DOUBLE SUPPLEMENT: THE APOLLO ASTRONAUTS; THE EARTH FROM SPACE

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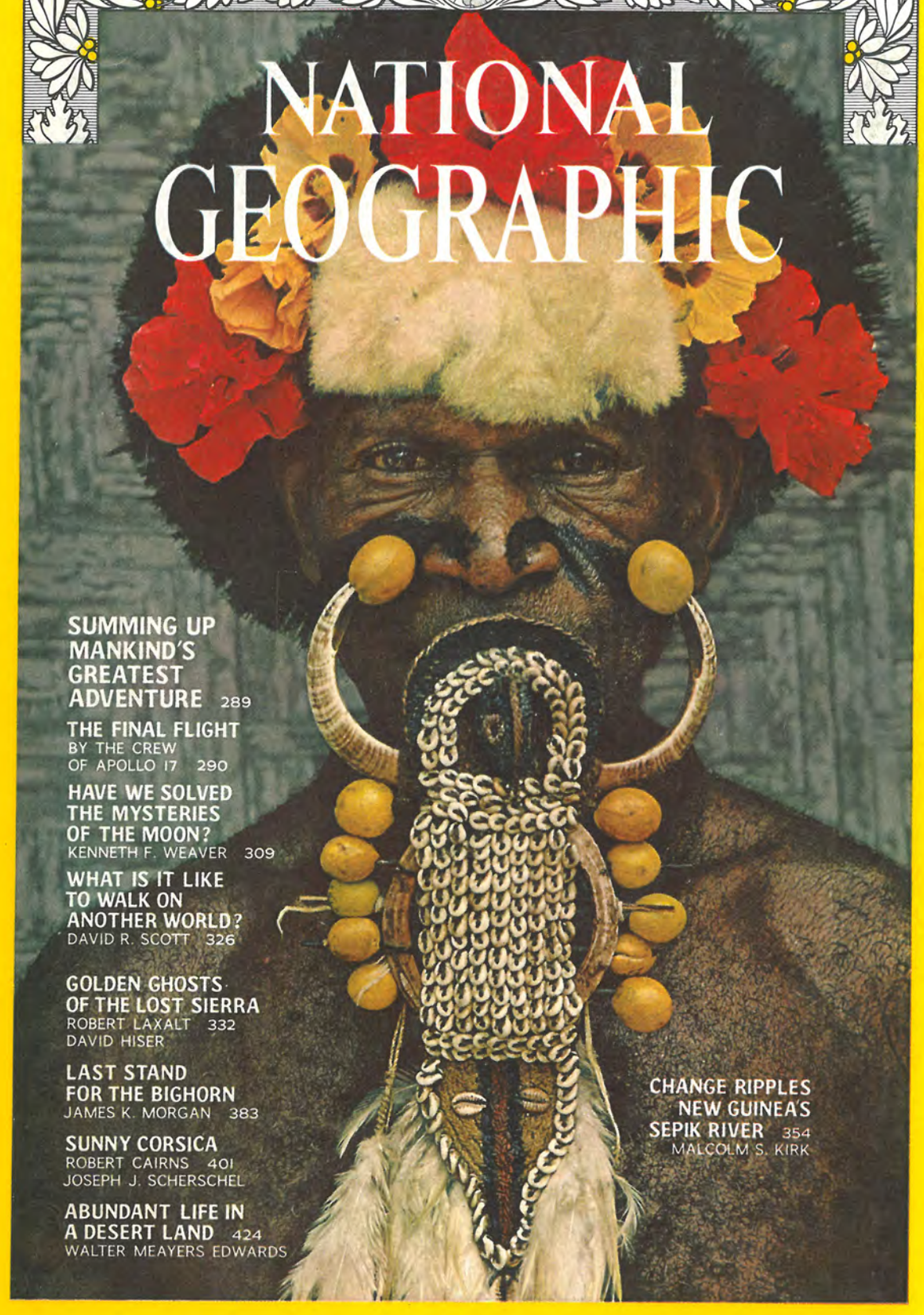

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NATIONAL GEOGRAPHIC September 1973

NOW WE'VE ALL been to the moon, all of us who thrilled to Apollo 8's Christmas message from lunar orbit, who saw Neil Armstrong's booted foot make the first human track on lunar soil, who watched as space-suited astronauts bounded kangaroo-like over stark moonscapes. And we think back to a prophecy by President John F. Kennedy in 1961, when he pledged that the United States would put a man on the moon within a decade: "In a very real sense, it will not be one man going to the moon. . . . it will be an entire nation."

He understood how that single feat would lift the spirits of all mankind. Apollo epitomizes what a nation can do when it commits itself. Therein lies our hope for an answer to the energy crisis, the environmental crisis, and to every other major problem of humanity. Apollo proves to us that man can do almost anything he dares.

There are more tangible rewards, of course, in 841 pounds of moon rocks and soil—the prizes of six lunar landings. Generations of scientists will study these fragments of an alien world for clues to the origin of the moon, of their own planet, and of the universe.

