitaker, a specialist in analysis of moon photographs, and Robert Strom, who has mapped the satellite's fracture lines.

EKTACHROME (BOTTOM) BY SOL GOLDBERG; KODACHROMES BY ROBERT W. MADDEN AND THOMAS DEFEO (RIGHT) © N.G.S.

JOHN A. O'KEEFE, a leading astronomer at NASA's Goddard Space Flight Center in Maryland, is one of those who contend that glassy objects called tektites splashed to earth from the moon (page 223). He helped discover in 1958 that the earth is slightly "pear-shaped."

THOMAS GOLD of Cornell University trowels ordinary cement powder onto the footpad of a Surveyor spacecraft. He believes lunar soil consists of particles that fine. In the long-argued question of the moon's surface composition—whether rocky, sandy, or powdery—Professor Gold also insists that the material of the maria is dust that flowed from the highlands much as a fluid would, to accumulate as compact soil.



EUGENE M. SHOEMAKER, foremost U. S. astrogeologist, sits amid detailed maps of the moon's surface at the Geological Survey laboratory in Flagstaff, Arizona. He organized the Survey's Center of Astrogeology there to serve NASA's needs for hard facts and educated guesses about moon geology. He now is chairman of the Division of Geological Sciences at the California Institute of Technology. As an expert in both meteoritic impact and volcanism, he believes both have shared in shaping today's lunar surface.

CLOSE, CLOSER, CLOSEST: *Three pictures show the Crater Alphonsus from the Ranger 9 spacecraft hurtling moonward. . . .*

258 MILES *from the moon, Ranger televised this scene to earth, March 24, 1965.*

42 MILES *to go: Furrows called rilles appear clearly; tiny craters now grow large.*

ALL NASA

4½ MILES *away—3 seconds before crashing. Circle on pictures marks impact point.*

Mare Humorum and Mare Nubium as his mouth. Orientals imagine a long-eared rabbit, or a monkey pounding rice. Others see a lady (see insets on supplement map).

These dark seas appear to be smooth and level, as though water did indeed lap their shores. Actually, most scientists believe that lava or volcanic ash filled them long ago (page 211). Oddly, there are few large basins on the far side of the moon, and those that do exist often lack the dark filling that makes the near-side maria so noticeable.

The bright, silvery regions of the moon which shine so intensely are mountainous. These jumbled highlands cover 60 percent of the face we see and virtually all the far side, which man knows only from Luna, Zond, and Orbiter photographs.

Long mountain chains, bearing such names as Apennines and Alps, separate the maria. They rise as much as 20,000 feet. To men on the moon, however, they may not seem that high—or be visible at all. The surface of the moon, only a fourth the diameter of earth, curves so rapidly that the horizon, to a six-foot man, will be only about a mile and a half away. On earth it is twice as far. To an astronaut on foot, the moon will appear for the most part flat or gently undulating, with all but nearby peaks hidden below the horizon.

The lunar seas and uplands dominate the naked-eye view of the moon, but in the magnificent photographs snapped by spacecraft, nothing catches the eye like the mad profusion of craters. Thousands upon thousands of these symmetrical pockmarks saturate every square mile of the moon, from colossal basins like Bailly, 183 miles across, down to tiny cups less than an inch in diameter.

Even the maria floors, which seemed so smooth in photographs from earth, are riddled—more, actually, than the highlands. On the front side alone, one can count a third of a million craters that measure more than a mile across, and they in turn are peppered with countless smaller ones.

So numerous are the craters that they often overlap. The older a feature is, the more craters have pocked and altered its surface.

By and large the craters have rims, and some have central peaks or terraces (top left and page 234). Some are more than three miles deep, some are shallow, and some are ghosts, apparently all but drowned in lava.

One small depression bears the name Hell—a seemingly apt description for its Dantesque setting; in reality it was named for an 18th-century Jesuit astronomer, Maximilian Hell of Vienna.

When the moon is full, another feature becomes strikingly visible—the enormous system of bright rays flaring in all directions from several of the youngest and most prominent craters: Copernicus, Kepler, and—most notably—54-mile-wide Tycho, whose rays can be seen with the naked eye (page 235).

The rays seem to be ejecta—debris sprayed from a crater at the time of its formation, like milk splashed out of a pan when a ball is thrown forcefully into it—and scars opened up by the ejecta. Probably, say most scientists, these large craters were created by the impacts of comet nuclei or asteroids.

The object that blasted out Tycho is estimated to have been at least two miles in diameter. So violent was the impact that "the moon must have shaken like a bowl full of jelly," to quote Harold Masursky of the U. S. Geological Survey, one of the principal interpreters of the Lunar Orbiter photographs (page 212).

Some of Tycho's rays reach more than 1,000 miles. Because there is no air resistance, because the surface gravity is low (1/6th that of earth), and because of the sharp curvature of the moon, ejected material travels up to ten times as far on the moon as it would on earth.

Less prominent and far more puzzling are the sinuous rilles, strange narrow channels or valleys that meander like rivers for as much as 200 miles (page 237). Scientists are truly perplexed by these features. They seem to originate in craters, and some specialists think they were carved by lava or ash flows. To others they suggest underground lava or water channels that have collapsed or subsided.

And a few say that only surface water could have cut such distinct, wandering channels. Many observers suspect that the moon holds large quantities of water in the form of permafrost extending deep under the insulating surface layer.

If the water rises to the surface, however, it is difficult to explain satisfactorily what prevents its swift disappearance by evaporation in the moon's intense vacuum. Possibly this sudden evaporation cools the near-surface water so much that it freezes into a protective layer of ice and mud. Beneath this temporary shield, flowing water might gradually etch a rille. In all cases the rilles simply peter out; none shows a delta such as would characterize a similar stream on earth.

Sinuous rilles are comparatively rare; only fifty or so are known. A more common and much different kind of channel, called linear rille, goes in a relatively straight line instead of meandering. Linear rilles represent tension cracks or faults in the crust. More than a thousand of them have been catalogued.

Occasional low domes add variety to the lunar surface, especially in the region known as the Marius Hills, near the crater Marius (4H on the map). As much as 6 miles across and 1,000 feet high, they resemble low volcanic domes on earth. They provide significant evidence that at least part of the moon's formations are volcanic (page 220).

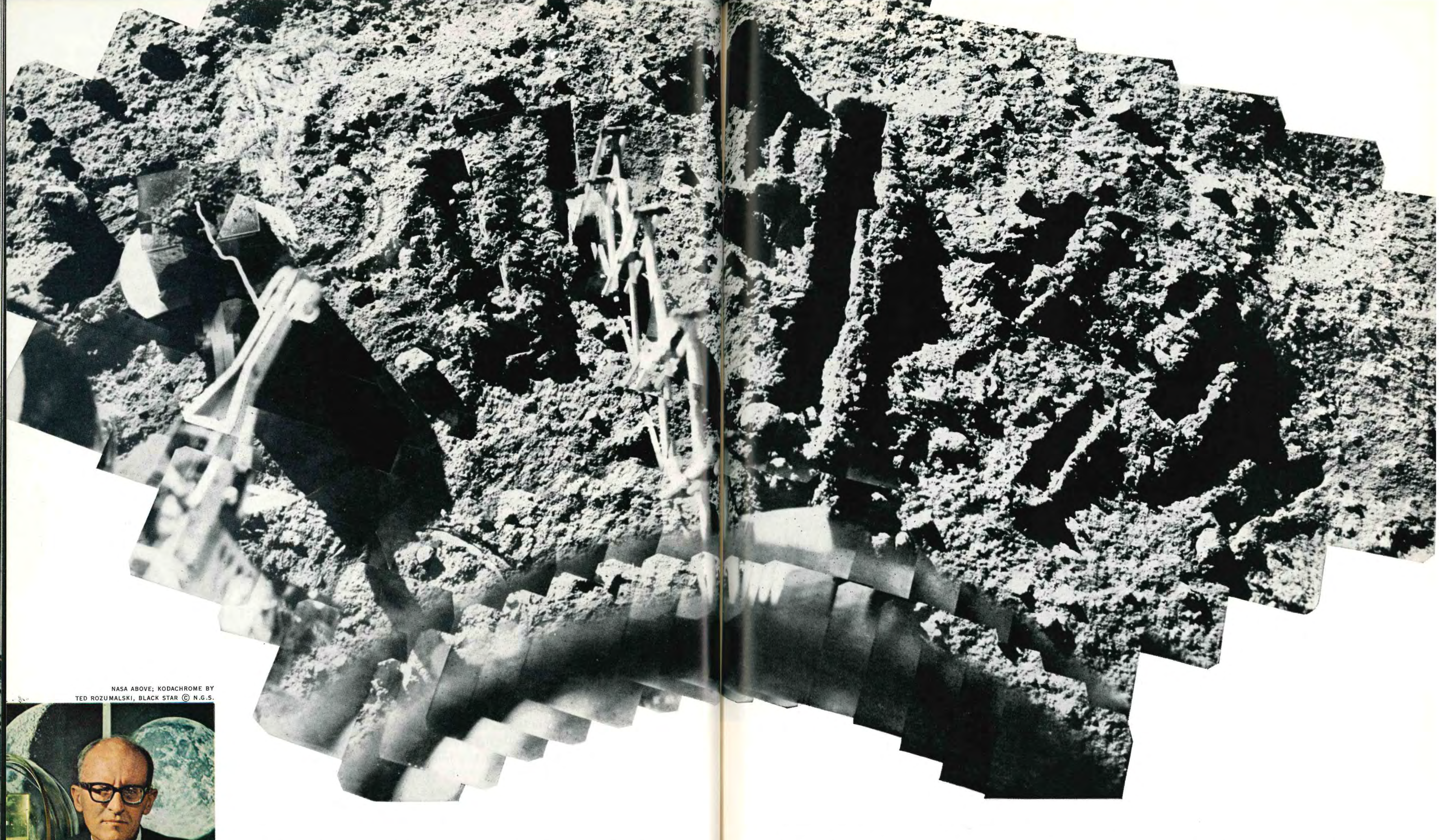
Approximately 5,000 markings on the battered face of the moon have been given names by the International Astronomical Union, which must approve all lunar nomenclature. Only a handful of the myriad formations on the back side have yet been officially tagged, and these bear names suggested by the Russians, whose Luna 3 first photographed that side in 1959.

He made an
Instrument to know
If the Moon shine at
full or no . . .
And prove that she
is not made
of Green Cheese.

SAMUEL BUTLER,
"HUDIBRAS"

As I write these words, the full moon has just risen above the buildings across the way. From my office window I can view the black-and-silver face in all its glory. I am intrigued by the thought that, although I cannot see them, some very special and expensive instruments designed by man lie at 23 different sites scattered across that glittering moonscape. For that is the number of spacecraft—17 U. S. and 6 Soviet—that have crashed or soft-landed on the moon as of this autumn night.

With the best of earthbound telescopes (and the best are very good indeed), lunar photographs have been able to show nothing smaller than 800 feet across. That is roughly



NASA ABOVE; KODACHROME BY TED ROZUMALSKI, BLACK STAR © N.G.S.

"Surveyor 7's battleground"

Thus moon men label this 50-square-foot plot of lunar highland. Here, near the crater Tycho, the final craft of NASA's successful Surveyor series soft-landed a year ago, scouting the lunar surface.

Monitoring through Surveyor's television eye, whose photographs form the chips of this mosaic, scientists on earth dramatically utilized the robot's two movable sensing tools: an extensible digger called a soil mechanics surface sampler, visible at center, and a chemical analyzer called an alpha back-scatterer, held by a jointed arm at left. A model of the scatterer (left) rests before one of its designers, Professor Anthony L. Turkevich of the University of Chicago.

