ATLAS MAP SUPPLEMENT: CHINA (page 641)

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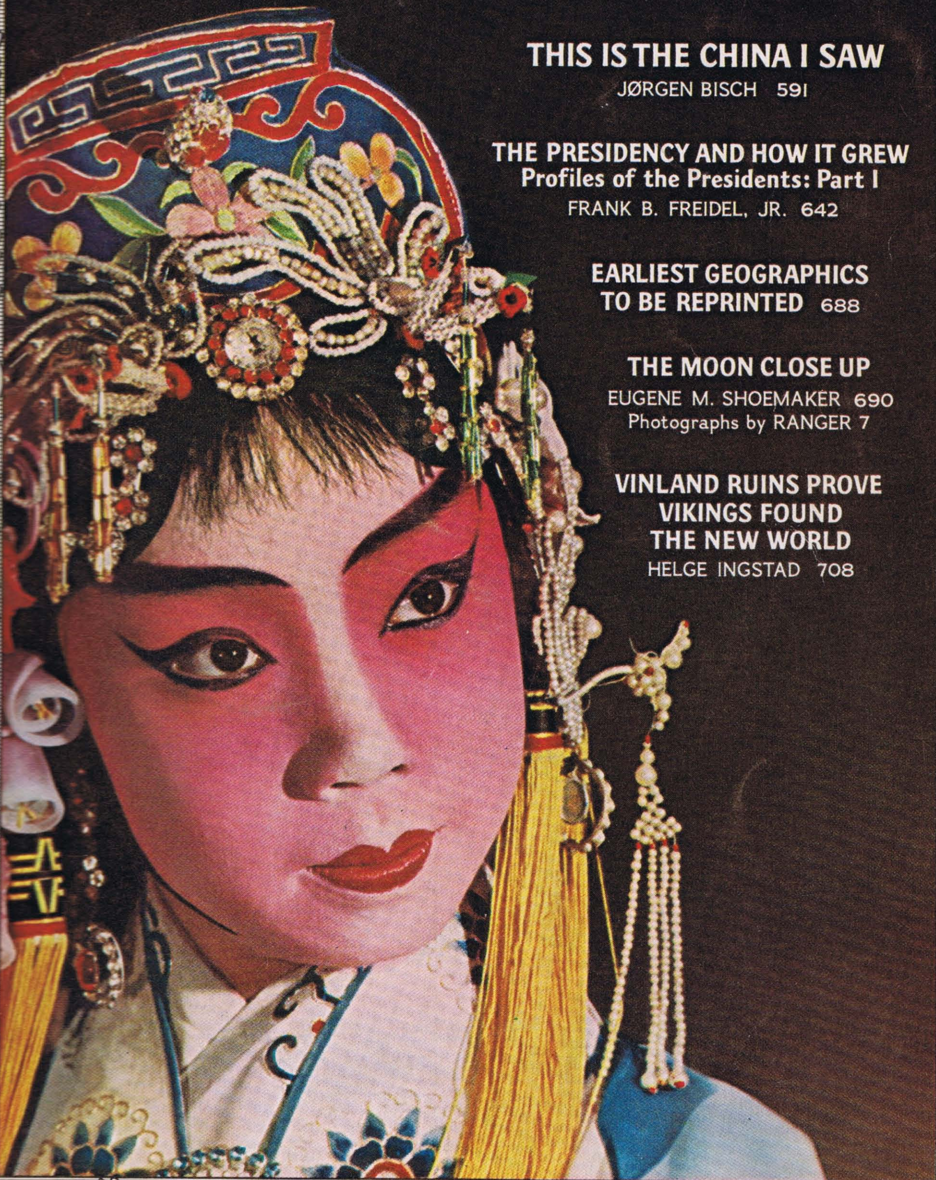

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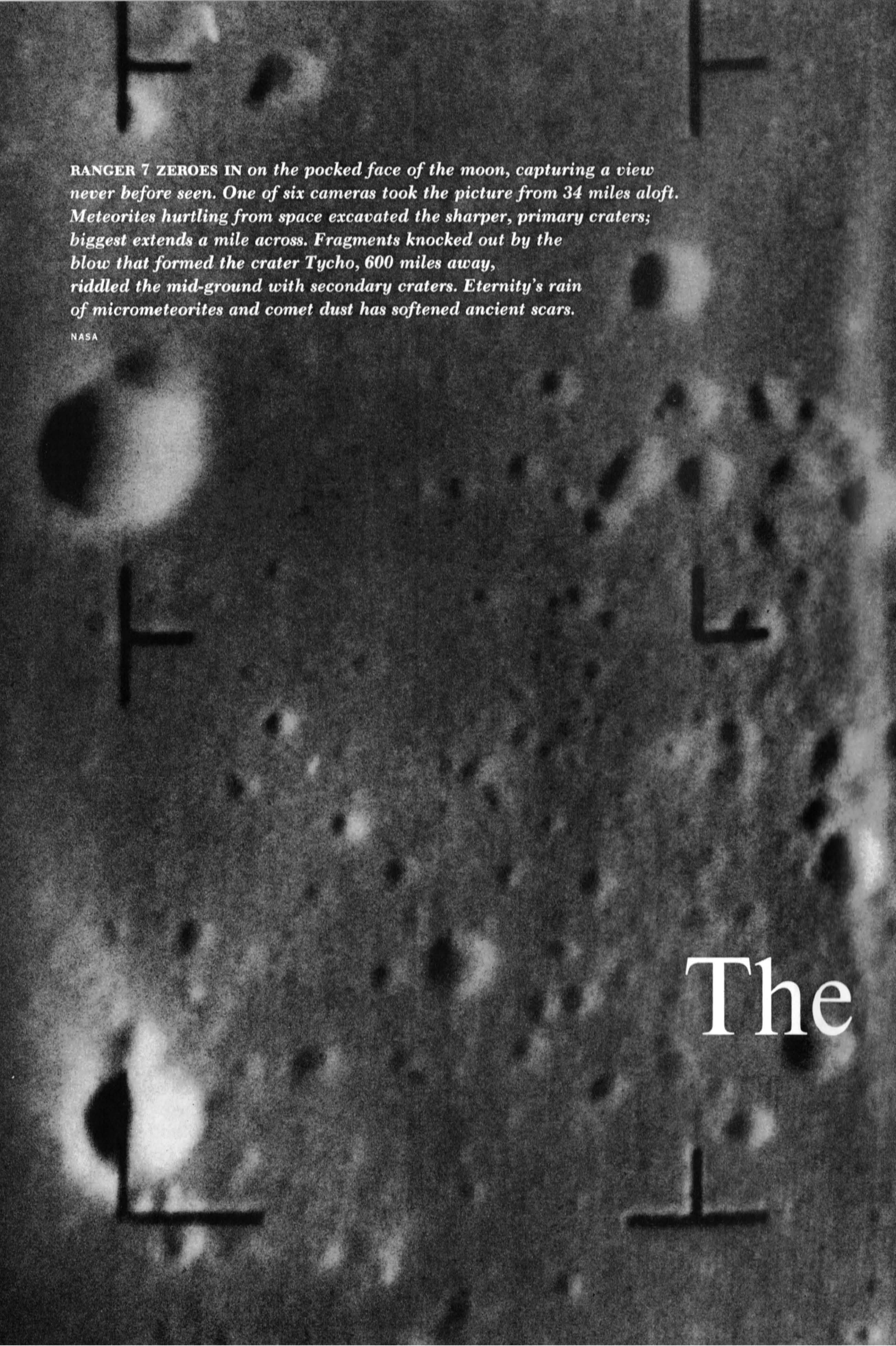
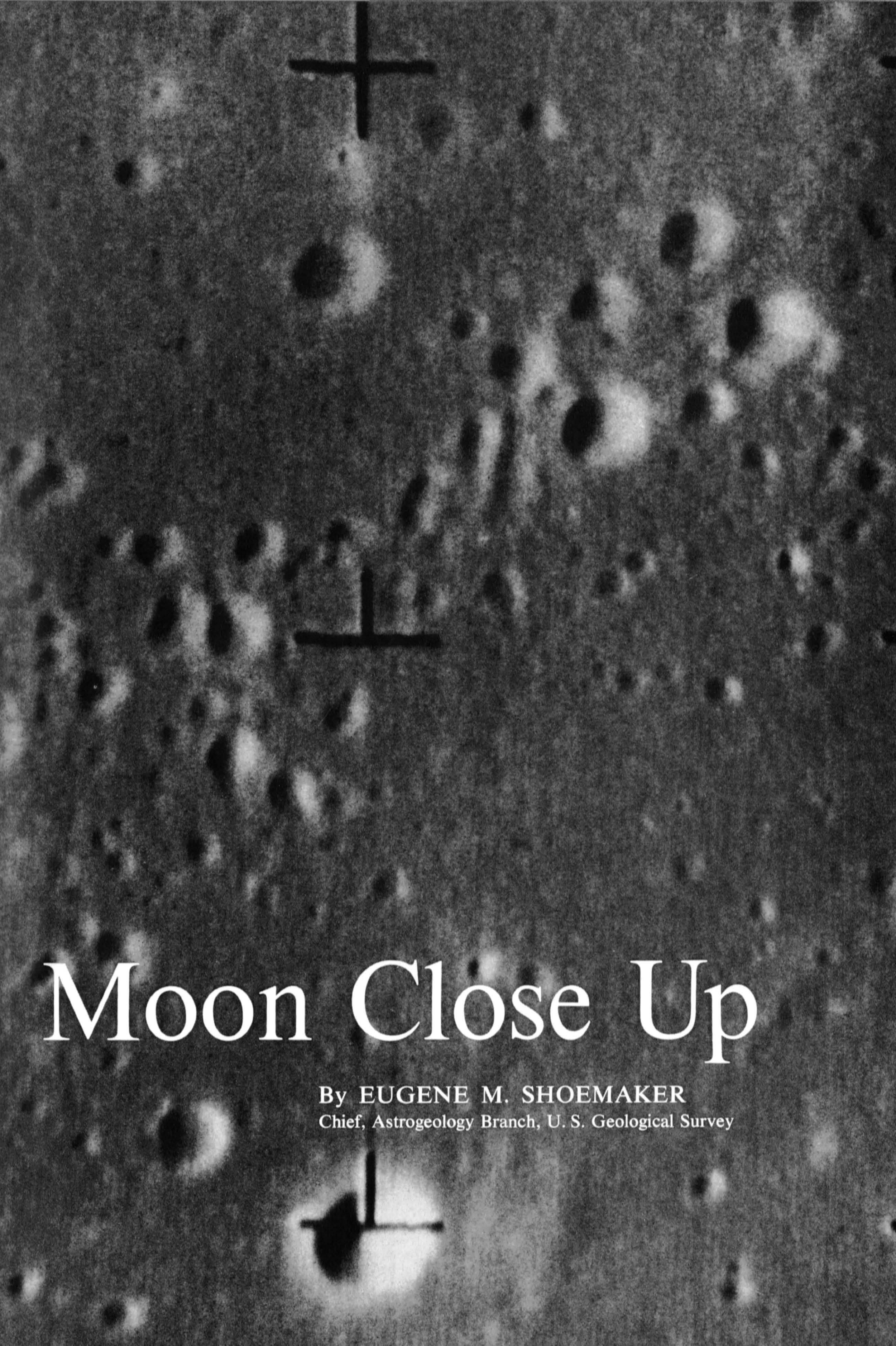