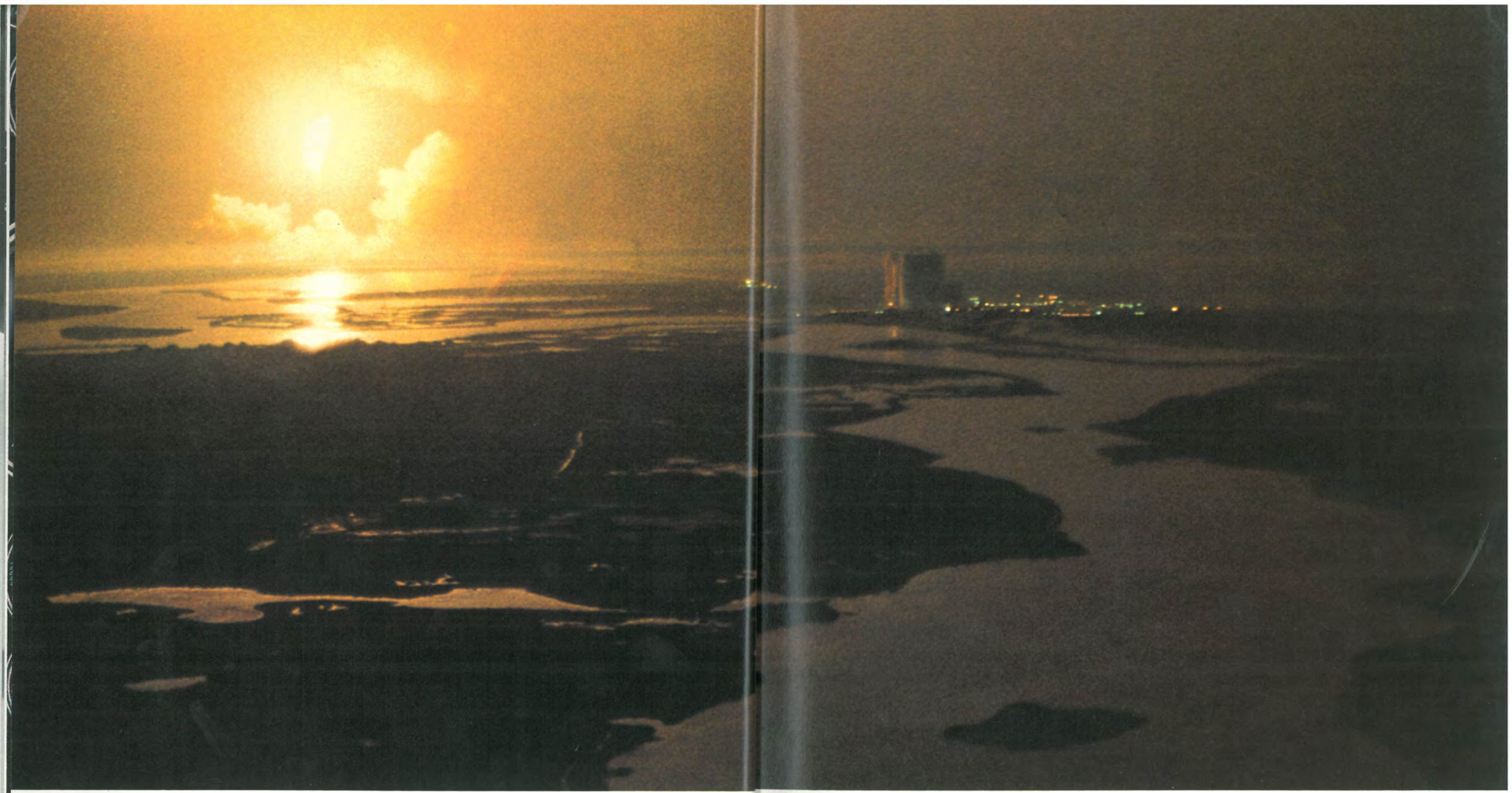
Increasingly tangible, too, are far-ranging spin-off benefits, from worldwide weather forecasting by satellite to vastly improved testing for tires, from better electrical circuitry for homes to more-antiseptic procedures for surgery.

Despite such practical aspects, our thoughts keep turning back to those breathless moments when the first man took the first steps in a world apart from his own. As the dramatic moon landings conclude and the mass of findings begins to yield appreciable results, NATIONAL GEOGRAPHIC publishes a special salute to the space program. On the following pages you will find the climactic story of Apollo 17, the final mission, as described in the words and photographs of its crewmen. Space editor Kenneth F. Weaver draws on lunar knowledge only now available to re-create significant events that helped shape the moon. Astronaut David R. Scott of Apollo 15 writes a personal revelation of how it feels to walk on the moon.

A special supplement brings to members an enlarged photograph of our own space-voyaging planet, as the astronauts saw it, aglow with the hues of its continents, seas, and swirls of cloud. On the other side a painting unites 32 Apollo astronauts as artist Pierre Mion visualizes them at an earth training site. The light on their faces reflects a shared dream of reaching the moon—first port of call on man's greatest voyage of discovery.