On orders pulsing from earth, the alpha device went into action. Lowered to the lunar surface, it bombarded the soil with atomic alpha particles and measured the energy of their rebound. A weak bounce indicates light elements; a strong bounce, the presence of heavy elements such as iron. Analyzing the rebounds later, scientists concluded that much of the moon stuff must be chemically similar to earth's most abundant volcanic rock, basalt.

Next the digger probed, jerkily gouging trenches whose sharp edges bespeak a slightly cohesive soil. Its scoop picked up a rounded stone near the scatterer, weighed it, then fumbled it. Twice the digger clawed futilely for a large rock just out of reach, upper center. Poising above another, at the end of the trench at far right, it slammed down and chipped off a fragment, determining the strength of lunar rock. Magnets on its scoop picked up grains and bits of moon matter, more evidence of iron-rich minerals.

Obedient robot, a test model of Surveyor 7 crouches behind Professor Ronald F. Scott at the Jet Propulsion Laboratory in Pasadena. Responsible for the spacecraft's digger, Dr. Scott saw the mechanical arm function almost flawlessly on Surveyors 3 and 7. Its testing of the moon's soil gave data that have helped fix the size and shape of footpads for the Lunar Module landing craft.

Because liquids quickly evaporate in the lunar vacuum, the digger was designed with joints that require no lubrication. Three tiny motors move the accordionlike arm sideways, vertically, and in and out, while a fourth works the hand-size scoop at the end.

Here Surveyor also lowers its alpha scattering device, to the right of the digger. The central mast holds a steely-blue solar panel used to convert sunlight to electricity. Just below it hangs a cylindrical TV camera, man's first eye on the moon.

KODACHROME © N.G.S.

the same as looking at the moon from about 400 miles away. A much closer look was necessary to scout suitable landing spots for Apollo astronauts.

So seven Rangers were sent up to transmit television pictures as they plummeted toward crash landings on selected flat regions near the lunar equator. The last three succeeded spectacularly, in 1964 and 1965, sending back thousands of detailed scenes of Mare Cognitum, Mare Tranquillitatis, and the crater Alphonsus (page 214). Mare Cognitum, the Known Sea, or the "Sea That Has Become Known," received its name in honor of the first close-up photographs, taken by Ranger 7.*

Ranger increased a thousandfold our ability to see detail. But the Apollo planners needed more. They needed actually to test the surface, to assure that astronauts and spacecraft would not be swallowed up, as some people feared, in a deep, treacherous sea of dust.

Five successful Surveyors, out of seven attempts in 1966, '67, and '68, soft-landed on the moon and gave unequivocal answers.† Their TV cameras were able to see particles as small as a fiftieth of an inch. But more

*See "The Moon Close Up," by Eugene M. Shoemaker, NATIONAL GEOGRAPHIC, November 1964.

†This historic project was described in "Surveyor: Candid Camera on the Moon," by Homer E. Newell, NATIONAL GEOGRAPHIC, October 1966.

important, as each spindly, spraddle-legged craft dropped gingerly to the surface, its speed largely negated by retrorockets, its three footpads sank no more than an inch or two into the soft lunar soil. The bearing strength of the surface measured as much as 5 to 10 pounds per square inch, ample for either astronaut or landing spacecraft.

"It will be like treading on old snow with a set of oversize galoshes," says Gene Shoemaker. A man will sink enough to leave footprints, but he will be able to walk without a great deal of trouble.

Two of the Surveyors carried a soil mechanics surface sampler—a clamshell digger on the end of an extensible lazy tongs. At the Jet Propulsion Laboratory in Pasadena, California, I talked to Dr. Ronald F. Scott, a soil engineer from the California Institute of Technology, who sent commands to the device on the moon (opposite). He took me into a cavernous workshop where a mock-up Surveyor was still being used for post-flight tests.

Together we worked the remote controls that scissored the digger out a distance of five feet and moved it sideways and up and down. At our command its steel jaw opened, closed gently on a roll of tape, and held it up—like a newly trained puppy waiting for a reward.

"You may remember," Dr. Scott told me, "that we used the digger in several kinds of tests on the moon. We pressed the closed jaws hard into the soil and measured the force required to compress the surface. We dug trenches—one of them 30 inches long and 7 inches deep. We picked up one rock fragment and tried unsuccessfully to crush it; lifted another, weighed it, and determined its density. And we broke off a chunk from a rock by lifting the digger and dropping it like a hammer" (pages 216-17).

There were, of course, other ways of assessing the lunar surface: blasting it with exhaust from Surveyor's vernier rockets to see if dust would coat the spacecraft (it did very slightly); showing in photographs the depths to which the craft's footpads sank; noting the effects when Surveyor 3 bounced twice on landing, or when Surveyor 5 skidded down the slope of a small crater.

All these tests and observations gave a consistent picture of the lunar soil. The long debate about whether the moon is covered with something like ashes, or light fluffy dust, or fragile "fairy castles" of cemented particles, or hard rock, was settled. The surface, at least in the five regions where Surveyors landed, is made up of gray, finely divided, granular material that is slightly cohesive, much like terrestrial garden soil.

Professor Thomas Gold at Cornell likens it to cement powder (page 213). Dr. Shoemaker says it is more gritty than that, with a wide range of particle sizes. He calls it a regolith, or debris layer.

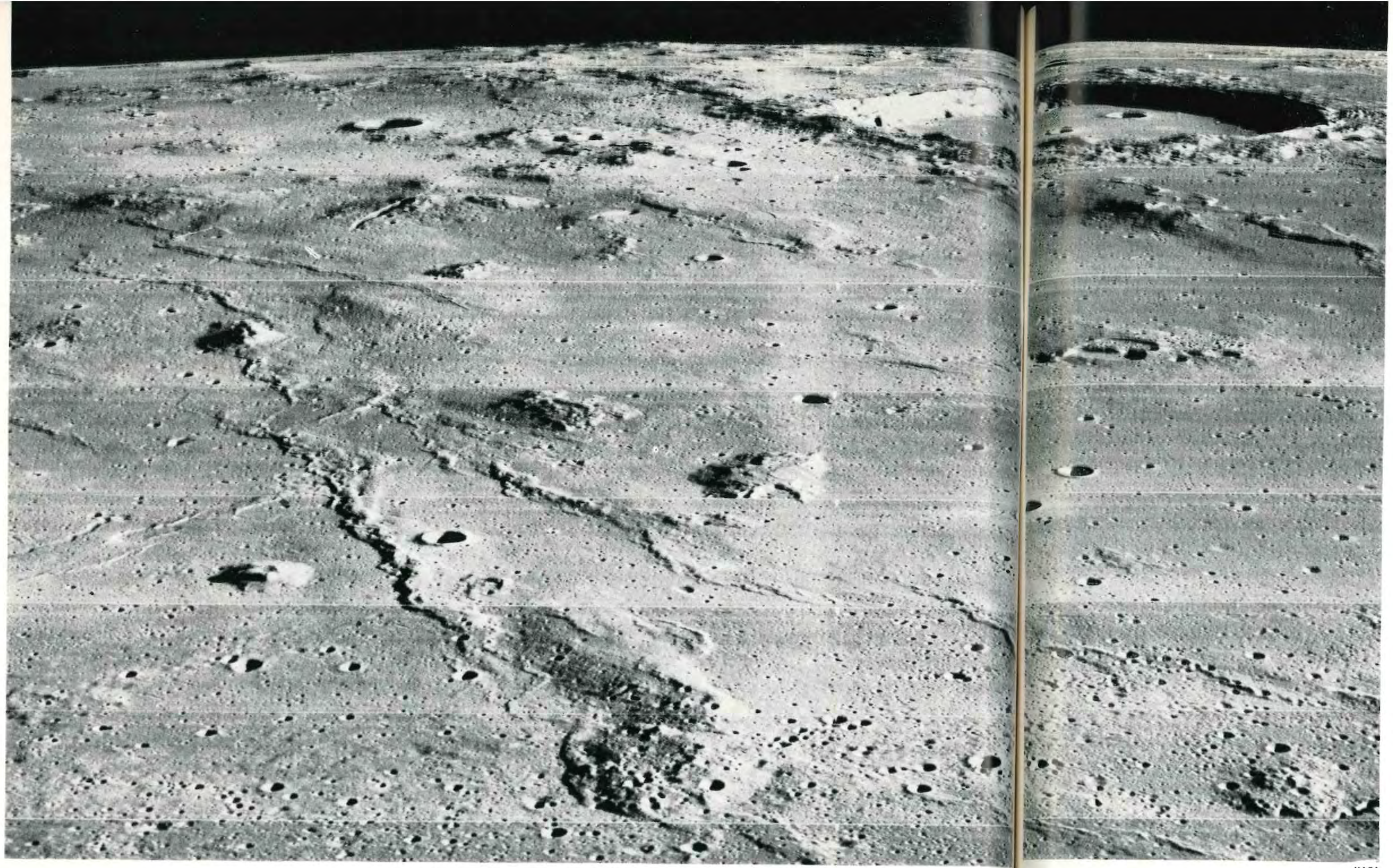
"You can compare it to fine river silt, if you like," Dr. Scott told me. "In fact, we have a big tank of silt here, from the Arroyo Seco near this lab, with which we experiment; it acts much like lunar soil when the digger plows through it."

As I tested the feel of the material with my hand, he re-created for me the scene of the first groundbreaking on the moon. A surface sampler identical to the two operated on the moon had been set up to test various soils in the tank. A huge parabolic mirror far up in a corner of the ceiling focused brilliant light on the scene, throwing dramatic long shadows just like those in Surveyor photographs. Chains and springs slung from the ceiling suspended the tank, allowing it to "give" when the digger bit in, thus permitting a measurement of how much force the sampler exerted on the soil.

Commands to the instrument came not from manual controls, as on the mock-up Surveyor, but from a computer, which in turn was controlled by coded instructions punched on a paper tape, just as it was on the Surveyor 7 mission. Four tiny motors in the digger whined, whirred, whoofed, and whiffed, each with its own characteristic obbligato, as the miniature backhoe jerkily extended, positioned itself over the soil, and dug in.

Indeed the results did resemble those on the moon—a clean trench with little slumping. Loose material brought up by the hoe clumped together in clods. Clearly the bulk of the material on the surface of the moon must be at least as fine as this. Anything as coarse as beach sand would not act the same way.

Even before Surveyor, most scientists had abandoned any idea that the moon was surfaced with hard rock. Tests from earth showed that the lunar surface reflected and polarized light and bounced back radar beams in a way that only fine particles can do. But one question had been far from settled: How deep is the soil? Some scientists were sure that it was a very thin layer, a few inches at most; others



NASA

Historic evidence of a "hot" moon. This Orbiter 2 picture of the bleak Marius Hills helps resolve a classic lunar controversy: Whether the moon has forever lain cold and inert, disturbed only by external impacts, or whether it once was molten like earth's core today. Studying the Marius features, most experts now agree that many of the domes, rising as high as 1,000 feet, are outpourings of lava. They find a parallel on earth in domes such as 500-foot-high Howard Mesa (below) in Arizona's San Francisco volcanic field. Ridges on the Marius field may be lava forced up through fractures, or bucklings of the lunar crust. Marius crater, upper right, gave its name to the region.

U. S. GEOLOGICAL SURVEY

predicted that it might be thousands of feet deep in the maria.

Dr. William L. Quaide and Verne R. Oberbeck at NASA's Ames Research Center, near San Francisco, have an answer that is becoming widely accepted. After years of experimenting and after studying thousands of Orbiter, Surveyor, and Luna photographs, they are certain that the mare filling has been pulverized and churned to depths varying from 3 to 30 feet by the incessant rain of small meteorites striking the moon. In the highlands the average depths seem to be somewhat greater. The top of this layer, of course, is littered with coarse boulders and fragments of infinite variety and size.