RANGER 7 ZEROES IN *on the pocked face of the moon, capturing a view never before seen. One of six cameras took the picture from 34 miles aloft. Meteorites hurtling from space excavated the sharper, primary craters; biggest extends a mile across. Fragments knocked out by the blow that formed the crater Tycho, 600 miles away, riddled the mid-ground with secondary craters. Eternity's rain of micrometeorites and comet dust has softened ancient scars.*

NASA

The



Moon Close Up

By EUGENE M. SHOEMAKER
Chief, Astrogeology Branch, U. S. Geological Survey

THE MOON WILL NEVER seem the same. For scientist and romanticist alike, its enigmatic face is altered. It's our fault, and we're delighted. We've taken the first close look at our space mate, and if fantasies have faded, facts have replaced them. And the facts suggest that we can set down a manned spacecraft on the lunar landscape without unreasonable risk.

Earth's Satellite Brought Nearer

Ever since man became man, and so learned to wonder, the moon has seized his emotions and teased his curiosity. Millenniums of myth and mystery brought him no closer to an understanding of the eternal traveler of the night skies than was his low-browed ancestor, watching naked on the African plains.

Then, an instant ago in the time span of the planets, an Italian named Galileo made a telescope and at once saw many wonderful things. In that moment our knowledge of our place in space leapt forward. The moon took form and revealed its features. A period of great astronomical discovery began.

By July 31, 1964, when the spacecraft Ranger 7 hit the moon, we had gone about as far as we could in discerning lunar topographic features with earth-based optics. Our best telescopes had brought us visually to within 400 miles of the moon's surface. But they could do no more. The protective atmosphere that shields us from the blaze and bombardment of the universe also shields its secrets from us; our vision is blurred. No lunar detail less than 800 feet across had been distinguished from our planet.

Still, we had inherited many basic facts about the moon. We knew its diameter: one-quarter that of the earth; its mass: $1\frac{1}{4}$ percent of earth's; its orbital and rotational periods: both $27\frac{1}{3}$ days, keeping the same face always toward us.

And we had learned much that was new, as befits a nation on the verge of space travel. We had measured variations in the brightness of the moon's reflected light. We had charted its features, all the way down to those of one mile or less across. We had worked out the layering of its surface, and so learned the sequence of major events in its history. We had even bounced radar off it to determine its exact orbit.

And yet, the face of the moon raised more questions than it answered. We could only guess at its exact topography and the roughness of its surface—matters of particular interest to an astronaut bound for the moon.

We needed a breakthrough greater than Galileo's glass, of a kind never before achievable. The Jet Propulsion Laboratory of the California Institute of Technology at Pasadena had spent five years and $200,000,000 trying to deliver just that to the National Aeronautics and Space Administration. Through its Ranger program, JPL sought to provide future manned and unmanned lunar landing projects with vitally needed information about the surface of the moon.*

A series of Ranger spacecraft had been sent out to get it. None had succeeded. But Ranger 6 proved beyond question the excellence of the Ranger design by a flawless if scientifically unproductive flight.

Ranger 6 sent home no photographs; its cameras were knocked out by an accident shortly after launch. But now JPL proposed again, with Ranger 7, to provide man with distant eyes, positioned perfectly in space, through which to see what nature had made invisible to him.

Scientists Compile Moon Portrait

As JPL's research progressed, my organization, the Astrogeology Branch of the United States Geological Survey, focused its instruments and intellects on the moon. We, too, were set up to support NASA's programs.

We mapped the Ranger target areas not only by observation but by applying such astronomical techniques as photometry to geological procedures. With the data obtained, we assisted in the selection of sites for Ranger photographic coverage, hoping through its pictures to discover areas smooth enough for a manned landing.

Ranger 7's target was a promising site. A plainlike region about 400 miles south of the great crater of Copernicus, it appeared to be one of the smoothest in its part of the moon. And at the end of July, 1964, it would be well lighted for Ranger photography.

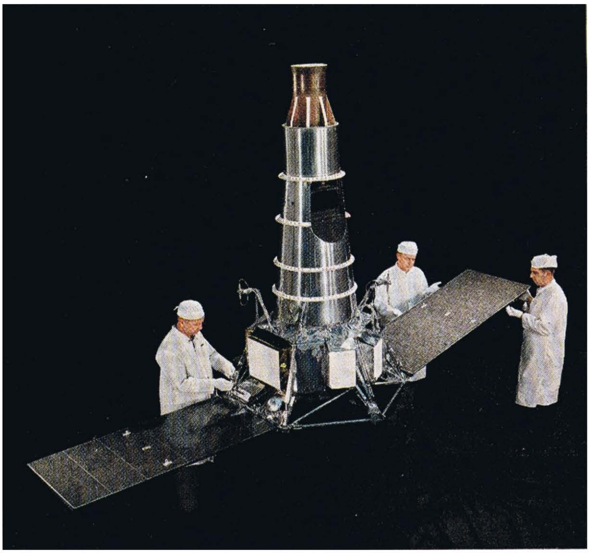
When Ranger 7 was launched, I was at JPL, closeted with other scientists responsible for choosing impact areas and interpreting pictures. In the control room, Pat Rygh, the space flight operations director, sent the messages that guided the little blue-winged, six-eyed spacecraft into a precise trajectory for a moon landing. It would have to fly through a 10-mile-wide "window" 120 miles

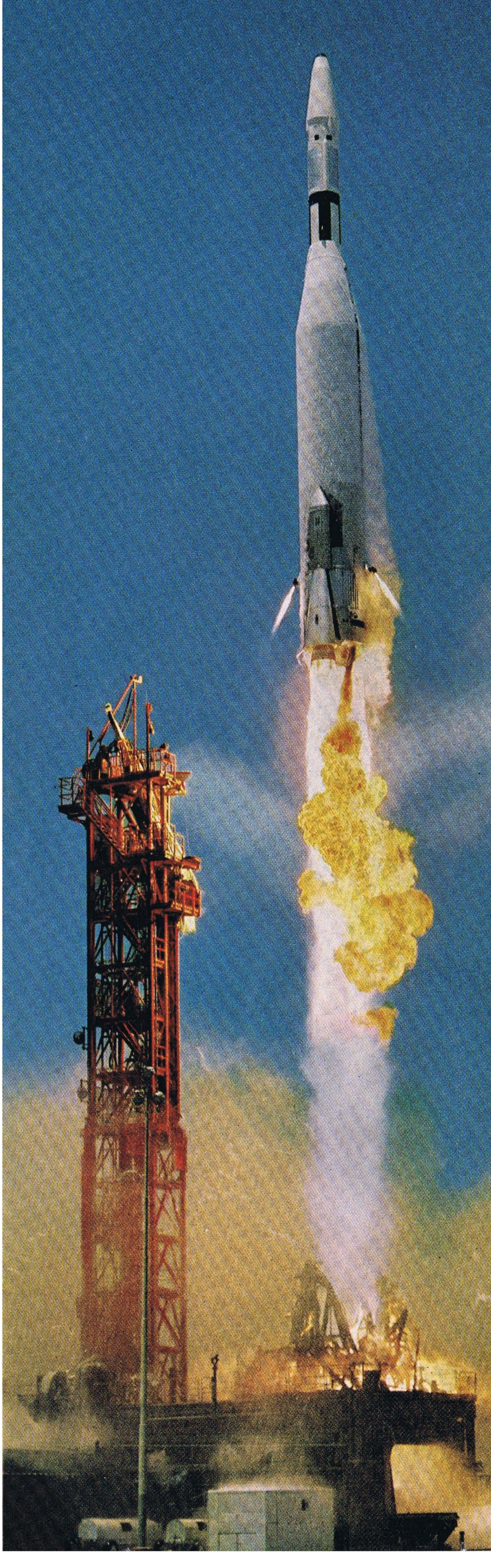
*See, in NATIONAL GEOGRAPHIC, "Exploring Our Neighbor World, the Moon," by Donald H. Menzel, February, 1958, and "Robots to the Moon," by Frank Sartwell, October, 1962.

Energy-gathering "wings" spread as Ranger 7 undergoes a final inspection at the Jet Propulsion Laboratory of the California Institute of Technology in Pasadena, before shipment to Cape Kennedy in Florida for launching. These panels of solar cells convert sunlight into the electricity needed to power the craft's equipment. Six television cameras in the silvery tower will focus on the moon through the aperture at center. Boxes at the base of the tower contain Ranger's complex electronic system, including a small computer. Topmost section is the omnidirectional antenna, used during launch and while the craft maneuvers in space. A more powerful dish-shaped antenna (here hidden beneath the craft, but seen on page 697) will send back the moon pictures.