Gilbert M. Grosvenor

ASTRONAUT RONALD E. EVANS GETS A FAREWELL HUG FROM HIS WIFE, JAN, AT CAPE KENNEDY; JON SCHNEEBERGER



JONATHAN BLAIR

Exploring Taurus-Littrow

By HARRISON H. SCHMITT

Photographs by the crew of Apollo 17

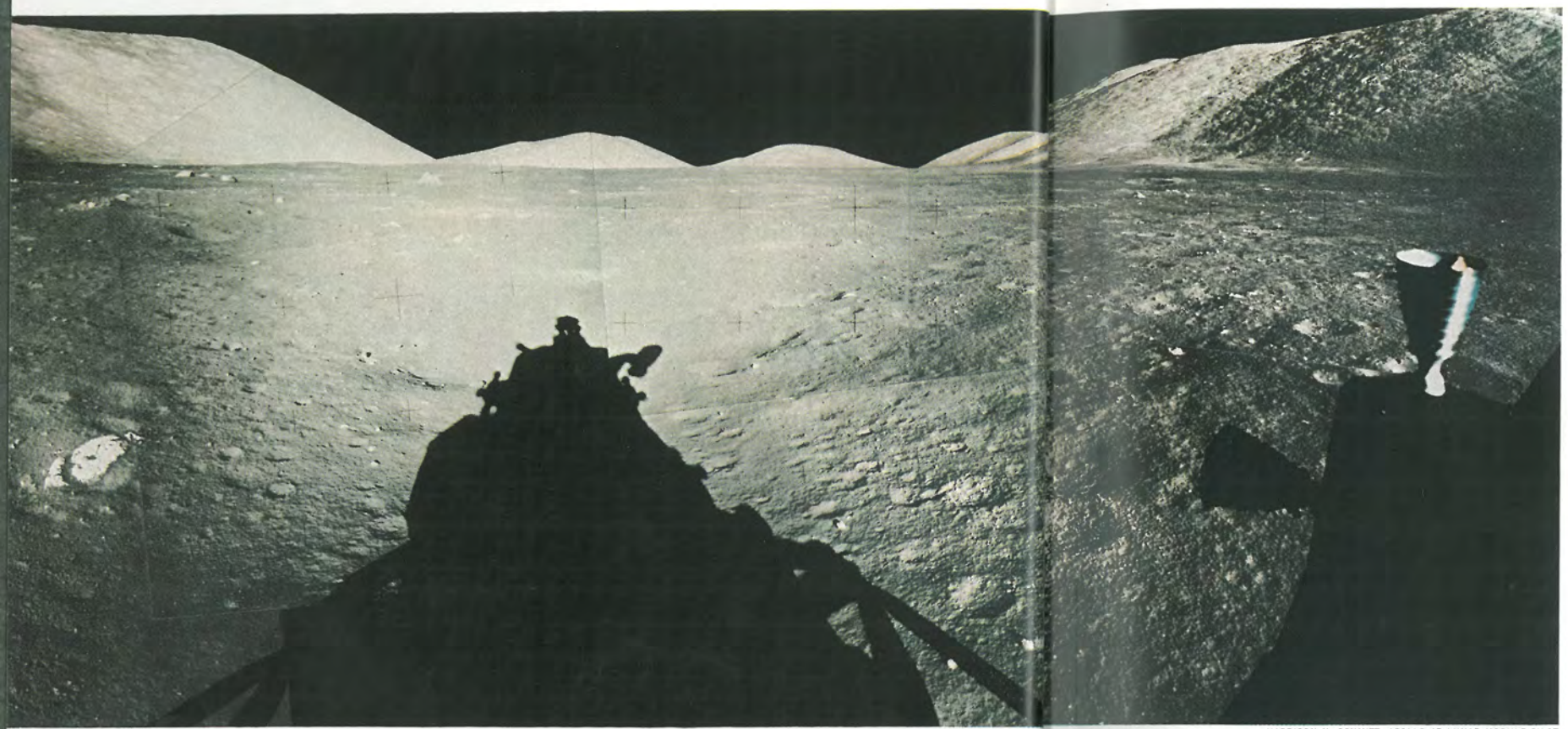
BILLOWING FLAME that seems to rival the sun, our Saturn rocket pulses the humid December night, spreading a false dawn across central Florida. As far away as North Carolina, spectators spot the bright wake of this unique Apollo night launch. Yet directly atop the five engines that lift Apollo 17, only faint flickers invade the spaceship *America,* whose cabin I share with Mission Commander Eugene A. Cernan and Command Module Pilot Ronald E. Evans.

Our launch has had its brief tense moments. Thirty seconds before takeoff an automatic sequencer discovers what it thinks to be an unpressurized liquid oxygen tank in the Saturn rocket and abruptly stops the countdown. More than two-and-a-half hours drag by before the problem is resolved and our journey begins.