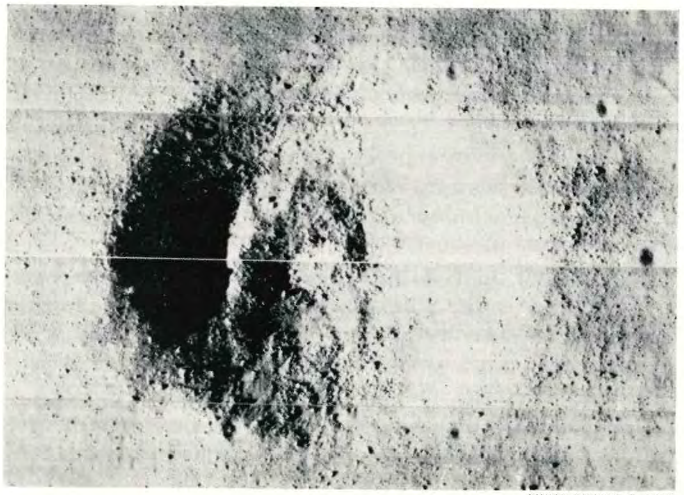
These scientists see overwhelming evidence that at least the smaller craters—those no more than half a mile across—are the direct result of meteorite impact, or of the impact of rocks thrown from other craters.

These conclusions were strongly supported by the work of another Ames scientist, Donald E. Gault (page 212), who invented a clever device known as the "vertical light-gas gun" to reproduce the effects of a meteorite. The gun fires small plastic or metal projectiles straight down, or at an angle, into targets inside a vacuum chamber.

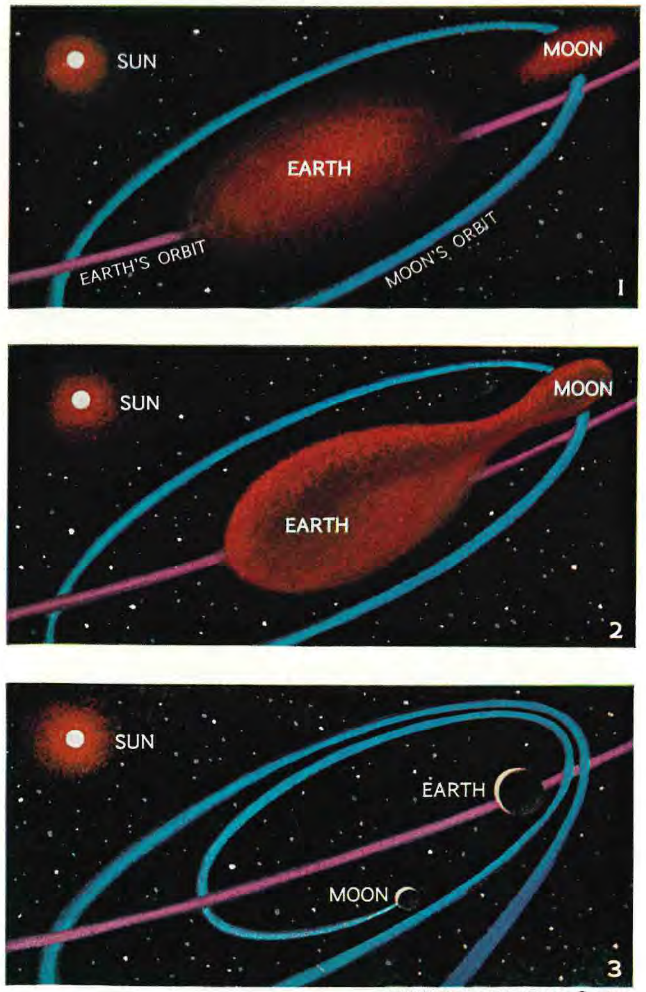
"We can get velocities of as much as 28,000 feet a second,"

KODACHROME © N.G.S.

Look-alike craters on earth and its moon give credence to the impact theory of the origin of many lunar features. Arizona's Meteor Crater (upper), 4,000 feet across, was blasted out by the crashing blow of a meteorite, perhaps no larger than the museum building perched on the near rim. Geologists find strong similarities between Meteor and an unnamed lunar crater (lower), about half Meteor's width. Both have raised rims and surrounding "aprons" of ejected material, hummocky and strewn with boulders. Hills within lunar craters, as at right, may be caused by the rebound of subterranean rock. What appears to be a mound inside Meteor Crater grew as tailings from a mine shaft, sunk in the early 1900's in an unsuccessful attempt to locate the iron-rich meteorite.



LUNAR ORBITER 2, NASA



PAINTINGS BY DAVIS MELTZER © N.G.S.

How did earth get its moon? Just as experts debate the causes of the moon's configurations, they dispute its origin. Three theories predominate. **1.** In the "sister" hypothesis (top), earth and moon formed at the same time from a vast cloud of cosmic matter that condensed into the bodies of our solar system. **2.** The "daughter" theory contends that the earth once rotated so rapidly that it became blimp-shaped and tore in two. The smaller blob of matter entered into orbit as the moon. **3.** The "spouse" theory holds that the moon came from elsewhere in the solar system. Sweeping too near, it was snared by earth's gravity and "married"—locked in orbit.

Nuggets of moon matter—so Dr. Dean Chapman claims of these tektites, gathered from Southeast Asia, the Philippines, and Australia. The glassy blobs indicate by their shapes and surface sculpture that they have passed through earth's atmosphere. Dr. Chapman, an aerodynamics specialist at Ames Research Center, believes with a number of colleagues that tektites are lunar fragments hurled into space during meteorite collisions with the moon.

After he acquired a number of huge tektites for his collection, a fellow scientist spoofed him by painting a super-tektite for his wall.

Mr. Gault told me as he prepared his gun for a demonstration. "That's nearly ten times the speed of a military rifle bullet, and it simulates the effects of a small meteorite striking the moon. We reproduce the lunar environment as closely as we can by putting the target in a vacuum and by dropping the target just fast enough at the precise moment of impact to simulate the moon's low gravity."

Hydrogen gas compressed by a powder explosion propels the missile for maximum velocity, but for our experiment we used a simple powder charge. We watched through a heavy quartz window as the pellet smashed into a bed of fine-grained sand, leaving a rimmed crater many times its own size.

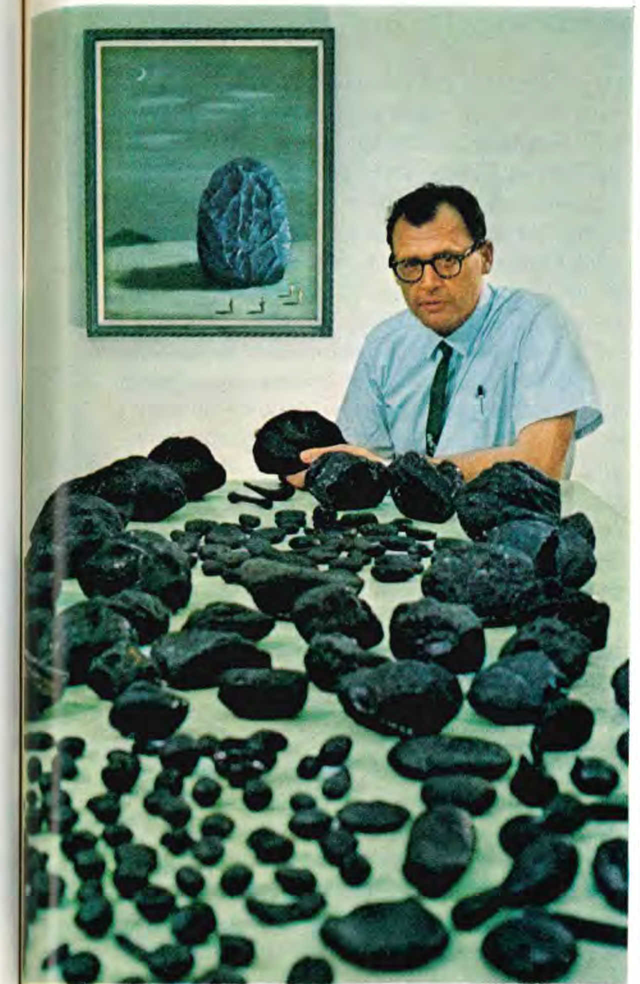
"That rim is the significant thing," said Mr. Gault. "When we fire the gun at rocks, we can knock out a rough hole, but we never get a rim like that, and we don't get small craters that look like that. But with granular material, or with such material over a hard rock layer, we can duplicate all the different kinds of small craters we see on the moon.

"With this help," Mr. Gault went on, "scientists can calculate the depths of the fine surface material from the photographs, either by the shapes of the craters or by determining how deep craters have to be before the impacts begin to excavate subsurface rock."

Large craters, of course, have broad "ejecta aprons" of rocks and boulders. These have probably come from much deeper than the present crater bottoms, however.

The very large craters were originally as much as six or seven miles deep, and the largest of the circular maria—Imbrium—may have been 50 miles deep for a very brief time. Many scientists think that the bottoms of these vast chasms rose to compensate for the loss of material. In addition, volcanic material has partially filled many of the pits.

As Dr. John O'Keefe of NASA's Goddard Space Flight Center at Greenbelt, Maryland (page 213), puts it, "The moon just won't accept an insult like that. It reacts!"


KODACHROMES © N.G.S.

Upon the corner of
the moon
There hangs a vap'rous
drop profound.
I'll catch it ere it
come to ground.

SHAKESPEARE, "MACBETH"

In times gone by, superstitious folk believed that witches could call down a vapor from the moon for use in their incantations. But something far more solid than Hecate's "vap'rous drop" may indeed reach earth from the moon, if the findings of an Ames scientist named Dean Chapman are correct.

He demonstrates quite convincingly that certain tektites, small blobs of black glassy material found from Australia to Southeast Asia, splashed to earth when Tycho was formed, less than a million years ago.

Dr. Chapman is an aeronautical engineer who holds top rank as an expert in ablation—the melting and sloughing away of objects flying through the atmosphere at high velocity. His knowledge helped design the heat shields that protect American astronauts reentering the atmosphere after space flights.

No one else in the world has so varied a collection of Australasian tektites as does Dr. Chapman, and no one else has studied these strange objects so thoroughly. The chemical makeup of tektites is unlike that of any other material on earth.

"We can tell by experiments and by examination of certain of the tektites from Australia that they must have been melted twice," Dr. Chapman told me. "The first time was in a vacuum, as on the moon, because the molten material took the form of a ball; and the second time was in earth's atmosphere, because of the way these glass balls have ablated on one side."

He showed me a tray full of samples. They looked like flanged hemispherical buttons.

"Potassium-argon and fission-track dating tell us they melted about 700,000 years ago," he continued. "We know how fast they were traveling by the way they have melted. And by their distribution on earth we can calculate their trajectories. All this points squarely toward the southern part of the moon for their origin, and Tycho fits exactly. We believe it is a relatively young crater, about the same age as the Australian tektites, because its rays have not yet eroded away."

Not all scientists agree with Dr. Chapman, but he gets support from his colleagues at Ames, such as Don Gault; from John O'Keefe, who has long argued that tektites come from the moon; and from Gene Shoemaker.

"The earth is strewn with lunar debris," says Dr. Shoemaker. "A meteorite striking the moon at tremendous speed can eject hundreds of times more material than its own mass. Some of this material goes so fast that it escapes the moon's gravitational pull and travels freely in space. Earth continually sweeps up these sprays of moon stuff."

Tens or hundreds of tons hit the earth's atmosphere daily, he says, much of it to burn out and sift to the ground as dust, and a small fraction to crash-land as solid chunks.