Incredibly successful in its stated mission to "acquire and transmit a number of images of the lunar surface," Ranger returned 4,300 pictures in 17 minutes, giving man a view 1,000 times clearer than through any earthbound telescope. The achievement has been hailed as the greatest single technical advance in astronomy since Galileo.

EKTACHROME (BELOW) BY JET PROPULSION LABORATORY AND KODACHROME BY NATIONAL GEOGRAPHIC PHOTOGRAPHER OTIS IMBODEN © N.G.S.





Mighty Atlas Lifts Moon Explorer From Cape Kennedy: July 28, 1964

Shrouded in the nose cone, Ranger rests atop second-stage Agena-B rocket that will place it in earth orbit, then at the precise instant hurl it toward its goal.

Atlas and Centaur rockets will team for forthcoming attempts to "soft-land" on the moon a laboratory craft, Surveyor, carrying stereo TV cameras whose swiveling gaze will be able to see objects as small as marbles.

Two Mariners, scheduled for launching this month to photograph Mars, will ride Atlas-Agena-D. For manned moon excursions, NASA plans to use the immensely more powerful Saturn 5.

EKTACHROMES BY THOMAS

Hub of an electronic web that stretches to the moon:

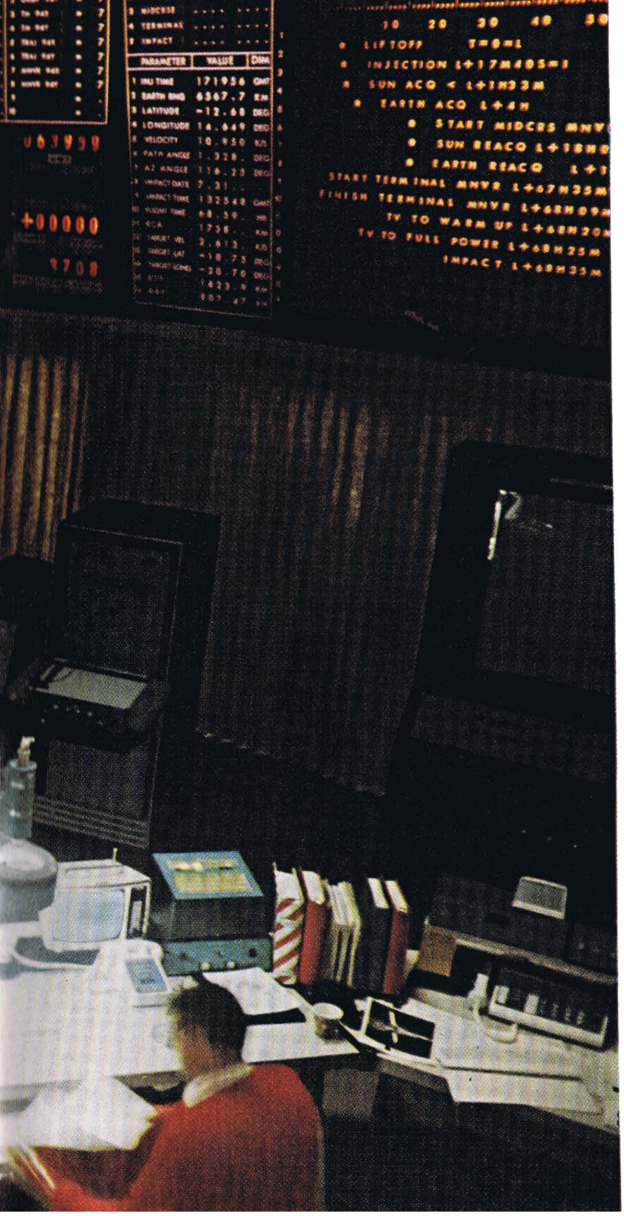
HERE THE CAPTAINS of the strange ship made their decisions and gave their orders; Ranger 7 obeyed without fail. Photographed seven hours before the end of a perfect flight, the control room is calm. Some of the experts who will man the empty positions are sleeping nearby. In more than 20 practice runs, JPL scientists set up so many bizarre accidents and emergencies that Ranger's actual flight, acclaimed a "textbook exercise," seemed dull by comparison.

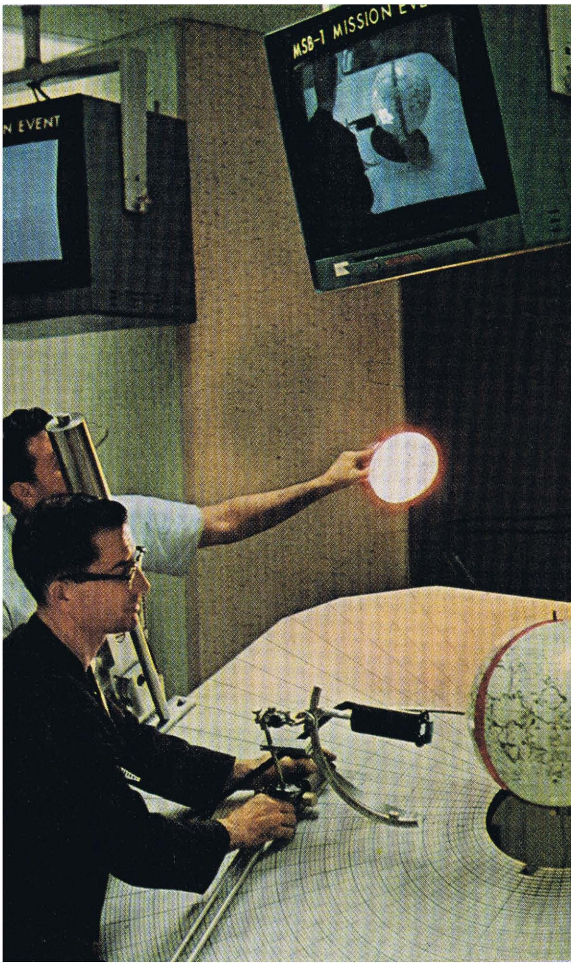
Electric wall panels above the control consoles carry information fed from supporting technical areas. There are enough boards here to handle two simultaneous missions.

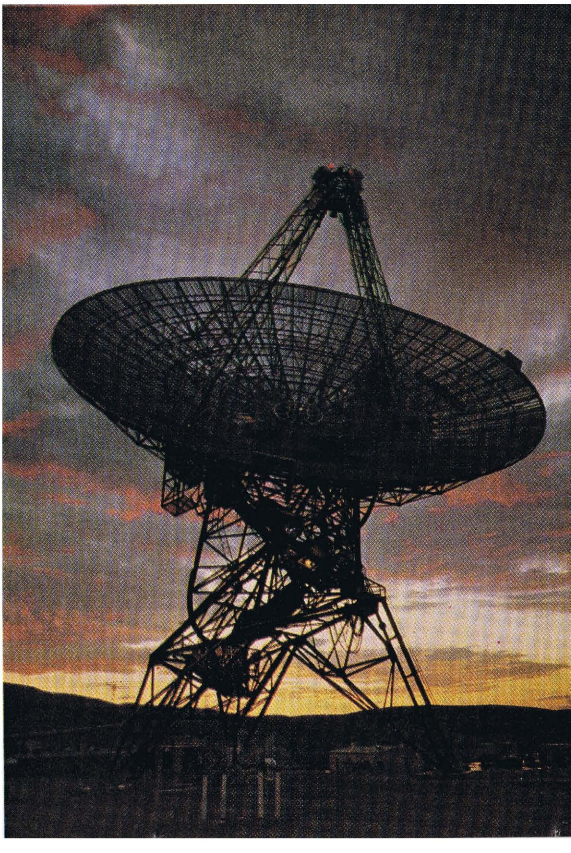
The two men in foreground, blurred by the long exposure, select data for transmission by television cameras, which hang before them like lamps. During the flight, JPL used 100 TV cameras to relay such information to 200 monitors spaced throughout the center.

Celestial navigator William Kirhofer (upper right), plotting Ranger's approach to the moon, simulates the cameras' bearing 10 minutes before impact. He projects on the target area a small beam that covers the cameras' field of view.

Using this engineering model, developed in cooperation with 26-year-old mathematician Ezio Piaggi, Mr. Kirhofer helped plan the spacecraft's important mid-course maneuver. The action slowed the too-speedy Ranger in order to put it on







R. SMITH, NATIONAL GEOGRAPHIC STAFF, AND J. R. EYERMAN (LOWER RIGHT) © N.G.S.

JPL control room

the moon at the desired position and to allow a preset clock to turn on the cameras at the proper distance from the lunar surface.

Tracing the new trajectory on the model, Kirhofer determined the areas that the cameras would scan. Moon model rises above a tilted tabletop scaled to represent distance.

Floodlight held by technician softens the contrast for a television camera, whose picture shows on the monitor above.

Mighty antenna at Goldstone in the California desert tracked Ranger, sent it orders, and received its radio waves that were converted into pictures. Other stations at Woomera, Australia, and Johannesburg, South Africa, watched the craft.

above the earth at 24,470 miles per hour, with an allowable error of only 16 miles per hour.

To the Goldstone tracking station in California's Mojave Desert (page 695) came cryptic signals acknowledging commands and reporting their execution. For more than 68 hours Ranger 7 sped on. Then, 17 minutes before impact, its cameras raised their warbling voices. Images formed in their TV tubes were being translated into electrical impulses and transmitted back for photographic and tape recording.

The voice on the hot line from Goldstone told us, "... 10 seconds ... we're receiving pictures to the end ... impact ... impact!"

Suddenly, silence. Then shouts and handshakes all through JPL hailed America's first successful photographic mission to the moon.