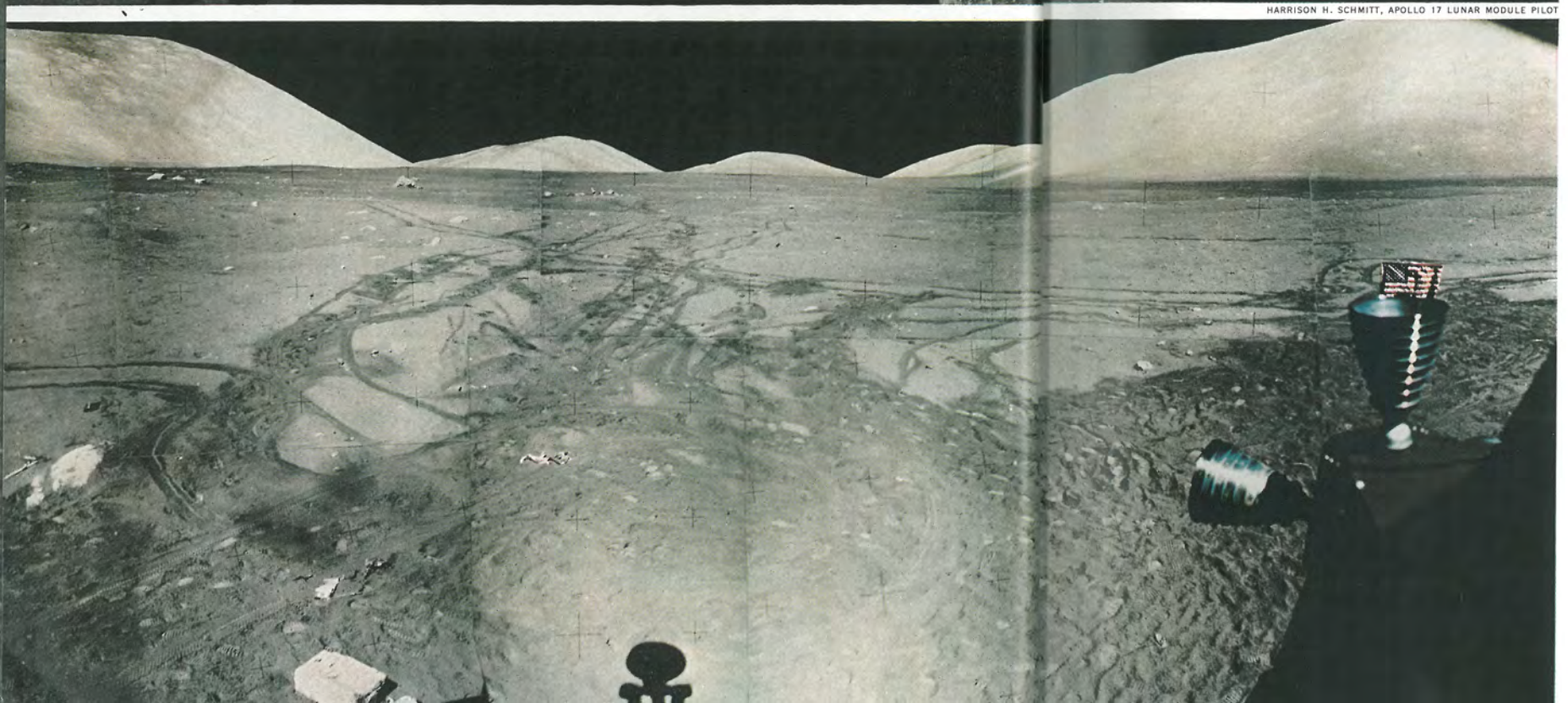
Now we feel the battering vibrations of engines shouldering 6½ million pounds into space, feel the gradual weight of acceleration as our race to orbit quickens. These physical sensations and my duties crowd from my consciousness any anticipation of being the first geologist to walk on the moon.

Aloft in *America* with the lunar module *Challenger* locked in tandem, we speed toward the intriguing valley of Taurus-Littrow, which lies near the coast of the great frozen "sea" of Serenitatis. Our newly won knowledge of the moon indicates the site will richly reward those who read the library of the planets. This helps to mitigate the sadness that our visit signals the end of the era of Apollo exploration.

Shadows shorten and the lunar trails lengthen outside the LM window



HARRISON H. SCHMITT, APOLLO 17 LUNAR MODULE PILOT



LONG A SILENT WITNESS to unfolding time, the Taurus-Littrow valley has been altered by its visitors from another world. When *Challenger* first alights (**upper**), our view embraces a pristine moonscape of craters, rocks, and sunny slopes agleam like virgin snow. This is just after the dawn of a lunar daytime that will last for 13 more earth days —a dawn when shadows etch the smallest features in high relief, prime time for the lunar explorer.

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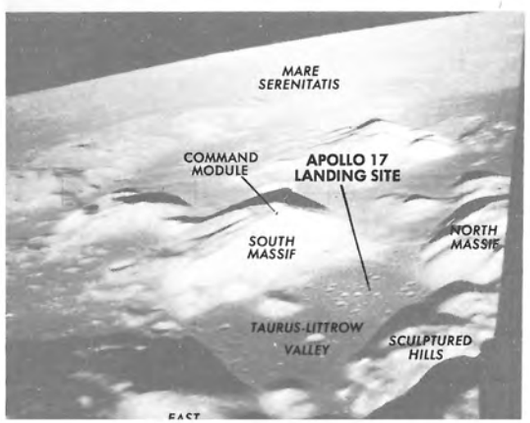
This valley of history has seen mankind complete his first steps into the universe. From this larger home we move to greet the future.

"A pitted, dusty window into our own past..."

THE VALLEY of Taurus-Littrow is confined by one of the most majestic panoramas within the experience of mankind. The roll of dark hills across the valley floor blends with bright slopes that sweep evenly upward to the rocky tops of the massifs. The Taurus-Littrow valley does not have the jagged youthful majesty of our Rockies. Rather it has the subdued and ancient majesty of a valley whose origins appear as one with the sun.