Strenuous efforts, of course, are made to find such meteorites. Eugene E. Horton, at the Manned Spacecraft Center in Houston, tells a story about Project Moon Harvest, which several years ago enlisted the aid of farmers in seeking likely rocks in Midwest fields that normally are rock free.

One old farmer said to the investigator, "Now what exactly is this you are looking for, young man?"

The scientist explained, "We're looking for moon rocks—that's what you might call it."

The farmer, with eyes twinkling, replied, "Well, fella, have you looked in your head?"

A ruined world,
a globe burnt out,
a corpse upon
the road of night.

SIR RICHARD BURTON,
"THE KASÎDAH"

Is the moon cold and dead? Or is it, like the earth, a living body with a hot interior? Schopenhauer, more than a century ago, wrote of "the frozen moon." In 1901, H. G. Wells described it as a dead world of extinct volcanoes and lava wildernesses, alternately blazing, then freezing in absolute zero.

More recently, in the mid-'40's, when the U. S. astronomer Ralph B. Baldwin had begun the intensive studies that qualify him as the moon pioneer of the 20th century, a professor said to him, "Why are you wasting your time on the moon? It is dead and gone!"

But Baldwin persisted, and today a large part of the scientific community would agree with him that the moon is indeed hot inside—and very much worth studying. In fact, he says, "Surveyor has killed off the possibility of a cold moon."

Surveyor's evidence came primarily from a six-inch box, gold-plated to reflect the solar heat, that was carried on each of the last three voyages. This radioactive instrument, known as an alpha back-scattering device, was conceived by Professor Anthony L. Turkevich of the University of Chicago to make a chemical analysis of the lunar soil (pages 216-17).

When the instrument was lowered to the surface, a bit of radioactive curium bombarded the lunar soil with alpha particles, heavy atomic particles equivalent to the nuclei of helium atoms. Some of the particles bounced back up. Detectors inside the box counted them and measured their energy.

The secret of this device lies in the fact that alpha particles scatter, or bounce, from heavy elements, like iron, more vigorously than they do from lighter ones, such as carbon or oxygen. It is like bouncing a rubber ball against a stone wall, a barn door, and a cardboard box; clearly the ball will bounce farther from the wall than from the door, and farther from the door than from the box. Dr. Turkevich and his colleagues had determined in advance what kind of response to expect from each chemical element the instrument might find on the moon.

When Dr. Turkevich made his first report of alpha back-scatter findings, chemists, physicists, and geologists held their breath. Would it indicate some exotic material, unlike any found on earth? Would it be stuff like that of the primordial earth before it melted and the greater part of its heavy iron and nickel sank to a central core, leaving lighter stuff behind? Or would it be like the familiar rocks in the earth's crust—granite or basalt, for example? Several cherished theories would rise or fall according to the findings.

As had been long predicted by Ralph Baldwin and by Dr. Gerard P. Kuiper, Director of the Lunar and Planetary Laboratory at the University of Arizona (page 212), the lunar soil which Surveyor tested is very much like basalt, the most common volcanic rock on earth. A basalt layer several miles thick probably underlies all the earth's ocean beds, and basaltic lava flows cover thousands of square miles in such places as the Columbia Plateau in Oregon, the Deccan Plateau of southern India, and Iceland.

The basalt-like material on the moon is made up of the same elements that are commonest on earth: oxygen, silicon, aluminum, magnesium, calcium, and iron. The maria differ from the highlands chiefly in that the maria are twice as rich in heavy metals such as iron and nickel. This could help explain why the maria are darker: On earth, compounds of iron and other metals darken rocks and reduce their ability to reflect light.

The significance of finding basalt is that it strongly suggests a hot moon. Basalt on earth always comes from an igneous process—that is, it has been produced by melting and solidification. Moreover, when a planetary body melts, the heavier materials separate from the lighter in a process called differentiation. Basalt is a differentiated rock. So, from the alpha back-scatter results, most experts conclude that the moon must have been hot at some time in its history.

How did the moon get its heat? Experts suggest three possibilities, the same sources that account for the earth's heat: (1) from the energy of gravity when the chunks of matter forming the moon first rushed together; (2) from the heat of decaying radioactive elements such as potassium, uranium, and thorium; and (3) from mechanical processes such as the flexing of the moon's crust because of tidal forces.

And astrophysicists say that once a body the size of the moon heats up enough to melt its interior, it cannot be cooled down within the time we believe the moon to have existed—4½ billion years, the same age as earth. So the moon not only was hot, it still is, in the view of an increasing number of authorities.

If the moon is cool outside and hot inside, geologists say that it suffers severe stresses that must produce moonquakes. We see evidence of such jarring in the slumping of crater walls and the general downhill creeping of material. One Orbiter picture clearly shows the tracks of two rolling stones (page 236).

As evidence for a hot moon increases, one of the hottest debates in the whole field of lunar studies is cooling off slightly. That is the argument over whether the craters and other formations on the moon are volcanic in origin or were caused by impacts.

Many years ago everything was laid to volcanism. Then the careful studies of Ralph Baldwin led a number of people to believe that meteorites had caused most if not all of the moon's basins and craters, although Baldwin himself never went that far. Now the pendulum is swinging back again, and the majority of scientists see both processes at work. Some structures are generally recognized as impact craters, and others are more likely volcanic. Still others may show volcanic effect after the original formation by impact.

Two holdouts still stand at the two extremes. Dr. Jack Green, a lunar expert at the McDonnell Douglas Corporation in Huntington Beach, California, believes that more than 95 percent of the major lunar surface features are volcanic in origin. Yet he admits that "there must be some large lunar impact craters, for there are such craters on earth."

But Professor Thomas Gold, author of the early deep-dust theories, sees it the other way. "I am yet to be persuaded that there ever was any large-scale volcanism on the moon," he told me. "I think there is no hard evidence."

In between are all shades of opinion. Dr. Kuiper, who feels that too much attention has been given to impact theories, contends that many craters have been caused by subsidence of subterranean lava chambers.

And one of his associates at the University of Arizona, Robert Strom, says, "As I see it, about 10 percent of the craters are clearly impact-created, about 10 percent are volcanic, and the rest are uncertain. We will probably have to fight it out crater by crater!"

One thing everyone agrees on: There are no huge volcanic cones, like Mounts Fuji or Rainier, on the moon. And no clear-cut volcanic eruptions or lava flows have ever been observed to occur. For that matter, no one has ever seen a meteorite or a comet strike the moon. Of course, man's observation of the moon has covered only a moment in the long eons of lunar geological history.

But people have seen something else which excites suspicion that volcanic fires are still lit. In March 1587, an English observer wrote of seeing a bright spot on the moon "directly between the pointes of her hornes, the mone being chaunged not passing five or six daies before." In 1855, another observer wrote in the *Monthly Notices of the Royal Astronomical Society* that he had seen with his 10-inch telescope "two luminous spots, one on either side of a small ridge . . . of a yellow flame colour, while all the rest of the enlightened part was of a snowy white. . . . I observed it for five hours."

One could disregard such reports were it not that they number more than 800, many of them from respected astronomers. The sightings have been concentrated in a few locations, notably the craters Aristarchus (brightest spot on the moon) and Alphonsus. They take the form of temporary bright spots, red glows, red and blue bands, veils, violet tinges, and other peculiarities known generally as transient phenomena.

EKTACHROME BY RALPH MORSE FOR NASA

Rehearsing for M-Day, men and machines train on simulated lunar landscapes. At NASA's Manned Spacecraft Center in Houston, Texas, Astronaut Dr. Don Lind sets out a seismometer designed to measure moonquakes. Aluminized ground cloth will deflect the 243° F. heat of the lunar noon. This and other devices cram a compact kit, background, called ALSEP—Apollo Lunar Surface Experiments Package. Carried to the moon on an early manned landing, the instruments will radio scientific findings back to earth for as long as a year.

With an instrument for testing magnetism slung from its boom (right), a training vehicle threads a realistic reconstruction of a lunar crater field near Flagstaff. Some sort of roving, instrument-laden vehicle will one day traverse the moon to map its features and minerals. The Arizona field yawns with pits up to 80 feet across and 25 feet deep, blasted in volcanic soil by the U. S. Geological Survey.

In 1958, powerful impetus was given to the idea of "red spots" on the moon when a Russian astronomer, Nikolai Kozyrev, not only saw a bright "cloud" on or near the central peak of Alphonsus but also managed to record the phenomenon in a spectrogram.

And then in 1963 two United States observers, James C. Greenacre and Edward Barr, at the Lowell Observatory in Flagstaff, Arizona, both saw the same peculiar sight: three reddish patches near Aristarchus that lasted only half an hour.

There could be no doubt—something strange happens sporadically on the moon. NASA became so interested that the following year it supported Operation Moon Blink, with volunteer observers at a number of observatories to watch for transient phenomena.

These observers use a special device on their telescopes—a rotating filter wheel with an image tube—that causes any color spots on the moon to blink rapidly. So far Moon Blink teams have observed 10 such phenomena, of which 3 have been separately confirmed.

One analysis of the dates of sightings reveals a curious fact: The events happen much more frequently when the moon is closest to earth (when tidal forces distorting the moon's crust—81 times as great as those on earth—are at their peak), and again when the moon is farthest away (when its crust goes through maximum relaxation from such distortions).

Faced with this evidence, a few scientists have suggested that under the stress of tidal forces fractures open in the moon's surface, allowing gases to escape. These elusive gases might be from volcanic sources, or they could be cold gases fluorescing under solar radiation. Few entertain any idea, however, that they are flows of molten lava.

> The innocent moon, that nothing does but shine, Moves all the labouring surges of the world.
>
> FRANCIS THOMPSON, "SISTER SONGS"

Anyone who has sat by the sea and observed the unfailing regularity of the tides knows something of the mysterious gravitational force the moon exerts on earth.

That force affects not only the waters but

KODACHROME © NATIONAL GEOGRAPHIC SOCIETY

the land as well. It creates a tidal bulge in the earth's surface that, like a wave, moves around the earth with its crest pointing directly toward the moon.

No, not quite. Because of friction within the earth, and because the earth is spinning so much faster than the moon is orbiting, the bulge is dragged slightly forward in the direction of the earth's rotation.

To picture this in your mind, imagine that the earth is the face of a clock, and that the moon at this moment hangs directly above it at twelve o'clock. Theoretically the earth's bulge should also be exactly at twelve o'clock, right under the moon.

But as the earth turns, it makes a full rotation in only one day; the slower moon takes more than 29 days to cover the same circle. So the bulge on earth tends to get dragged forward, and (in our imaginary model) points to one o'clock instead of twelve. This means that it is always moving slightly *ahead* of the moon. Now, because of the laws of gravity, that tiny bulge gives a continuous extra pull whose effect is to tug the moon forward and thus speed it up. The same force, working in reverse, tends to slow earth down.

As any astronaut can tell you, if you attempt to speed up a satellite it immediately goes into a higher and larger orbit and slows down—and that's exactly what happens to the moon.

This might all sound like theoretical nonsense were it not for evidence that it is all happening, and has been happening for many hundreds of millions of years.

For example, studies of daily and monthly growth lines in fossil corals suggest that in the Devonian Period, 350 million years ago, earth days were only 21.9 hours long and there were about 400 days in a year instead of 365. Our planet did indeed spin faster then.

And astronomers, making very exact checks on the position of the moon against the stars, discovered long ago that the moon is taking longer and longer to make its circuit. It is, in fact, steadily pulling farther and farther away from us.

Today, by timing radio signals from earth relayed back by Lunar Orbiter, the moon's distance has been measured with an error of less than 1,000 feet. It varies throughout the month by about 31,247 miles, but the mean distance, center to center, is 238,856 miles.