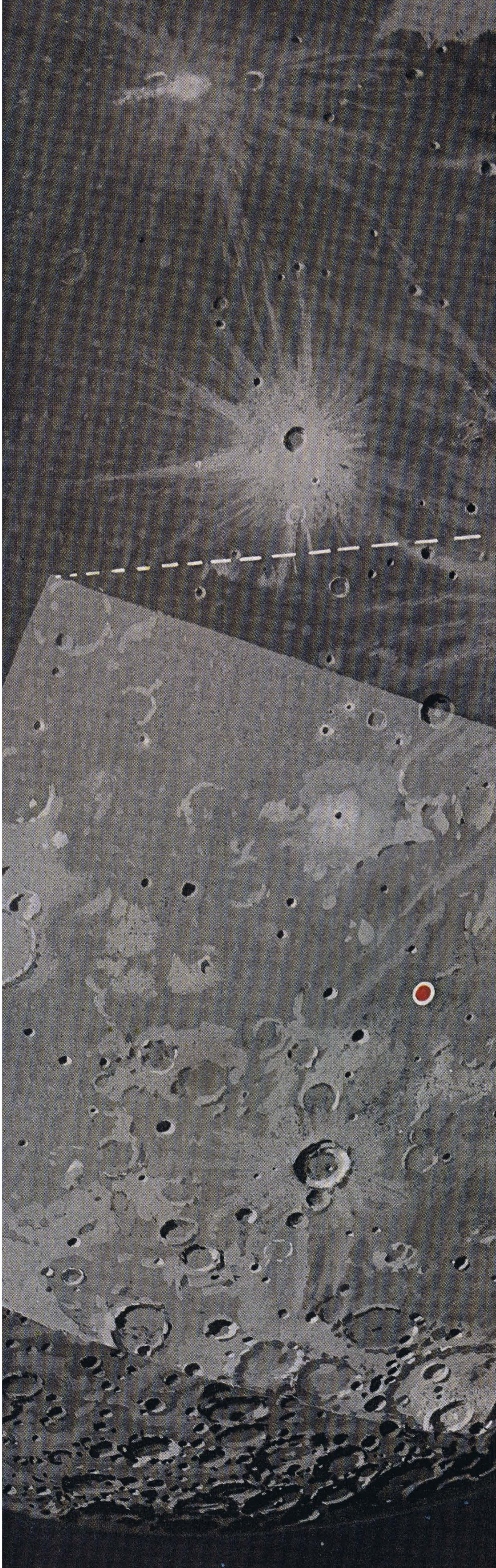
Craft Hits Six Miles From Mark

Afterward Project Manager Harris Schurmeier said, "We did it, and we're going to be able to do it again. Not every time perhaps, but there'll be other flights as perfect as this one.

"We're learning," he added. "With Ranger 6 we missed our predicted target by 18 miles. This time we missed by about six."

In its final minutes of flight, Ranger 7's cameras transmitted more than 4,300 photographs. The last was recorded at Goldstone just 1.49 seconds after the shutter clicked in the spacecraft. I scanned the photos a few hours later with my colleagues in the Ranger program, Dr. Gerard P. Kuiper (the principal investigator) and Ewen A. Whitaker, both of the University of Arizona, and Raymond L. Heacock, of JPL (page 703).

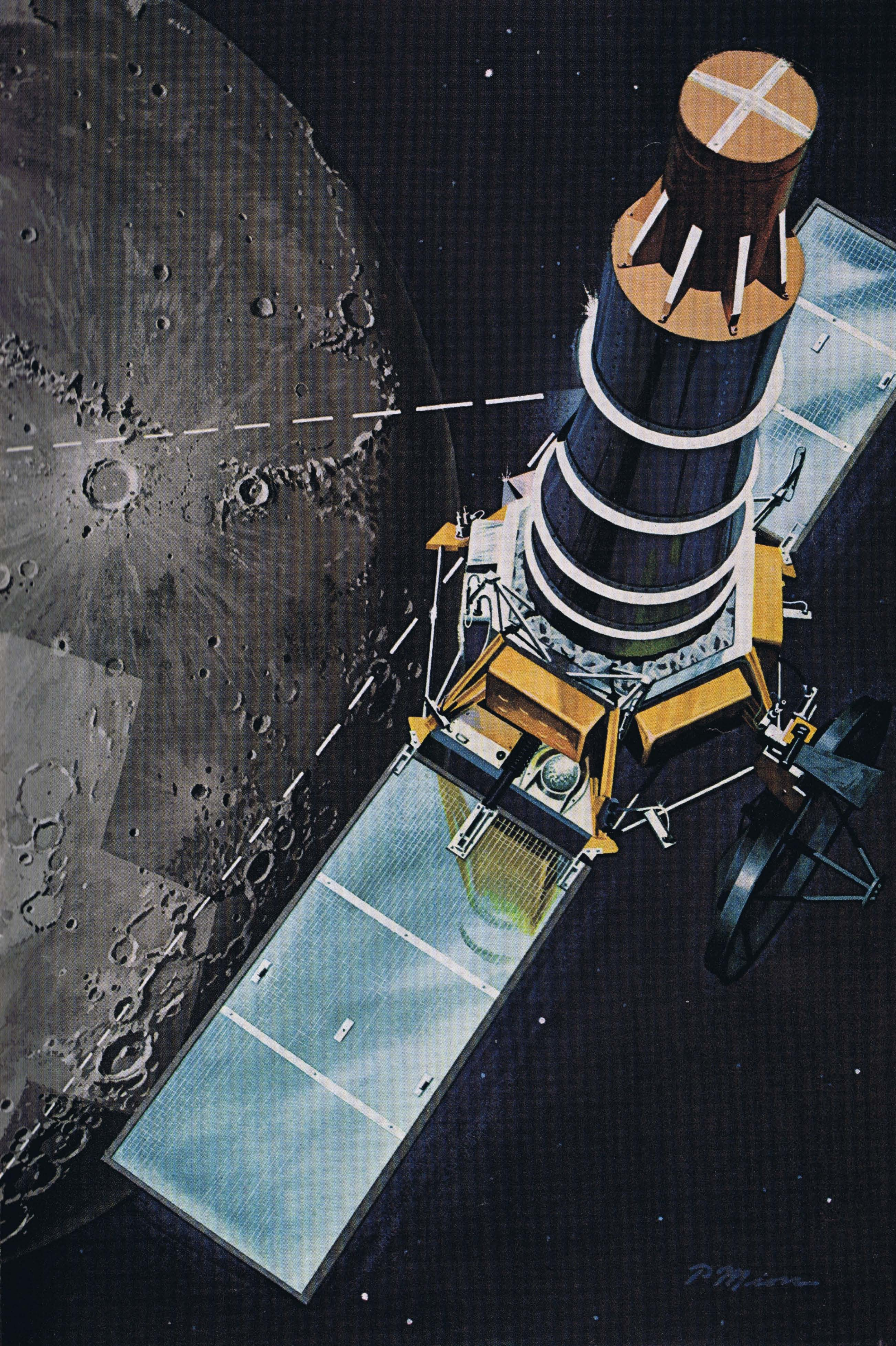
To us these unlovely rectangles of mottled gray were beautiful. They were nearly unbelievable. No one had ever seen details like these. Resolution in the last photograph taken



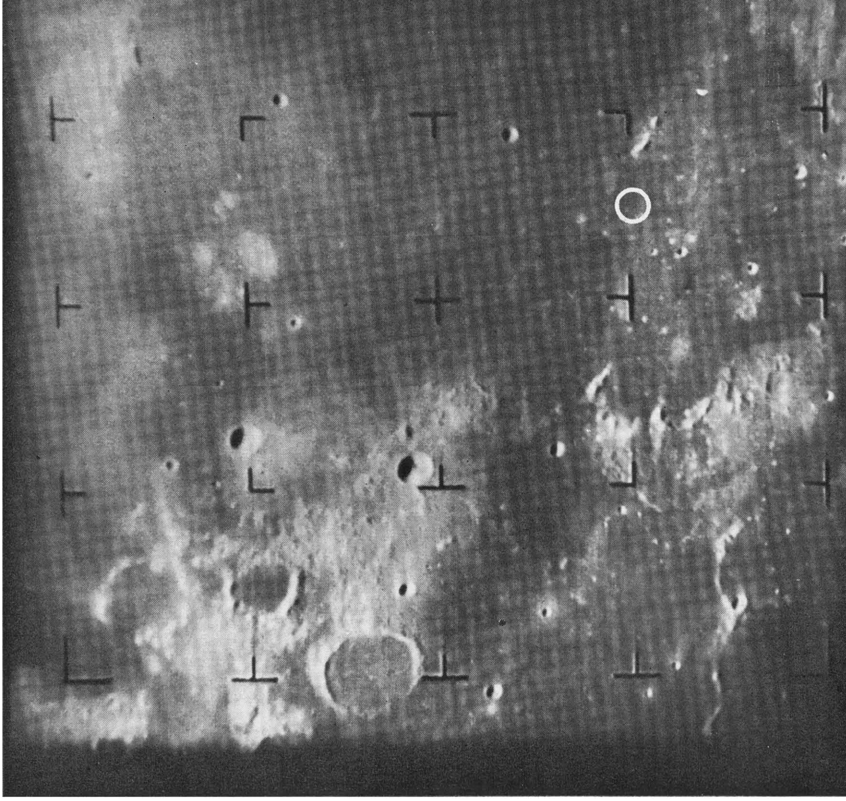
Its television eyes focused on a 300,000-square-mile segment of the moon, shown as overlapping rectangles, Ranger 7 flies the angled approach that allows unhindered vision from the camera window. Here 1,300 miles up, solar panels face the sun.

Moon's ravaged face reflects its explosive history. Lighter rays around the crater Copernicus (upper center) contain clusters of secondary craters that reach near to point of impact (red circle). Some of the lighter splotches in the camera view are debris from the cataclysmic collision that created the vast Mare Imbrium, Sea of Rains, which ranges over the horizon at upper right. Most mountains are remnants of crater rims.