Here Gene and I, who have already transferred to *Challenger,* view our destination from an altitude of ten miles. On a course that takes it a few thousand feet below us, *America* continues in lunar orbit; it appears insignificant against a ridge of the South Massif (right, center, and in the locator drawing below).

We complete our final orbit. Then: "*Challenger,* you're GO," announces Mission Control in Houston. As we monitor our instrument dials and gauges, Gene lets the spacecraft's computer have its head.



EUGENE A. CERNAN

GENE LANDS THE LM as if it were an everyday event. Our camp established (**top**), we begin unpacking—no small chore when the luggage includes your automobile. Unfolding the battery-powered Rover, we load it with TV camera and scientific accessories. A gentle leap in the moon's gravity—a sixth that of earth—easily vaults an eager geologist into the seat (**left**), soil sampler in hand.

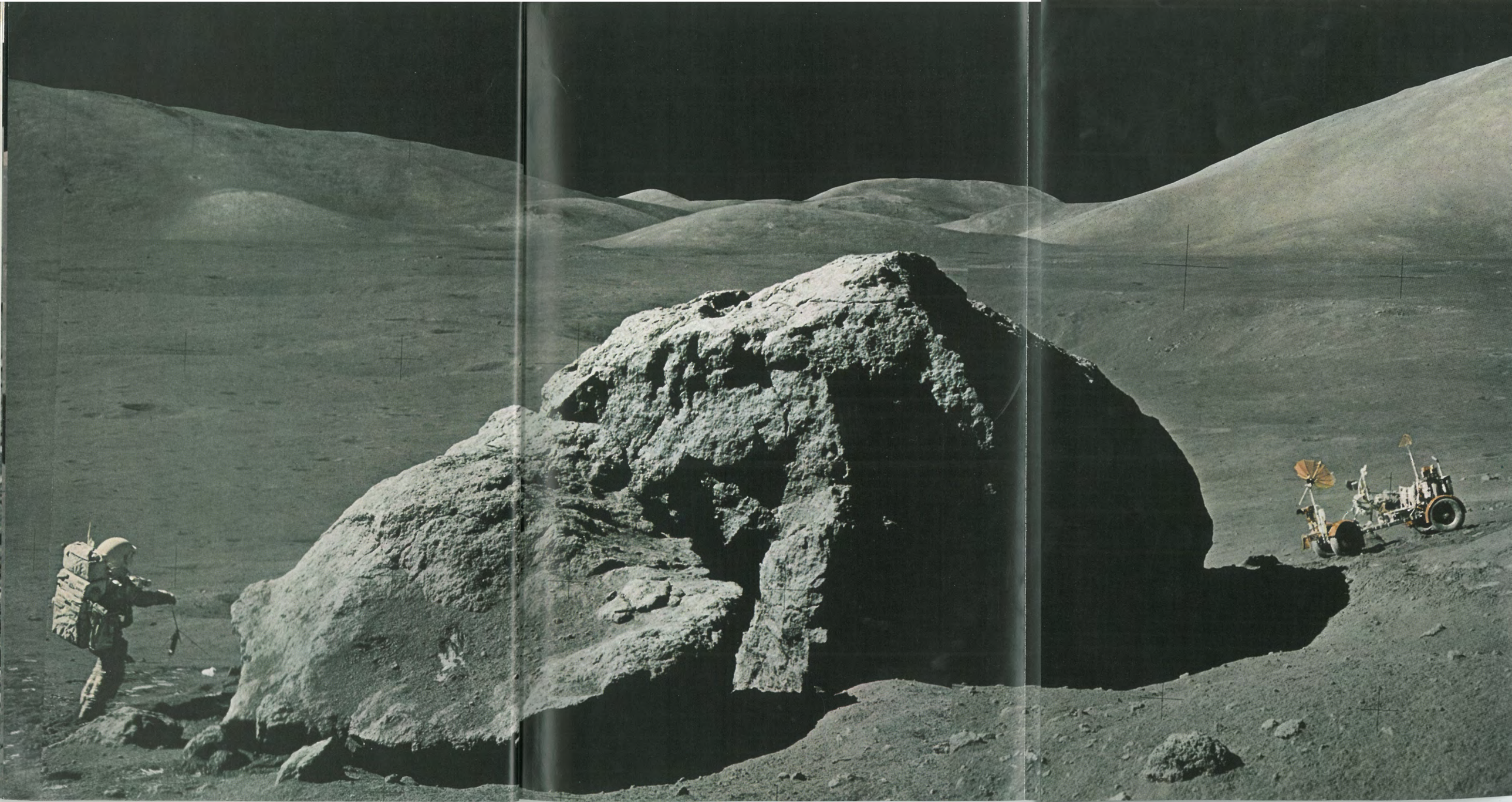
A hammer Gene carries accidentally tears off part of a fiber-glass fender, and dust from the wheel threatens to be a problem. Happily, Astronaut John Young and other friends back in Mission Control conceive a replacement, using clamps, maps, and tape. With their guidance, Gene and I perform the first successful automotive repair job on the moon (**above**).