How close might it have been in earlier times? Scientists naturally have pondered this intriguing question, and have made intricate calculations. Dr. Gordon J. MacDonald, a geophysicist and a vice-chancellor of the University of California at Santa Barbara, finds that the moon would have been only 11,000 miles from earth less than two billion years ago. It could not have been much closer without shattering into fragments. Tides on earth, with the moon at such a distance, would have been a thousand times higher than they are now (assuming there were oceans then).

All this raises wonderful and fascinating questions about the moon's origin. Did it come into being at the same time as earth, as a sort of sister planet? Did earth at some early stage divide like an amoeba and give birth to the moon, as a daughter? Or did the moon come into being in some other part of the solar system, and, on one swing of an elliptical orbit, come so close to the earth that it was captured, like a spouse (page 222)? Or were there once a number of small moons that were swept up and coalesced into one? All these hypotheses have adherents.

Answers to such questions are not easy, but it is precisely such questions that astronauts and cosmonauts have in mind as they approach the moon. And it is clear that they will find that scarred and buffeted celestial wreck a far more complicated and interesting place than most people have supposed.

The first American astronauts on the moon will probably be able to do little more than gather a few pounds of samples—and each of the 130 scientists back on earth who have been chosen to study and analyze those samples hopes against hope that some of the material will represent the moon in its infancy.

Later astronauts will deploy a group of instruments on the moon, complete with their own nuclear power supply and a transmitter to send continuous information to earth about such things as moonquakes, solar wind, the flow of heat, and magnetic fields (page 226).

Still later will come roving vehicles, manned and unmanned, to traverse the bleak lunar terrain. And finally will come colonies, small bands of hardy men who, like their pioneer forefathers, will bend an unfriendly environment to their needs.

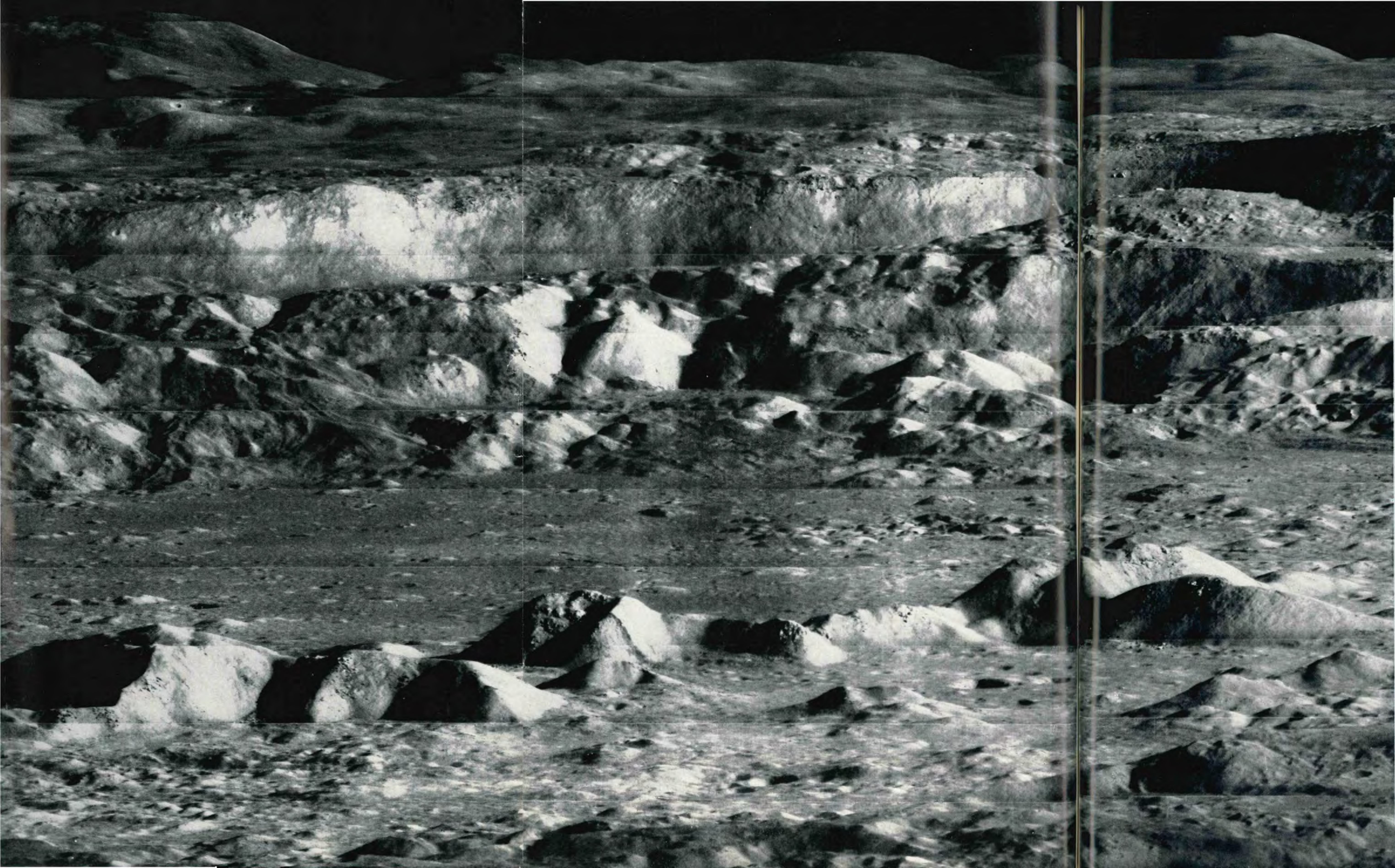
"It is strange to think," as Arthur C. Clarke says in *The Promise of Space,* "that in a few more years any amateur astronomer with a good telescope will be able to see the lights of the first expeditions, shining where no stars could ever be, within the arms of the crescent Moon."

THE END

For an artist's view of a future moon colony, fold out the opposite page. ▶

PAINTING BY DAVIS MELTZER © NATIONAL GEOGRAPHIC SOCIETY

Frontiersmen of the Space Age, engineers and technicians colonize the moon. Drawing on the most advanced thinking of experts, artist Davis Meltzer portrays a lunar outpost that might be possible in a generation. A survey team drills core samples and maps the surface as an attendant monitors the oxygen supply. Aluminum habitation modules lie almost buried for protection against micrometeorites and temperatures that fluctuate 500° F. between noon and night. In a laboratory module, foreground, biologists observe animals and experiment with raising vegetables in fertilized water. A multi-level main module encloses dressing rooms for entering and leaving, medical dispensary, dormitory, kitchen, and dining and recreation areas. Pressurized tunnel leads to a smelter, where lunar rock quarried on the surface is processed for the water chemically locked within it. The water not only fills the station's swimming pool, but also yields oxygen for breathing and hydrogen for fuel for a flying vehicle, far left. A fencelike radio telescope probes deep space, and an optical scope in a small observatory studies the heavens, undimmed by earth's atmosphere. Beside a hangar pit, a commuter rocket poises for return to the blue planet earth.



A NINE-PAGE PORTFOLIO

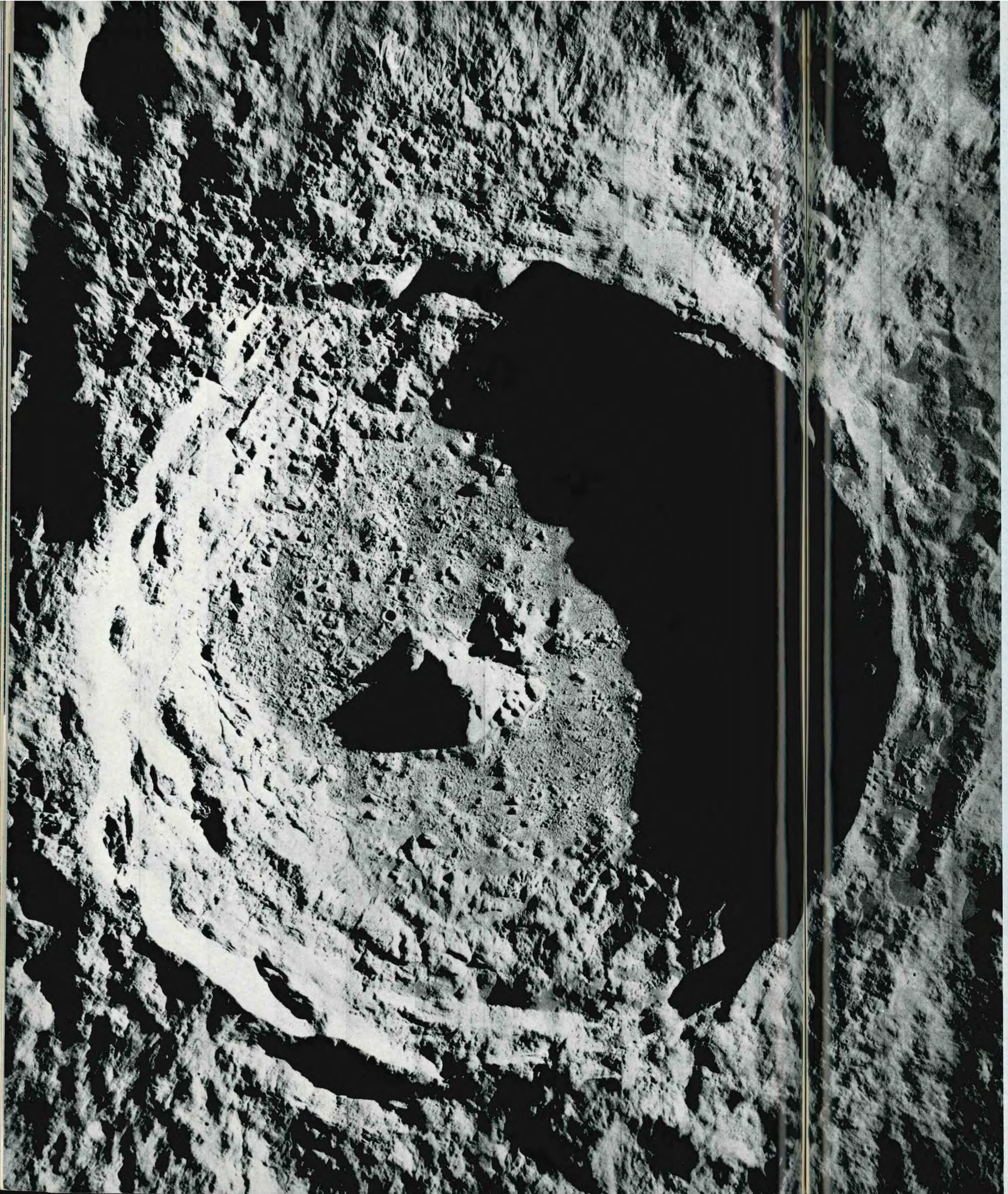
Awesome views of the forbidding moonscape

Badlands of the crater Copernicus loom menacingly in this extraordinary photograph taken by Lunar Orbiter 2 on November 23, 1966. As the picture-taking U. S. satellite swept past the moon 30 miles high, it captured this spine-tingling panorama—acclaimed "the picture of the century."

The tremendous sense of being on the moon derives from the camera's oblique shooting angle, plus the distance-shrinking power of its telephoto lens. Instruments aboard the satellite scanned the original film in bands and transmitted them bit by bit to earth in digital form; a computer reassembled the picture.

Lunar Orbiters photographed 99.6 percent of the moon's surface while probing for Apollo landing sites. Though the first manned craft will land in smoother regions, Copernicus will be an early target for exploration. Sequences of rock formations visible in its plunging walls will offer lunar geologists a look back through time into the moon's early history.