PAINTING BY PIERRE MION; LUNAR SURFACE BASED ON LICK OBSERVATORY PHOTOGRAPH, COURTESY OF LUNAR AND PLANETARY LABORATORY OF THE UNIVERSITY OF ARIZONA © N.G.S.



Tension grips Mrs. Edna Haggard, JPL secretary, as she listens to Ranger reports coming over a loudspeaker.



480 MILES Dark dry "sea" surrounds brighter uplands. The city of Los Angeles could fit within the rim of Lubiniezky Crater (lower center).

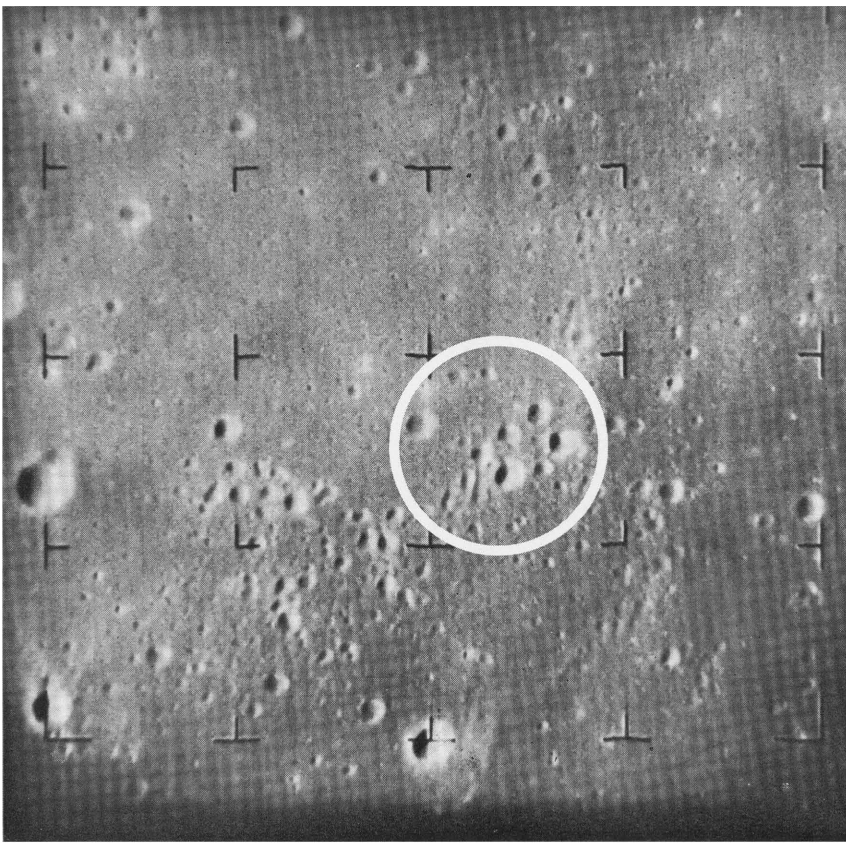
Consider the rain, the eons-long relentless downpour that causes erosion, change, transformation.

On the earth the rain is water. Rain feeds rivers which, at their mightiest, can cut such glories as the Grand Canyon. Freezing rain breaks rocks; packed snow and ice form glaciers that can gouge beds for such majestic waters as the Great Lakes.

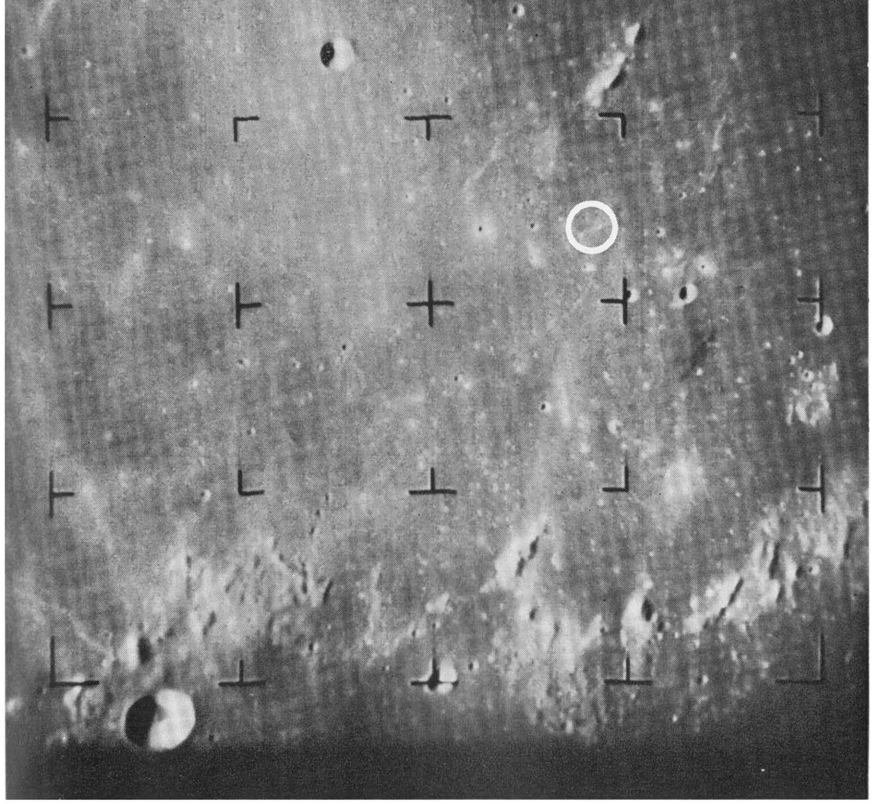
On the moon the rain is hardened matter. Space debris, crashing in at terrific speeds, buffets the tortured surface, cracks and scatters the rocks, and digs holes small as a pinhead or big as Hudson Bay.

Earth's water erosion usually heals the gaping wounds inflicted by attacks from space. But the moon forever reflects the awesome shattering of celestial barrage.

Circles enclose the same area in all pictures.

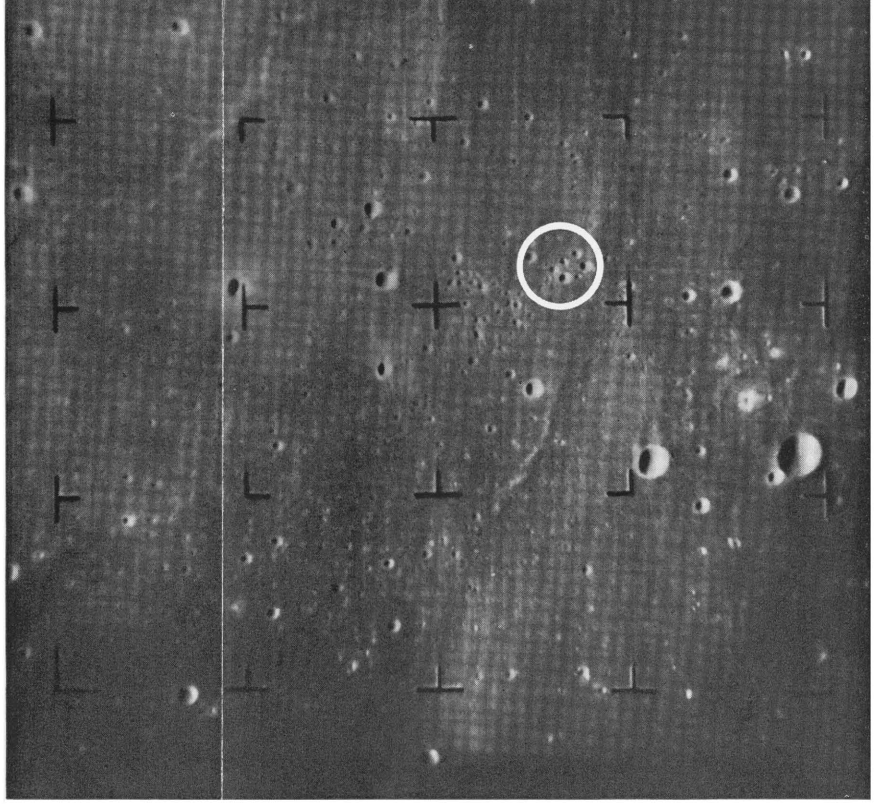


34 MILES Shallow, elongated secondary craters reflect the glancing strike of fragments thrown by impact of meteorites elsewhere on the moon.



ALL MOON PHOTOGRAPHS FROM NASA

235 MILES Steep-sided, flat-bottomed primary crater (lower left) shows walls firm enough to hold their shape, not formed of soft, shifting moon dust.