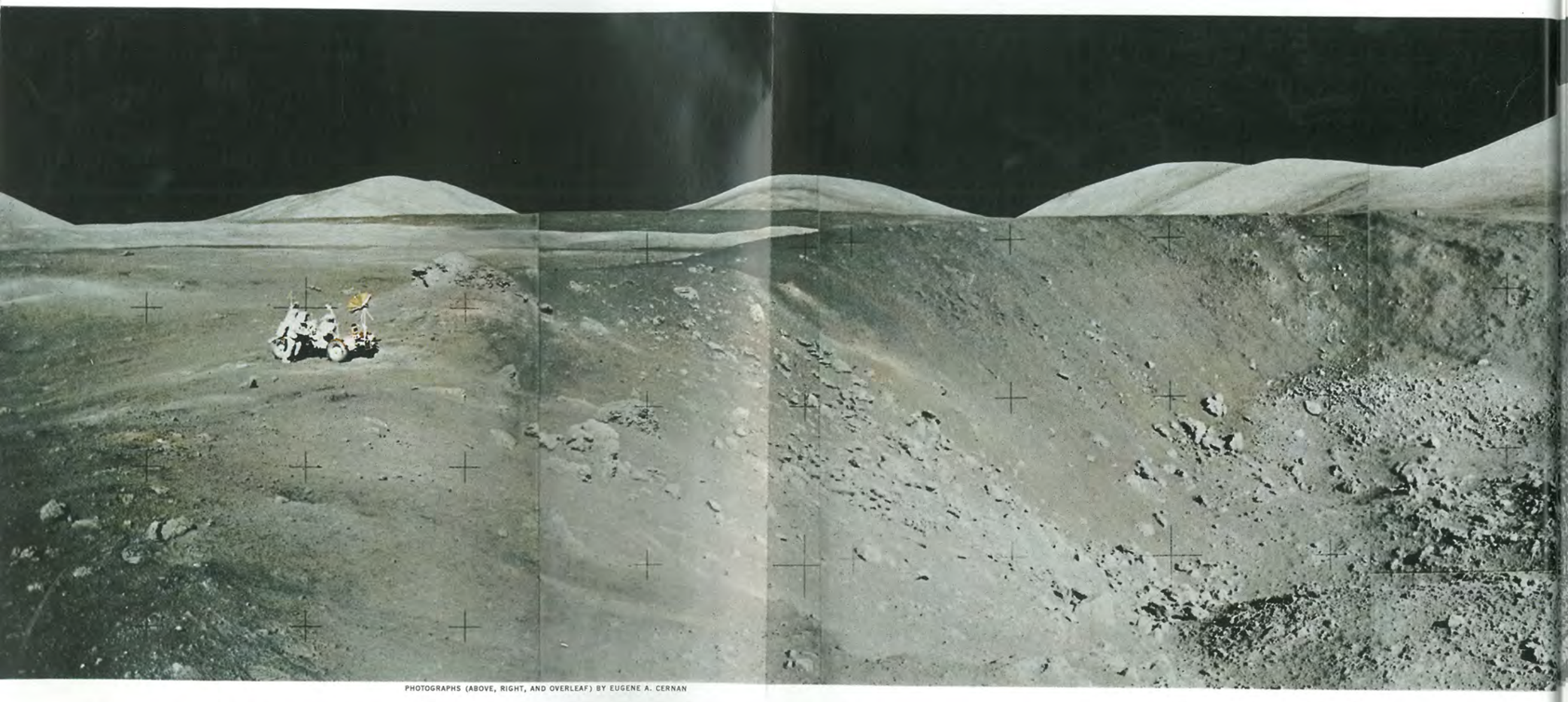
DESPITE sophisticated equipment, a rake is still the best tool for picking up dime- and quarter-size fragments (**left**), which often hold information not found in fine soils or larger rocks. Clean suits advertise that we are new on the job; dust quickly begrimed us and eventually seriously clogged moving parts of some equipment.

Three miles beyond the Rover, a boulder nearly fifty feet across had plowed a path down the North Massif (**right**), tracing its signature on a massive page of history. The track suggests that the rock waddled from side to side down the slope.

Lunar seas converge in an orbital view taken only 130 miles from our landing site (**below**). The darker basalt, lower, spread when lava flooded Serenitatis perhaps 3.7 billion years ago. Then a younger pale basalt crept in during the final filling of the basin. Long narrow rilles, crater chains, and an eight-mile-wide crater pattern this fascinating region.

EUGENE A. CERNAN (LEFT AND TOP) AND RONALD E. EVANS, APOLLO 17 COMMAND MODULE PILOT





PHOTOGRAPHS (ABOVE, RIGHT, AND OVERLEAF) BY EUGENE A. CERNAN

"A geologist's paradise, if I ever saw one..."

GARAGE-SIZE BOULDER on the valley floor (**left**) once perched high on the North Massif. Probably dislodged by a meteorite impact, it rolled down the mountain and split into five segments as it came to rest.

Our samples show that the boulder is composed of two types of rock, which probably formed during different cataclysms some four billion years ago. Any geologist who helps solve the riddles of Split Rock's history will add new pages to the calendar of violent events that helped shape both the infant moon and the earth.

I retrieve a gnomon, which we had placed to indicate color, scale, and angle of slope for our photographs.