NASA



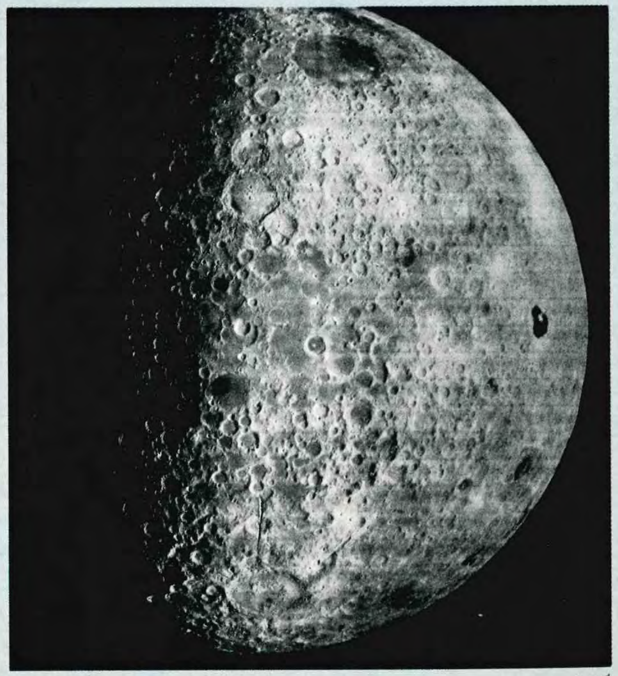
MT. WILSON AND PALOMAR OBSERVATORIES

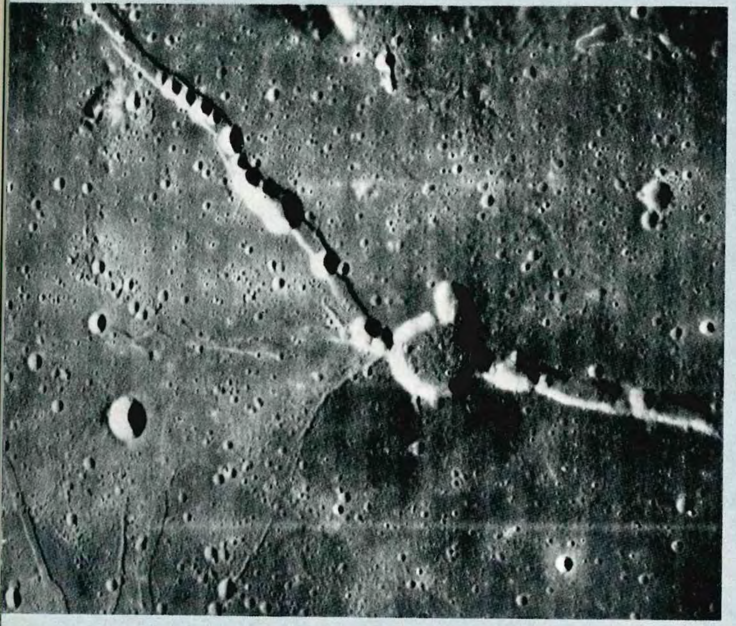
Familiar lunar face, seen through an earth telescope, flaunts its silver-and-black brocade of dark maria, bright highlands, and sequinlike craters. Flashy rays of the crater Tycho beguiled some into mistaking it for a south pole. Today the rays are thought to be highly reflective material spewed out or uncovered at Tycho's cataclysmic birth.

Crater Tycho's yawning mouth, 54 miles in diameter, pokes out a tongue of stone 7,000 feet high. The crisp rim and untarnished rays indicate that Tycho is recent by moon standards. Surveyor 7 soft-landed on comparatively smooth terrain just beyond the crest of the rim at upper left.

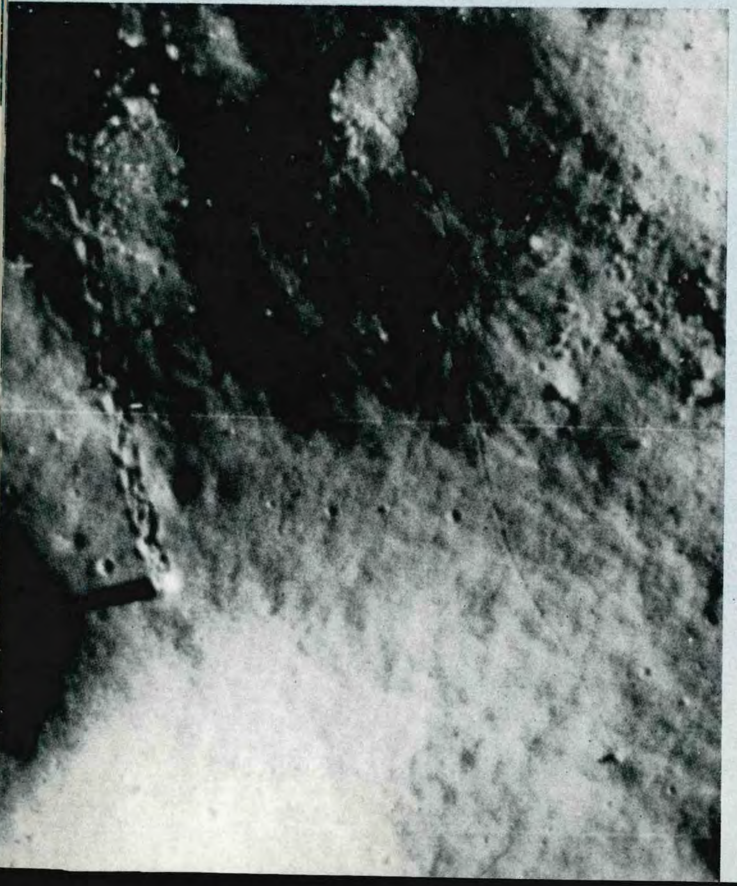
Around-the-corner glimpse from 1,856 miles shows a profile never seen from earth. Shadow blots out nearly all of the moon's front face. Tsiolkovsky crater, the dark patch at right center, pocks the orb's far side. The bright spot within it is a sun-struck peak, similar to Tycho's.

LUNAR ORBITER 4 (BELOW) AND LUNAR ORBITER 5 (LEFT), NASA





Long channel on the moon's face, the two-mile-wide Hyginus rille contains a chain of holes—possibly rimless volcanic craters or depressions formed as the floor of the rille subsided or collapsed. Relatively straight except for a dogleg, the rille probably formed from a tension fracture of the lunar crust. Other, quite different rilles, more meandering or sinuous, may have been made by flows of ash, lava, or water.



Startling signs of movement in an eerily silent world, two boulders—one of them as big as a house—have left clearly visible tracks several hundred yards long down a slope of the crater Vitello. What dislodged them? Some scientists say a relatively recent moonquake, on the theory that the moon is still a living, self-changing body like the earth.

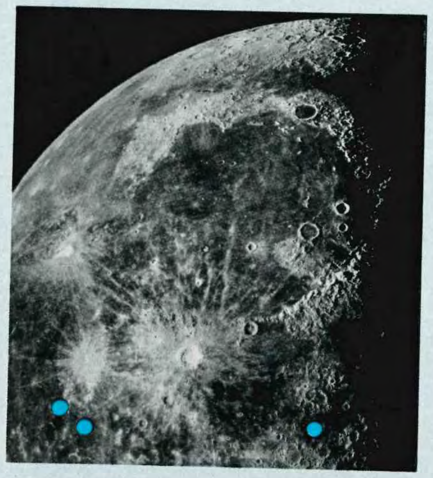
ALL BY LUNAR ORBITER 5, NASA

River bed on the moon? An eye accustomed to earth's landscape might identify the snakelike rille within the 75-mile-long Alpine Valley as a river channel. In fact, some experts believe that this and other rilles may indeed have been carved by rivers during a period when the moon had a temporary atmosphere. The Alpine Valley itself, most agree, was formed by faulting of the moon's crust in a process not unlike that which created earth's Great Rift Valley. Later, after debris or lava smoothed the valley floor, the rille evolved from flow or subsidence. The valley slashes through a range of rugged mountains called the Alps, part of the rim of smooth Mare Imbrium.

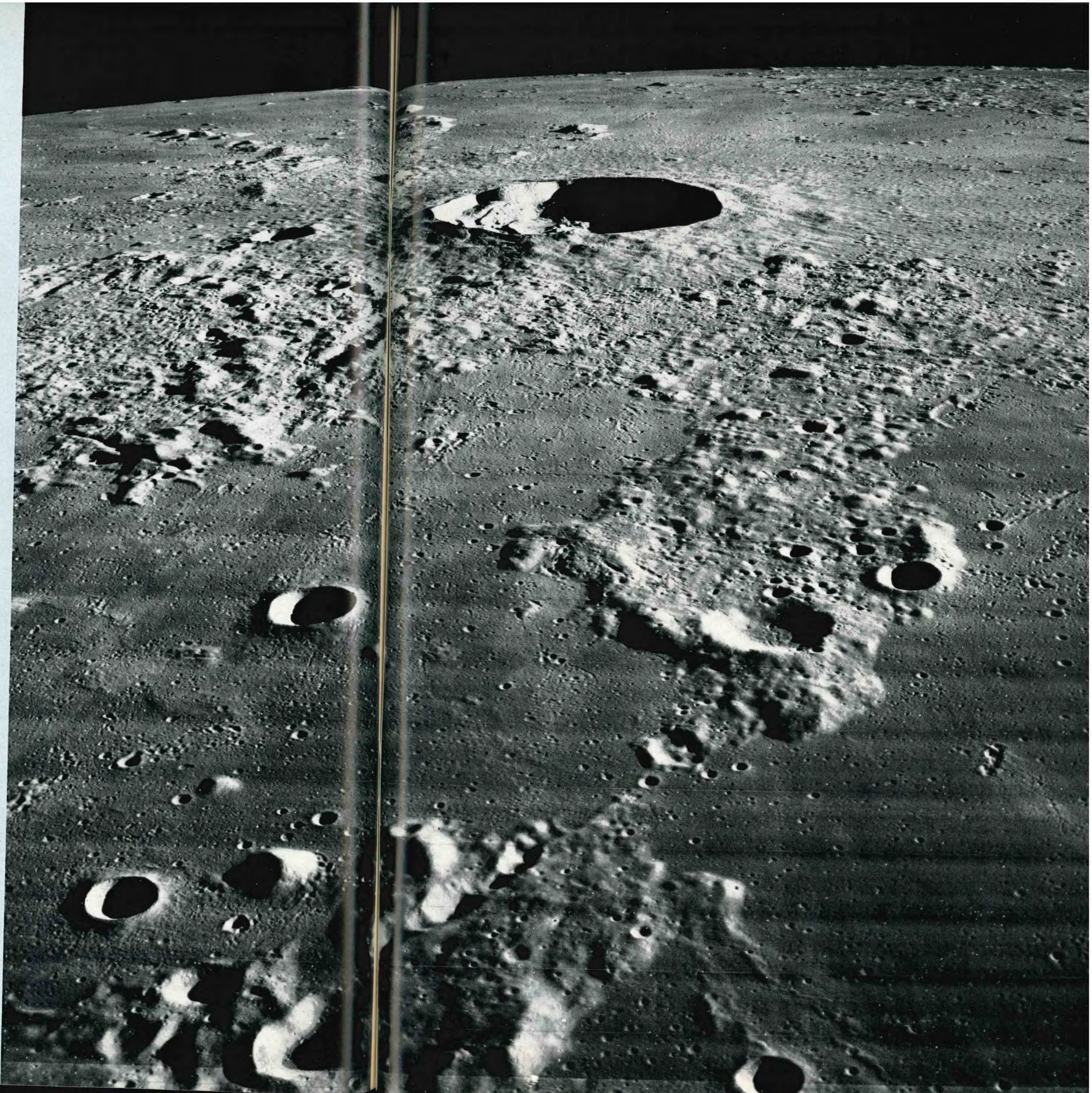
Apollo landing

As their spacecraft slows for its historic touchdown on the moon, two U. S. astronauts may well shiver in awe at this very view of Kepler crater (right). If the Kepler region proves to be the target, their spindly-legged Lunar Module (above) will probably land just beyond the lower left corner of this Lunar Orbiter 3 photograph.