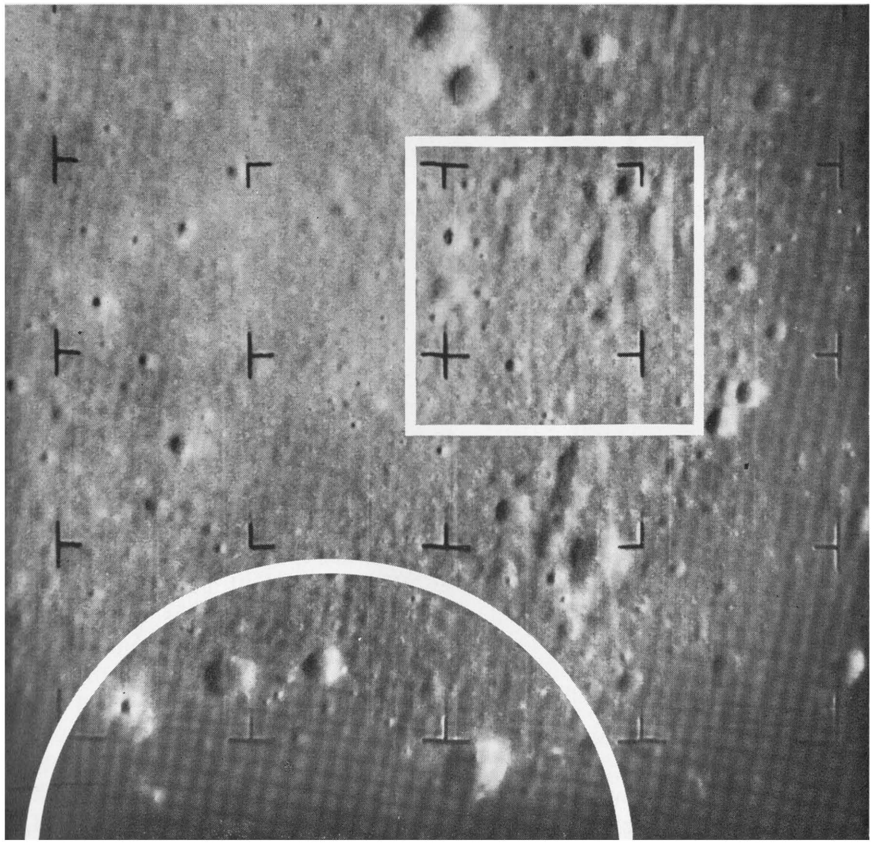
85 MILES Peppering of secondary craters looms into view. Cluster pattern indicates that they were dug by missiles loosed when Tycho Crater was created.

Consider the dust, the soil, stone, sand, water.

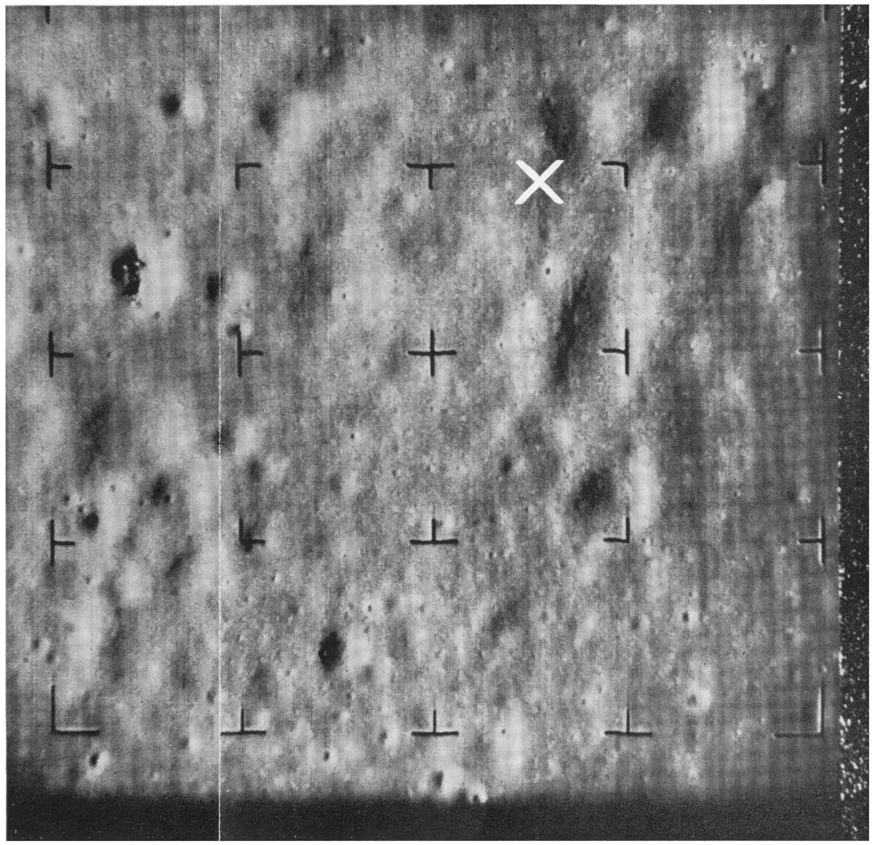
On earth such substances compose the planet's skin, which man has learned to live on, change, and often conquer. But what paves the surface of the moon? Do crags and craters make going rough underfoot, or does dust—soft, shifting, and many feet deep—lie in wait to swallow invading man?

To answer these questions and prepare for man's landing, Ranger 7 made its voyage. These images tell part of the story of what American astronauts will find when they step onto the moon, hopefully by 1970.

In interpreting the pictures, the author deduces that the moon's face is constantly being worn down and shaved away by the ceaseless cosmic rain. But to him the photographs fail to show any evidence of deep dust.



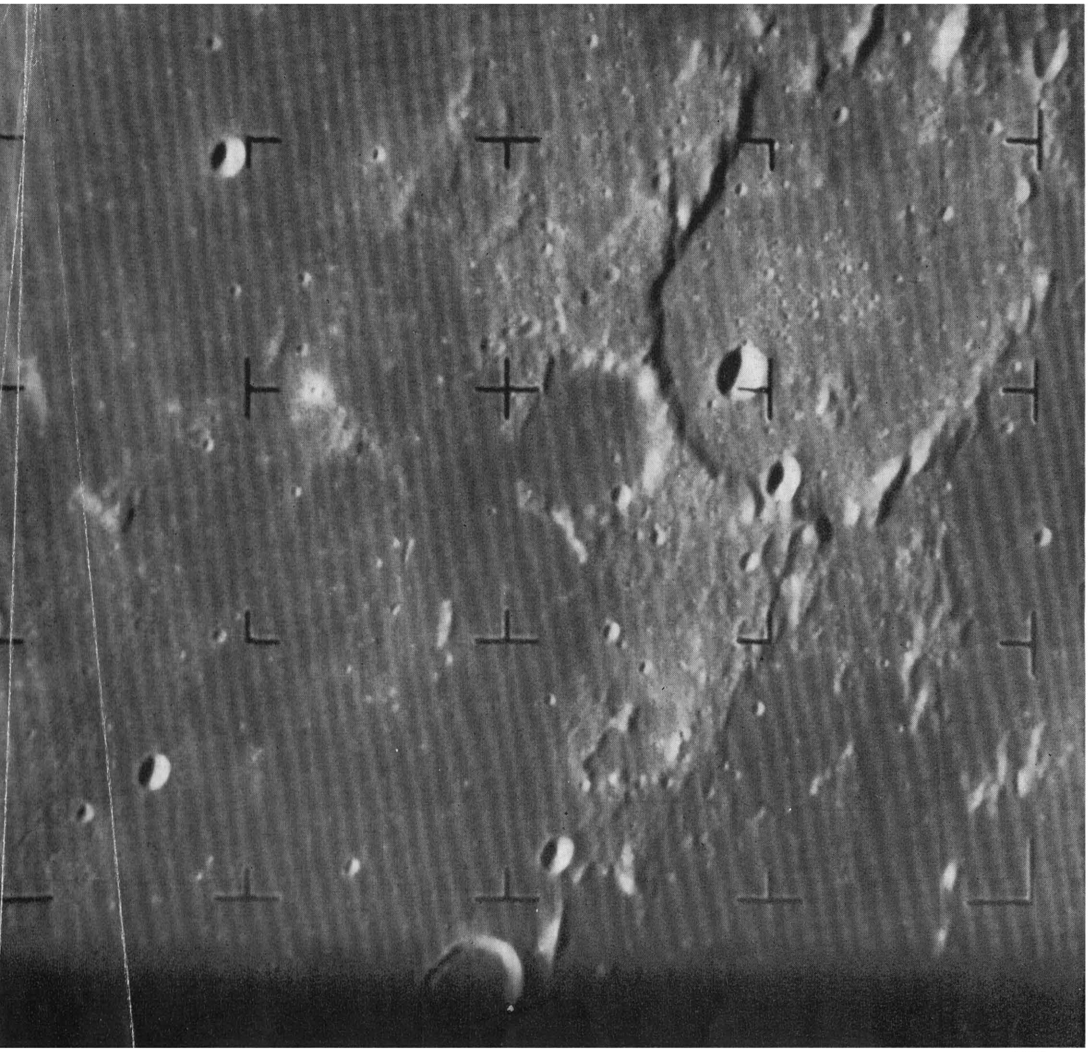
11 MILES Abrasion of cosmic rain gives secondaries the appearance of smooth dents. White square includes area of the picture at right.



3 MILES Three square miles are half pitted with craters. Receiver noise at right shows that the picture was not completely recorded at time of impact at "X."

EKTACHROMES BY THOMAS R. SMITH © N.G.S.

Joy of success transports Mrs. Haggard, who works for Harris M. Schurmeier, JPL Project Manager of Ranger 7. Cameras are sending pictures, she hears.



NASA

Ranger's view of Guericke Crater from 470 miles: Hitherto unseen craters appear in sharp definition. Two of the flying TV cameras scanned 1,150 lines per image, as compared to 525 lines in ordinary TV pictures in the United States.

was more than a thousand times better than had been achieved with earth-based telescopes.

Like all televised pictures, Ranger's had scan lines, but so much finer and more numerous than those of a standard television screen that they looked like direct photographs. What had been mere specks through the telescopes became clear, crisp shapes. In the closest shot we saw forms no bigger than a small boy.

We had little time and a lot to look at, but all of us noted at once the single greatest fact revealed by Ranger 7's cameras: The moon's surface, seen for the first time at close range, was not radically different from our idea of it.

To scientists, confirmation is as valuable as information. Since Dr. Kuiper and I have shared responsibility for telling the builders of future moon-landing vehicles what kind of terrain their machines would encounter, this discovery was deeply gratifying.

I headed back to my laboratory in Flagstaff, Arizona, elated and relieved. There was urgent work to be done connected with space projects already under way.

Mapping the geology of the moon was, and is, our main occupation. We are concerned not only with topography, but also with the distribution of different kinds of rock and the effects of forces that shape the surface. To a degree, we map the moon the way the Geological Survey maps the United States.