A landmark on our second traverse (**map at right**), Shorty crater (**above**) could accommodate a football field. As we skirt the rim, our feet scuff the surface and produce the unexpected. "There is orange soil!" It almost glows in a sampling trench (**far right**). Gases escaping from a fumarole—an indication of recent volcanism—could cause such coloration. But later studies show the bright soil to be microscopic glass beads, tinted by titanium, that formed 3.7 billion years ago from molten rock thrown skyward by a volcano or a meteorite. After cooling, the beads were buried, then blasted to the surface again only a few million years ago by the impact that dug Shorty.

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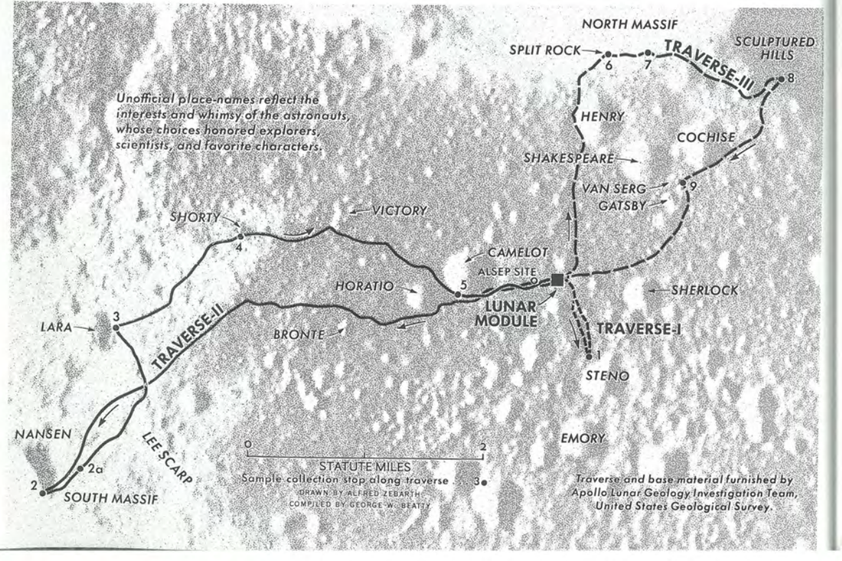

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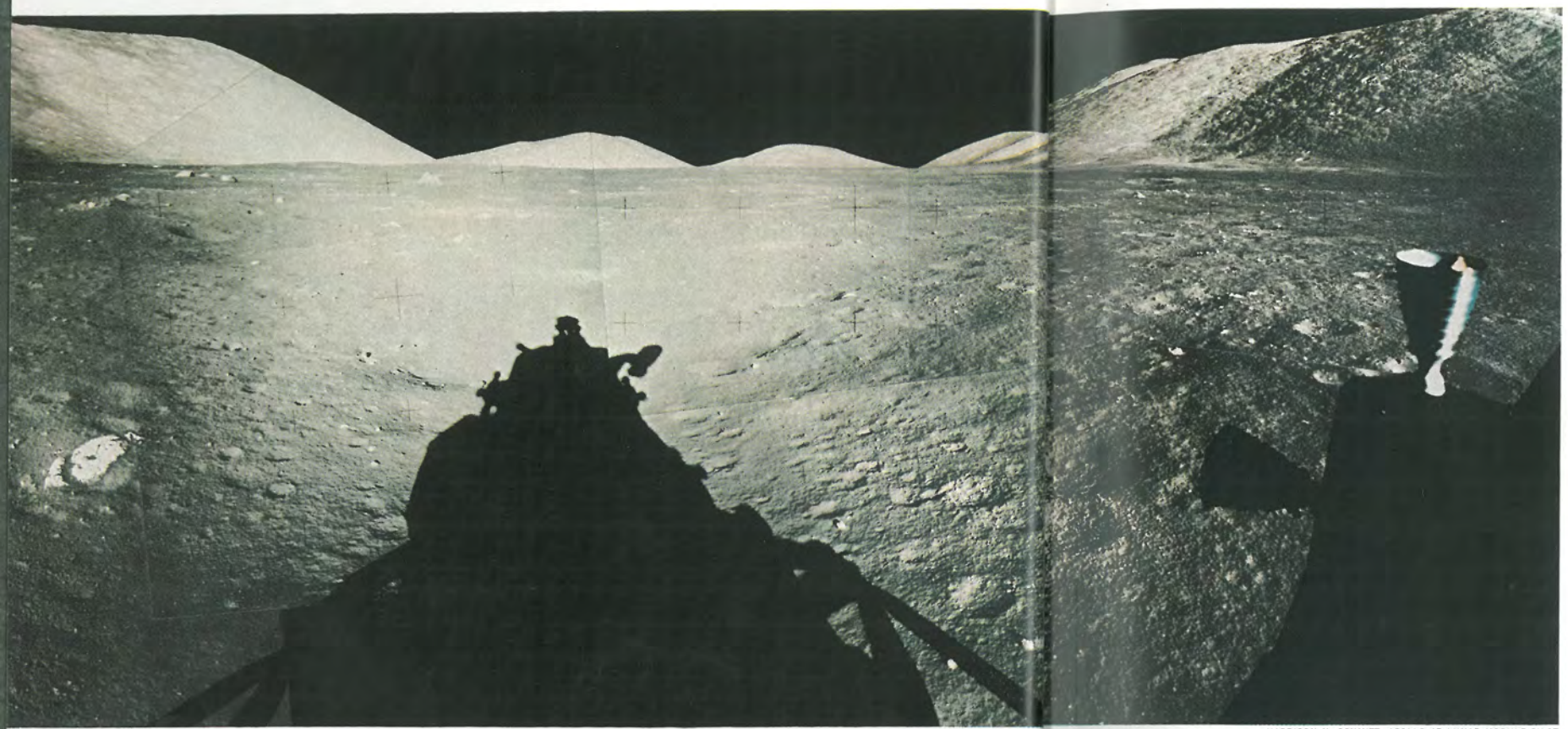