The blue dots on a telescopic view (below) represent three potential Apollo landing sites. Kepler is the bright-rayed crater at lower left. The oval in the mosaic strip map (bottom) shows a close-up view of the area within the blue dot nearest Kepler. (See supplement map, **The Earth's Moon**, for the five proposed Apollo landing sites.)



MT. WILSON AND PALOMAR OBSERVATORIES (UPPER); LUNAR ORBITER 5, NASA



How We Mapped the Moon

By DAVID W. COOK
National Geographic Staff Cartographer

THANKS to the full photographic coverage flashed back to earth by United States Lunar Orbiter spacecraft, the National Geographic Society this month presents to its 6½ million members a unique wall map, **The Earth's Moon**.

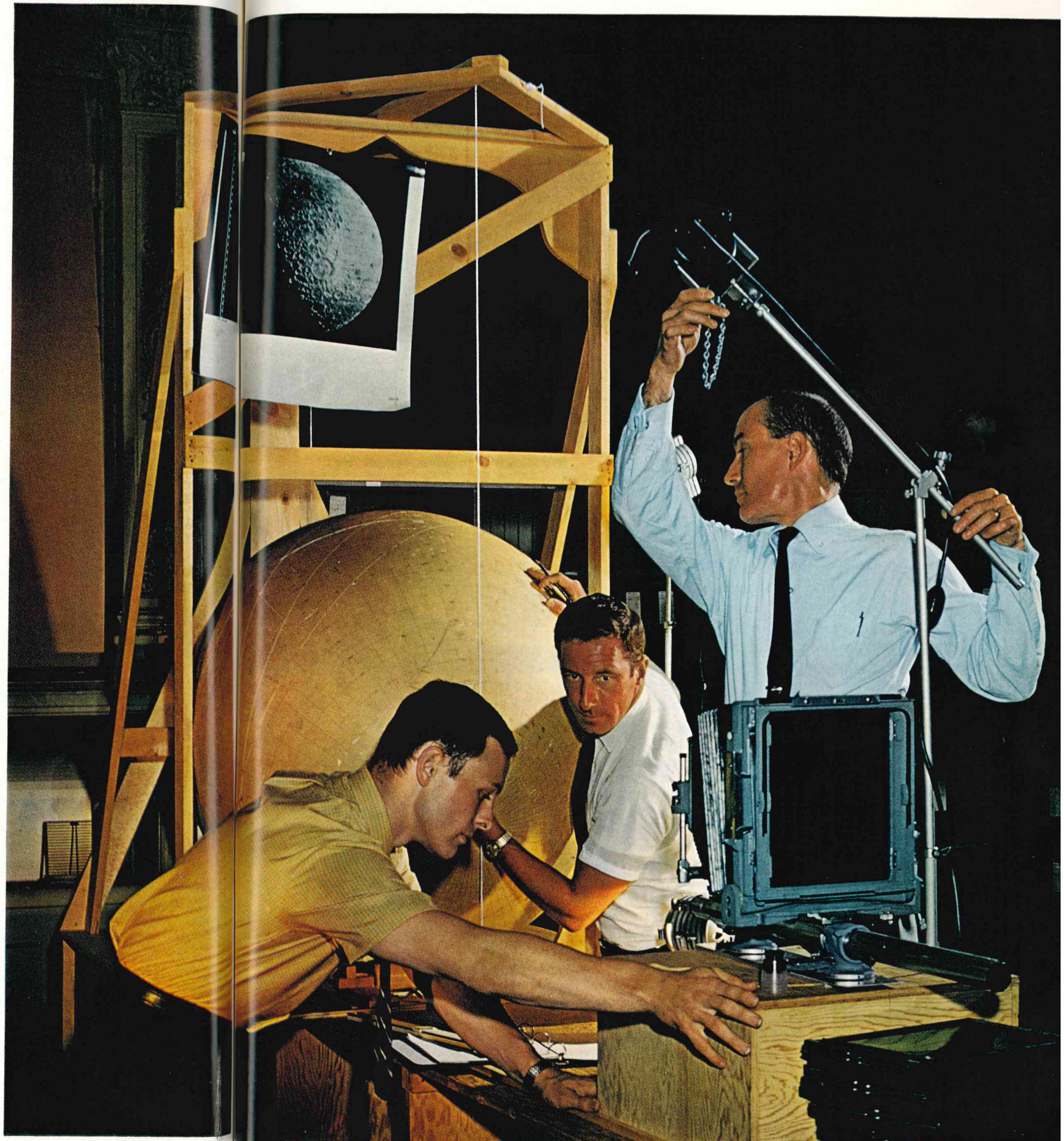
This special supplement to the February GEOGRAPHIC shows the moon in two hemispheres—not only the familiar face constantly turned toward our planet, but also the largely hidden far side, heretofore a synonym for all that is mysterious, remote, and unknowable.

Look along the equator of the moon's near side and you will see, marked in red, the five landing sites proposed for our Apollo astronauts. The final choice will largely depend upon the date of lift-off from earth.

Almost exactly in the center, very near Landing Site 3, lie Surveyor 4, which crash-landed in July 1967, and Surveyor 6, which set down gently nearby in November of the same year. Our first lunanauts may see those pioneer mooncraft.

The map shows in red the final resting places of all but one of the 23 unmanned spacecraft that have reached the moon's surface, 17 American and 6 Soviet. The crash site of one U. S. craft, Orbiter 4, is uncertain.

In 1959 and 1965 the Soviet Union's Luna 3 and Zond 3 looped around the moon and sent back the first photographs of the far side. But the pictures lacked sharp detail, and vast areas were not photographed at all. It remained for the United States space program, under the National Aeronautics and Space Administration, to obtain the first complete and detailed record of the moon's geography—more accurately, selenography, from *selene,* the Greek word for moon.



Putting moon craters where they belong: The Society's cartographic staff built this ingenious rig to fix the exact position of the thousands of features on the Society's extraordinary new map, **The Earth's Moon**. Using a 40-inch earth globe to represent the moon, Richard R. Furno adjusts a camera to simulate the distance from which a Lunar Orbiter spacecraft made the photograph hanging above. David W. Cook, author of this article and designer of the map, turns the globe to align it with the camera, while photographer Victor R. Boswell, Jr., positions lights. The picture thus obtained establishes the precise latitudes and longitudes of lunar features shown in the Orbiter view.

KODACHROME © N.G.S.

A map is born

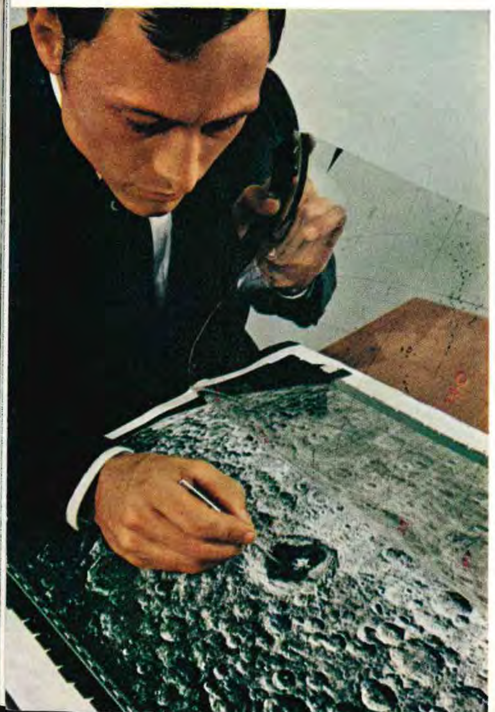
CRATER BY ENDLESS CRATER, National Geographic men fill in details of the moon's incredibly pocked far side.

Using data from the process shown on the preceding page, cartographer Furno (below) transposes grid marks onto a photograph of the crater Tsiolkovsky, a prominent feature of the far side. After placing a plastic grid on the Orbiter picture, he pinpricks holes through the overlay onto the photograph where the lines intersect, then connects the holes by lines that become parallels and meridians.

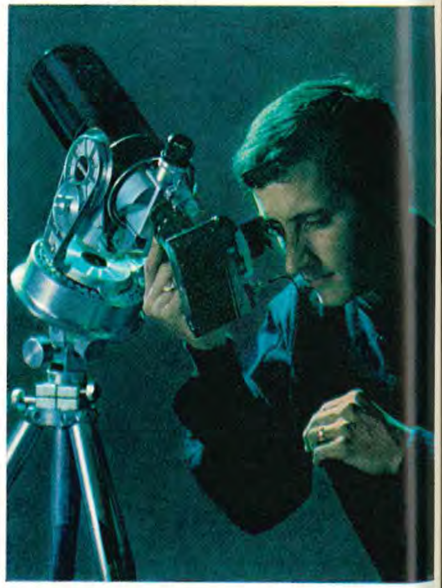
With airbrush and hold-down stick, artist Tibor Toth uses the grid-marked Tsiolkovsky photograph as a guide for portraying features heightened by shadows (right). To adapt Geographic relief-mapping techniques to the portrayal of lunar features, he trained under Terence C. McCann at Lowell Observatory in Arizona.

Because the Orbiters snapped photographs at various times of the lunar day, shadows vary in each picture according to the angle of the sun. To make the Society's map, Mr. Toth showed all lunar features as if lighted by a setting sun.

KODACHROMES BY JAMES E. RUSSELL © N.G.S.



Aiming moonward, David L. Moore focuses a Nikon F camera attached to a Questar reflecting telescope. A built-in motor, synchronized with earth's rotation, slowly pivots the 3.5-inch telescope to follow the moon as it arches across the heavens. This precision tracking makes possible long exposures on fine-grain film, thus improving photographic detail. From his pictures, Mr. Moore made 11 map drawings that illustrate the phases of the moon.



In 1966 and 1967 five Lunar Orbiters circled round and round the moon, swinging from nearly 4,000 miles above its surface to less than 30. By radio, strip by strip, they sent back thousands of pictures of the high quality that cartographers dream about (pages 210 and 234, for example). All together they covered 99.6 percent of the moon.

But before the Orbiter photographs could be used as the basis of our map, they had to be fitted with a grid of latitude and longitude. Staff cartographer Richard R. Furno came up with the solution.

"Why not," he asked, "take a globe with lines of latitude and longitude and let it represent the moon? Then we can photograph it from the same relative altitude and position from which each of the Orbiter photographs was taken. For each picture we have the data needed to position the camera."

In the spacious old library of the National Geographic Society's Hubbard Hall, we built such an apparatus (pages 240-41). Then we began taking hundreds of pictures, each from a different and carefully calculated point in relation to the globe. This took us about three months, but it gave us a grid that precisely located each moon mountain, mare (Latin for "sea"), and crater (opposite page).

A True Map, Not a Picture

Traditionally, moon maps have been drawn on the orthographic projection, which presents lunar features as seen from earth. In such maps the central portion has good accuracy, but features around the sides are badly distorted because they are shown almost on edge. Now, with photographs of virtually the whole lunar sphere, we could make a true map of each hemisphere and correct this visual distortion.

For our map we chose the Lambert Azimuthal Equal-Area Projection, which shows each feature in its true direction, or azimuth, from the center of its hemisphere, and also in true area scale. A dime placed anywhere on the map will cover exactly the same area—about 10,500 square miles.