Several quadrangle maps are finished —each covering an area about the size of

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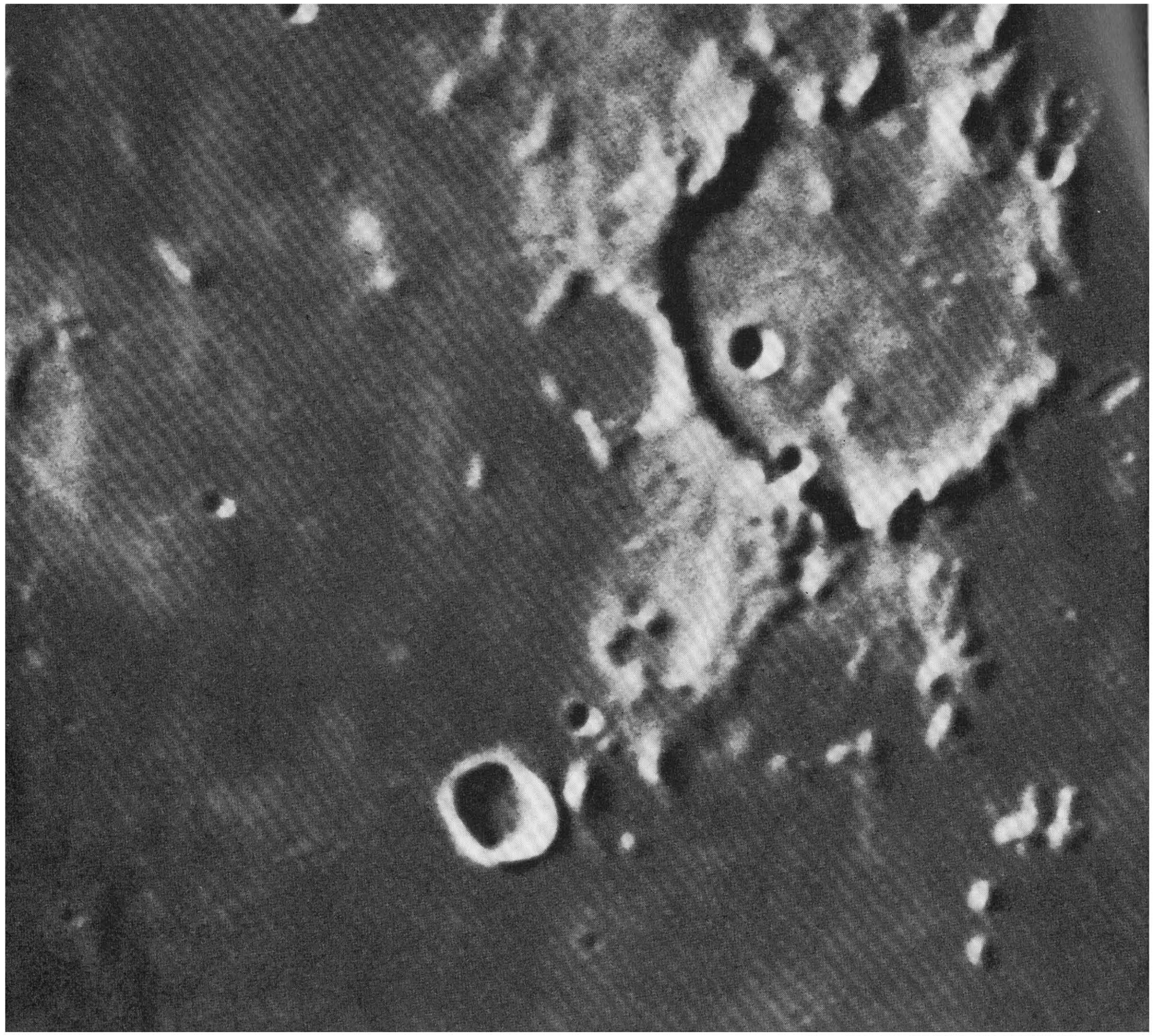


MOUNT WILSON AND PALOMAR OBSERVATORIES

Earth-based telescope picture approximates Ranger's, but atmosphere blurs details. Guericke Crater, whose filled basin and broken rim show its age, is 36 miles across; Arizona's Meteor Crater, one of the best known on earth, is less than a mile wide.

Arizona. The whole equatorial area of the moon will be mapped by the end of this year; this is the region in which our first manned craft will land. In three or four years we'll have mapped the whole visible side—about 50 quadrangles in all.

This geological mapping was the basis of my own pre-Ranger "model"—my personal conception—of what the moon might be like, close up. To explain what the Ranger pictures mean to me, I must first explain my mental picture and how I arrived at it. As it turned out, it wasn't far wrong.

Craters Pock Lunar Plains

There are differences, of course, between my mental picture and the real thing. All of us had tried for years to second-guess the results of Ranger's success. Each of us was surprised differently, according to his own preconceptions. And there are still differences between thoroughly qualified scientists as to what Ranger 7 taught us about the moon's surface. I give you my own conclusions.

We can set aside the various theories of lunar origin; Ranger's pictures for the most part don't bear on it. It's the surface we care about right now. We want to put a man on it.

Our satellite's main features have been known for centuries: rugged mountains; rocky, plainlike areas called *maria,* or seas (by Galileo, who thought they were); and craters. The moon is so pock-marked that even its craters have craters. Hundreds of thousands of them can be counted from earth. The biggest are hundreds of miles across, and, prior to Ranger 7, we could see smaller ones down to our frustrating limit of visibility.

Craters appear to differ as to their origins. Some are probably caused by volcanic outbursts, some by collapse. Others we can't identify. But the vast majority, I believe, are caused by impacts.

Those impacts not only made craters, they also sent us samples. When a piece of "space junk" smacks into rock at 10 to 20 miles per second, it knocks out a spray of fragments. Some of those knocked from the moon reach escape velocity and end up on earth.

Made of lavalike basalt or siliceous glass, they contain elements also found in the earth's crust. They give us an idea of the makeup of the moon's surface, but only an idea. The same elements are there. But the airless, waterless moon differs markedly from earth. It remains simple and primordial, a picture of our planetary past.

Yet it is a picture we have always seen "through a glass, darkly." I combined observation and deduction and came up with a mental close-up view of a *mare* surface, the likeliest place for a lunar landing.

This landing field must have impact craters, of course. They are everywhere on the moon. These are of two kinds: primary craters, formed by fragments hurtling in from space, and secondary craters formed by chunks of rock thrown out of the primaries.

All but the largest primaries are round, as if hollowed by explosive force; steep-sided, with raised, clear-cut rims and sometimes outward-reaching rays. Their distribution depends on the geological age of the surface on which they are formed; old surfaces, such as the *maria,* bear more crater scars than geologically younger surfaces.

The secondaries occur in swarms and clusters, concentrated around the primaries which produced them. They are elongated in shape, shallower than primaries of corresponding size, and their walls are more gently sloping. Their rims are irregular, and they have a smoother look.

Meteorites Throw Showers of Rock

So far I was on safe ground in my effort to build a mind's-eye model of the lunar surface. I could actually see through the telescope something of the shape and distribution differences between the primary and secondary craters. Now for some speculation.

Most of the material ejected when a primary is created falls nearby and forms a raised rim. But some of the bigger lumps fly farther. They always plunge into the ground at an angle, and their speed is relatively low—on the order of one mile a second. When they hit, they gouge out secondary craters.

It seemed to me that there was a uniform-size relationship between primary and secondary craters. The biggest secondaries in each swarm knocked out by a primary ap-

JET PROPULSION LABORATORY

The Author: Dr. Eugene M. Shoemaker (left) heads the Nation's most far-reaching group of geologists—those who practice their profession at a range of a quarter of a million miles. They work at the Astrogeology Branch of the U. S. Geological Survey, serving NASA's need for hard facts and educated guesses about the moon. Shoemaker and his colleagues advise the Jet Propulsion Laboratory on the lunar geology their spacecraft will encounter. Here at JPL, Dr. Gerard P. Kuiper, chief investigator (right), Raymond L. Heacock, and Dr. Shoemaker study Ranger 7's revealing photographs.

peared to be about one-sixteenth the primary's size, with the others grading on down out of sight. In a given swarm the smaller secondaries, I reasoned, were far more numerous than the large ones.

Nuclear Blast Bears Out Theory

By great good luck I found solid support for these ideas conveniently located on earth. At the Atomic Energy Commission's Nevada test site, there is a man-made nuclear crater which has the form if not the origin of a modest lunar primary. A swarm of more than 6,000 secondary craters was formed around that crater by the identical mechanics I had postulated for the lunar secondaries. Like the latter, they were shallow, irregular, and generally rimless. The largest of them was one-sixteenth the primary's size. And as they grew smaller, their numbers increased.

In the case of the moon's huge primaries which have rays extending outward from them, I observed that all the secondaries were clustered within the rays. The ray material was evidently debris tossed out by the secondaries. Such regions would be heavily pitted and poor places for an attempted landing. As one of my colleagues said, "We wouldn't want a spacecraft to put down in all that secondary jazz."

If the ray areas were unpromising, what about the other parts of the *maria?* What might we find there?

Dr. Kuiper and I agreed that the primary craters should not be a problem to "soft-landing" spacecraft. On the average, they seemed to occupy only about one percent of the *maria.* We inferred that even those too small to be seen by telescope would continue in about the same one-percent proportion.

But how about the secondaries? Their frequency would certainly increase more and more with decreasing size. To find out how much more, I began counting and comparing on the best photographs then available.

Though photographs reveal a little less than can be seen through the telescope by human eye, good pictures of the *maria* surface show all the primary craters from about 1,200 feet in diameter on up. But they show only a minute percentage of the secondaries. For one thing, most of the primaries seen are too small to produce visible secondaries. For another, even the largest primaries produce far fewer visible than invisible secondaries.

Would Debris Pose a Hazard?

Within the visible range, then, I expected to find a preponderance of primaries. I didn't. My count showed secondaries to be almost equally numerous. Projecting that fact mathematically, I concluded that as the secondaries decreased ten times in size, they would increase nearly ten thousand times in frequency.

A progression such as this presented a disturbing concept: The entire surface of the moon would be completely covered by craters of the 10-foot size. "Secondary jazz" indeed, and rough enough to be difficult, if not downright dangerous!

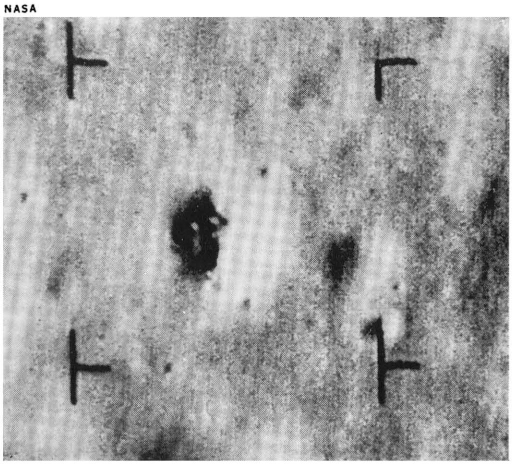
There would have to be a lot of debris on such a surface, too. Even though primary hits knock some fragments into space, most of the projected pieces fall back on the moon. On a surface covered by 10-foot craters edge to edge, the average depth of loose pieces should be equal to the average depth of such craters: several feet, and a nuisance if not a menace.

BY NATIONAL GEOGRAPHIC ARTIST ROBERT C. MAGIS © N.G.S.

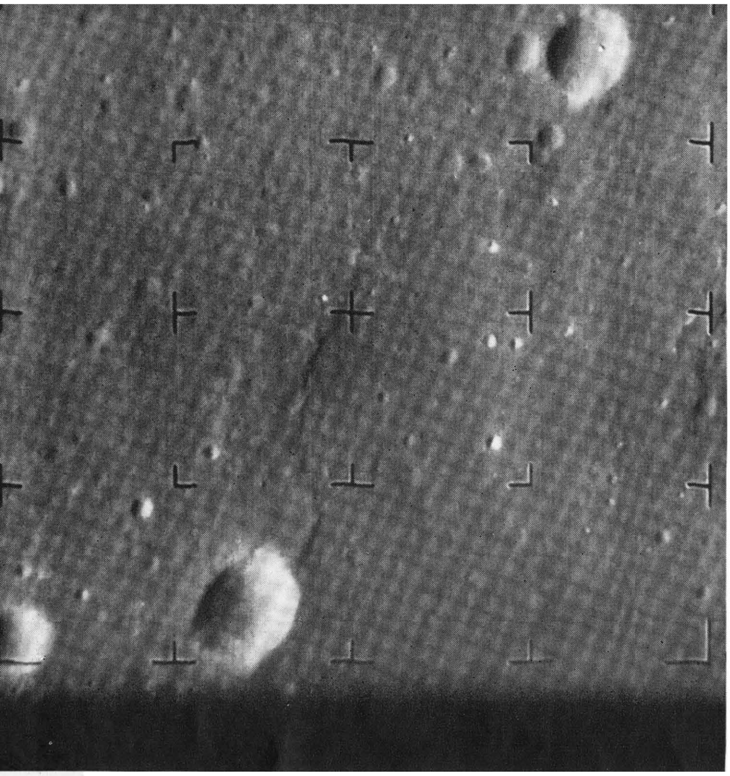
Like an unexploded bomb, a rock mass 300 feet long nestles in the secondary crater it excavated. An astronaut from his LEM—lunar excursion module—explores the terrain with a Jacob's staff, an instrument equipped with sun compass and cameras. His space suit protects him from extremes of heat and cold and from micrometeorite rain. Vastly smaller than grains of sand, such particles of star dust can penetrate the outer layer of the suit but should cause no injury.

Milky Way and more distant stars appear measurably brighter from the moon than from the atmosphere-veiled earth. Red dot at upper right marks the impact site of Ranger 7.

NASA



The rock: seen by Ranger from three miles up.



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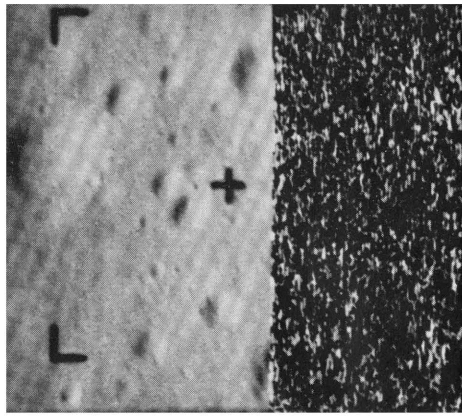


Last picture, from about 1,600 feet up, shows a scrap of lunar land 100 by 160 feet, the size of a plot in suburbia. Receiver noise pattern at right signaled Ranger's destruction.

Moon wrinkle at center is a ridge pushed up during internal heating or cooling. Marks transmitted by Ranger on all pictures serve as reference points; straight rows prove images were not distorted.

The surface of this debris layer would naturally have been bashed further by smaller and vastly more numerous pieces of cosmic matter. It would become a thin film of pulverized particles, as light and porous as our infrared measurements tell us it is. Below it would be fragments the size of coarse sand and gravel, and under that, the solid substance of the original *mare.*

Ranger 7 Springs a Surprise

Well, that was my model—my personal prediction, extrapolated far beyond known facts. What would Ranger 7's pictures do to it?

As I followed those extraordinary photographs closer and closer to the moon, it began to look as though my model would check out. Small primaries, never before seen, continued to occupy about one percent of the area, as predicted. They kept their characteristic sharp shape, too, which suggested that they had been formed in rock, as had the large ones of similar appearance.

I saw 300-foot secondaries for the first time; they covered just about as much of the surface as I had imagined they would—roughly half of it.

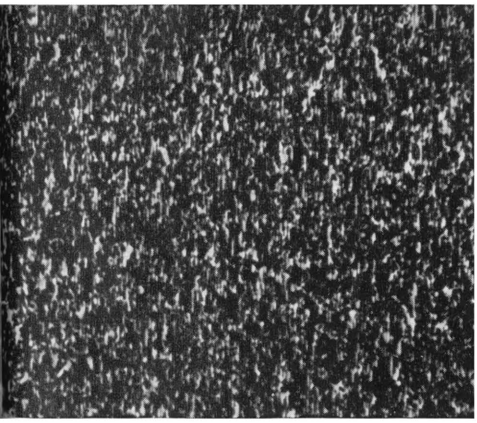
Then, strangely, the frequency progression changed. I saw smaller and still smaller secondary craters, but instead of blanketing the area, they took up less space than the 300-footers. Instead of growing rougher, the surface began to smooth out. At the limit of visibility there were smooth stretches between the craters.

Why? The shapes of those dishpan-size depressions gave me a clue. They were rounded, eroded, ground down.

How? By an intense bombardment of very small and very fast particles from space—far more intense than I had estimated. That, at least, is my best guess. Such particles would include not only meteorites, which form primary craters from dime-size to city-size, but also vast numbers of particles from the tails of comets.

These minute objects do not erode the air-protected earth. But on the moon they would form primary craters down to the size of BB shot. Their velocity is so high that they could knock into space several times their own weight of moon matter. Thus they would not only wear down the lunar surface but would actually remove it, slowly and steadily, and so reduce the mass of the moon. Although they would create new fragments in the process, the layer of fragments would never grow any deeper.

The effects of this erosive process would be barely observable through a telescope. Big



NASA

At the White House, President Lyndon B. Johnson inspects moon pictures shown by Dr. William H. Pickering, director of JPL. The jubilant Chief Executive assured visiting scientists that they had "the gratitude and admiration of all Americans of all faiths, of all parties, of all regions." He added, "You are welcome to the White House. The people who live here are mighty proud of you."

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features do not change their appearance much when a few feet or a few tens of feet of their surface are removed fairly evenly. To the eye, a 100-mile crater would remain practically unaltered. But a 100-foot crater so eroded would look like a dent in a dough ball. And so it does (page 700). As for the 3-footers, only the most recent would be visible at all, and they soon would fade.

The total wearing away of the *maria,* according to my interpretation of the Ranger pictures, may be more than fifty feet! That much of the surface has been removed during their 4½-billion-year existence, enough to have wiped out very old craters that once measured as much as 500 feet across.

Probably the 10- and 6- and 2-foot craters I had expected had in fact been made, and in about the numbers I had anticipated. But they had been erased by the enormous rain of minute missiles, which I had not anticipated.

Pictures Minimize Landing Risks

Our new picture is still conjectural. It must remain so in part until we can send a robot or a man to land on the moon and reach out and pat it. The landing is the payoff, and the payoff will be soon.

Meanwhile our corrected model looks more promising than its predecessor. Outside the rays, where the big secondary craters cluster, the *maria* are smoother than I had dared to hope. There are relatively level or undulating areas large enough for spacecraft landings. The regions roughened by car-size secondaries have been worn down. And although there is certainly a layer of debris, I'd now figure it to average less than a foot thick, to be fairly firm, and to present no problem for spacecraft or astronaut.

As a threat to man, the cosmic downpour responsible for all this leveling and softening looms less large than the other unavoidable hazards of space travel. Most of the particles involved would weigh a millionth of a millionth of a gram. Fast as they are, they stop when they hit. Both suits and spacecraft can be made impervious to the minute bits of matter which are likely to hit them in the course of a visit. As for the sizable chunks that have indeed been chewing up the surface of the moon for billions of years, their arrivals are too infrequent to count.

Beyond all this, we know one new and certain fact about our satellite: 390 miles south of Copernicus there is a raw, sharp-edged crater, about 20 feet wide by 12 deep. A few shreds of metal glint in its bottom. And the moon's mass is greater by the 800-pound weight of Ranger 7. THE END