Until the Space Age, most maps showed the moon's north pole at the bottom, since astronomical telescopes turn images upside down. Ours shows the moon with north at the top, to conform with modern usage.

At first glance, all the craters may look alike. Actually, every one has some distinctive characteristic, and Hungarian-born staff artist Tibor Toth tried to capture as many of these details as the scale of the map would permit. To enable him to become intimately familiar with the moon's pocked and ravaged face, Chief Cartographer Wellman Chamberlin arranged for him to spend several weeks at Lowell Observatory in Flagstaff, Arizona, where some of the world's most skilled selenographers have been drawing highly detailed maps of the moon for the Air Force Chart and Information Center. Then, by careful use of light and shadow, Mr. Toth made our map's relief drawings, in which each lunar feature stands out as if seen in three dimensions.

Perhaps the most striking aspect of the new map is the difference in appearance of the moon's two sides. Across the near side, particularly in the north, spread dark, level plains, the maria. Yet the far side, covered with craters, seems almost devoid of these plains. Why? Moon experts do not yet agree.

Features Indexed for Quick Location

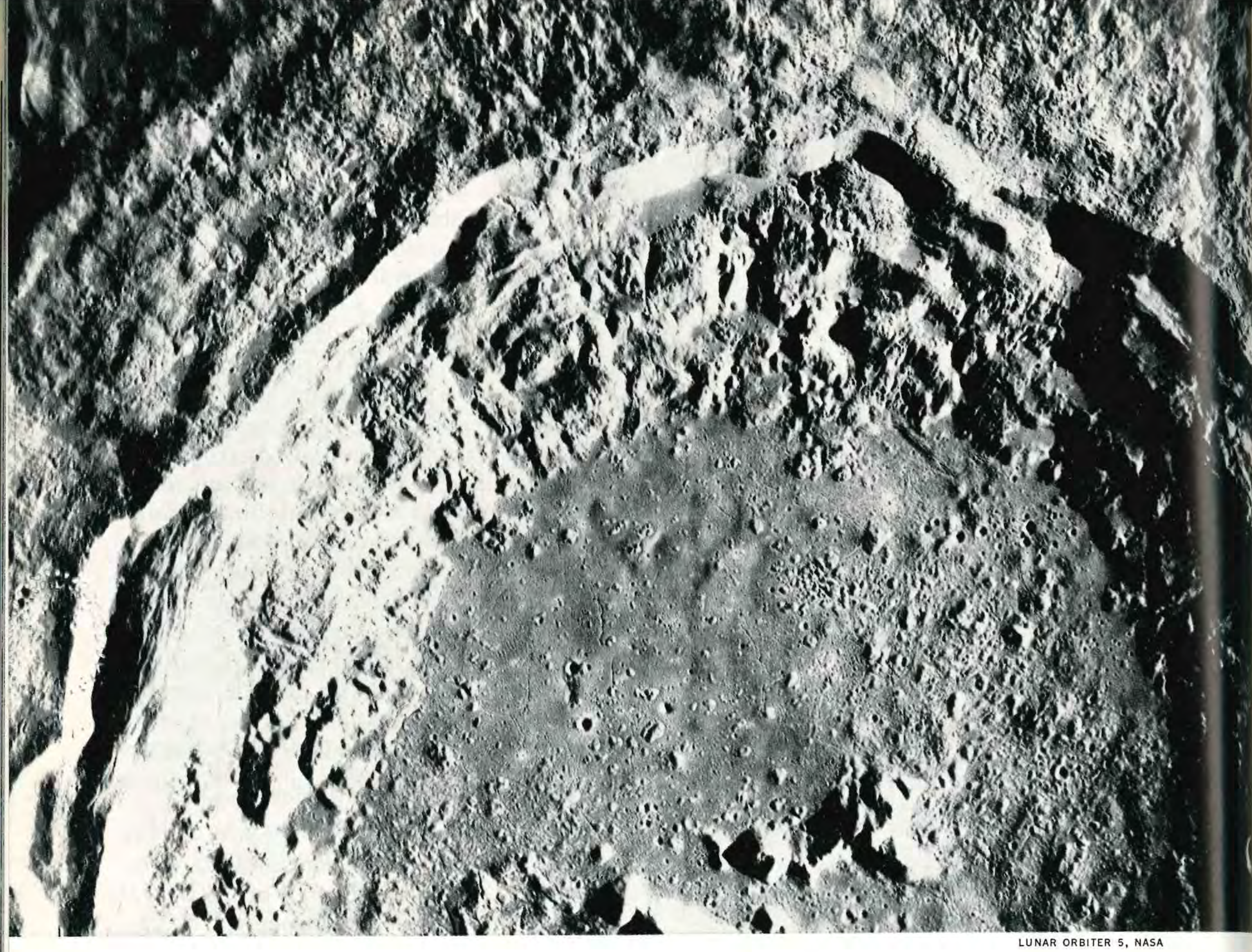
All the more prominent features of the moon are indexed on the map and can be located by coordinates: red letters on the central meridian through each hemisphere, red numbers across the lunar equator.

Many lunar features, especially on the far side, still lack official names, since the special commission of the International Astronomical Union which is charged with this responsibility does not plan to meet until 1970 to consider the hundreds of moon features now mapped for the first time. Outstanding exceptions are three far-side features—Mare Moscoviense and the craters Tsiolkovsky and Jules Verne—all named by the Russians and officially accepted.

Craters beyond number mark both the near and far sides of the moon. Copernicus, Darwin, Einstein, Colombo (Columbus), Vasco da Gama—their names read like a roll call of famous scientists and explorers. Jesuit astronomer Giovanni Riccioli in 1651 began this practice of naming lunar features for great men (see map, page 208).

Near the moon's north pole you will find craters named Peary and Byrd, for the American explorers of earth's North Pole; likewise, near the lunar south pole lie craters named Amundsen and Scott, for the Norwegian and the Briton who first reached the terrestrial South Pole 57 years ago.

Small areas near the south pole marked "Unsatisfactory Photography" remain the



LUNAR ORBITER 5, NASA

only parts of the moon not yet mapped—less than half of 1 percent.

Apart from the two large hemispheres, the map and its 3,630 words of notes contain a wealth of information and lore, ranging from the number of known moons in our solar system (32) to the plan for the Apollo moon-landing flight. This stretches across the map's full width at the bottom, thus making it possible to show the earth, the moon, and the distance between them in true relative scale.

Assigned to make the diagrams showing the moon's phases, staff cartographer David L. Moore (page 242) spent many sleepless nights photographing the moon to assure complete accuracy in his drawings.

Other diagrams and notes show how the moon "nods" and "shakes its head," how it causes tides and eclipses, how it compares to the moons of other planets.

To visualize its true size—2,160 miles in diameter—look at the moon's disk drawn atop the United States. Las Vegas, Nevada, peers around one edge and Philadelphia, Pennsylvania, just shows on the other.

Another sketch lets you grasp the true magnitude of the moon's craters. It shows our Grand Canyon dwarfed by Copernicus (above). By no means the largest crater, it compares to Yellowstone in size and could swallow the entire state of Rhode Island.

To give the map an intriguing border, we made it a sometimes serious, sometimes whimsical catchall of 163 names and terms related to the moon, moon lore, and space travel. The list includes astronauts, cosmonauts, spacecraft, scientists and rocketeers, lunar place names, technical terms, and such familiar Space Age expressions as A-OK, countdown, lift-off, and rendezvous.

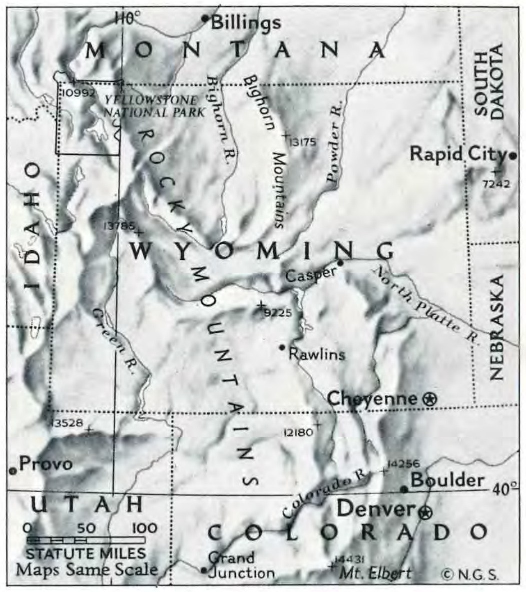
U. S. and Soviet Space Heroes Honored

Our map border honors Gus Grissom, Ed White, and Roger Chaffee, the three astronauts who died on January 27, 1967, when fire swept their spacecraft during a test at Cape Kennedy. Grissom was one of the original team of astronauts, and the other six—Glenn, Shepard, Slayton, Carpenter, Schirra, and Cooper—also appear.

The late Yuri Gagarin, the first man in space, is there. So are his cosmonaut colleagues Popovich, Nikolayev, Titov, Leonov, and Valentina Tereshkova—the first woman

Copernicus equals Yellowstone

For dramatic comparison, the Society's cartographers have mapped here a large slice of the American West and an equal-size area of the moon, employing the same technique and style used for the supplement map, **The Earth's Moon**. The comparison reveals that the moon crater Copernicus, shown in part in the Orbiter photograph at left, just about matches in size our largest national park, Yellowstone. Journeying from Copernicus to the crater Ptolemaeus, a traveler would log 400 miles—the distance from Yellowstone to Denver, Colorado. Interestingly, the 12,600-foot-high rim of Copernicus actually towers higher above the crater floor than do the Rocky Mountains over Denver's mile-high plain.



in space. Even Laika, the Soviet dog that circled the earth, made the list.

Spacecraft named in the border include the Soviet Union's Lunik 2, first to crash-land on the moon; Zond 5, the first craft to make a circumlunar voyage and return safely to earth; Friendship 7, the capsule in which John Glenn became the first American to orbit the earth; and Ranger 7, our first successful lunar photo-reconnaissance vehicle.

Three great astronomers of the past, Hevelius (who in 1647 produced the first real map of the moon), Tycho Brahe, and Kepler, are among a who's who of men of science on the border. It includes such present-day space experts as Wernher von Braun, Bernard Lovell, Robert Gilruth, and the late Hugh L. Dryden, for 14 years a Trustee of your Society, and, until his death in 1965, NASA's top scientist.

On the lighter side are popular descriptions of the moon, literary allusions, authors, fragments of nursery rhymes—even a comic-strip character, Moon Maid.

A puzzler, perhaps, is Wan Hoo. Who was Hoo? A rich merchant of Chinese legend who longed to visit the moon, he had himself strapped into a chair with 47 rockets fastened to its back. He held a kite in each hand, and his servants lighted the rockets. No one ever saw Wan Hoo again.

The Pill of Immortality comes from an ancient Chinese legend that the rabbit on the moon, shown in an inset on our map, keeps pounding away to make such a pill.

Cavorite? All of us might wish for a little of that, an antigravity substance dreamed up by H. G. Wells for a story, *The First Men in the Moon,* in 1901.

"I am Eagle!" That's what Gherman Titov exclaimed over the radio, exulting as Vostok 2 carried him around the earth on the second manned orbital flight.

And what color should we make our moon? Over the centuries our satellite has been variously described as red, golden, pale, gray, silver, even blue. For realism as well as beauty we decided to show it silvery-gray against the blue-blackness of night. THE END

Additional copies of **The Earth's Moon** wall map may be ordered from Dept. 61, National Geographic Society, Washington, D. C. 20036, for $1 each on paper, plus 15 cents postage, or $2 on plastic, plus 30 cents postage; both are available rolled instead of folded. A companion wall map, **The Heavens**, showing positions of the planets through 1970, is also available at the same prices.