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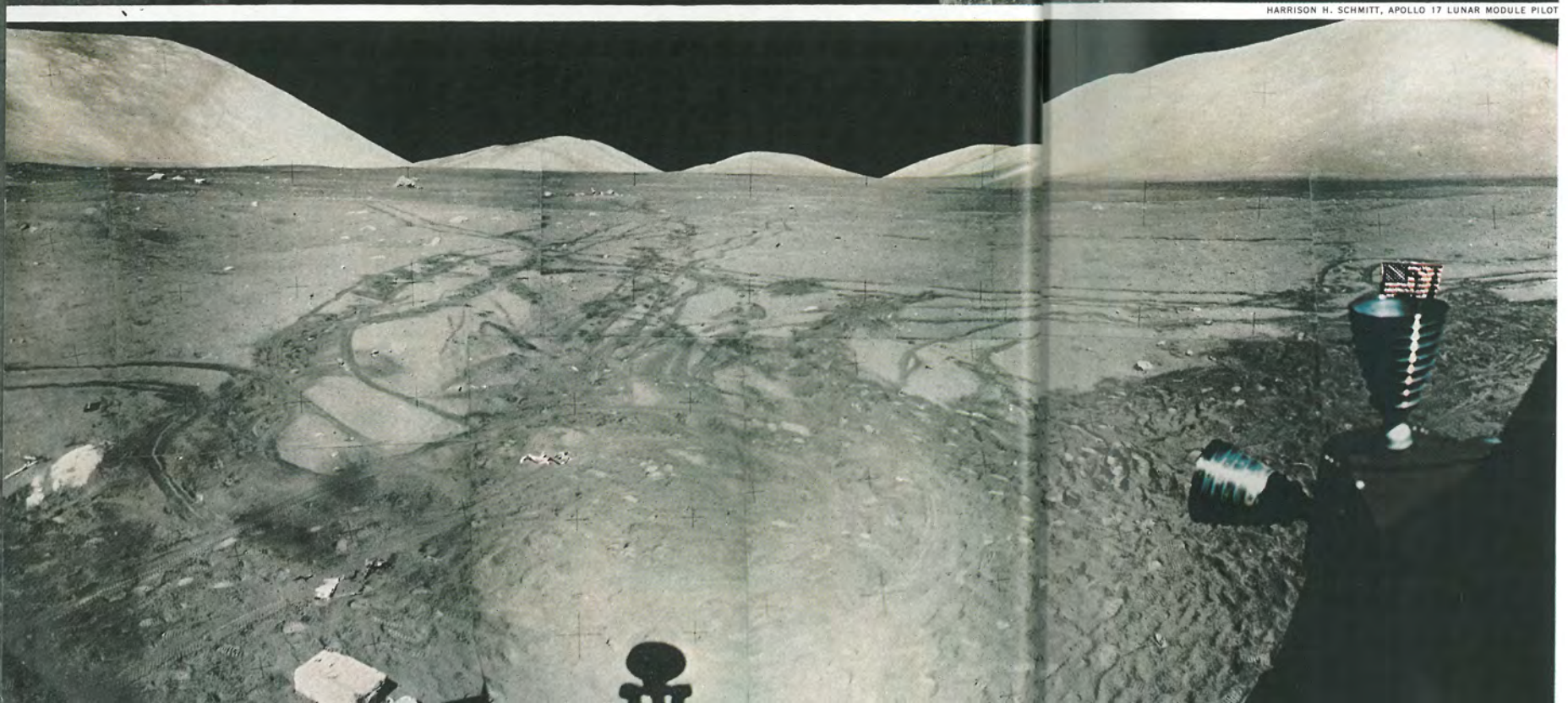

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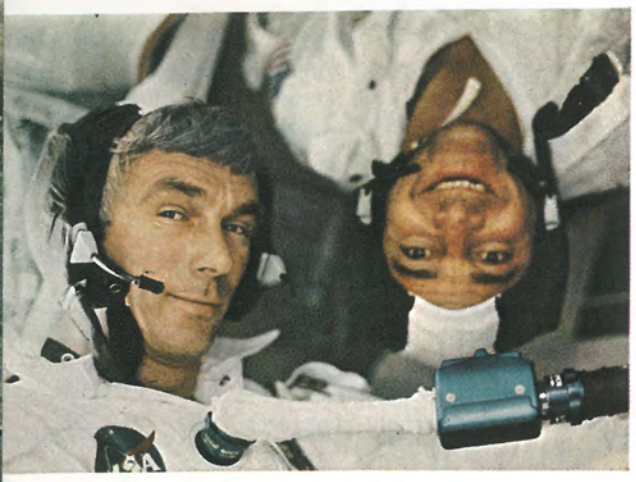
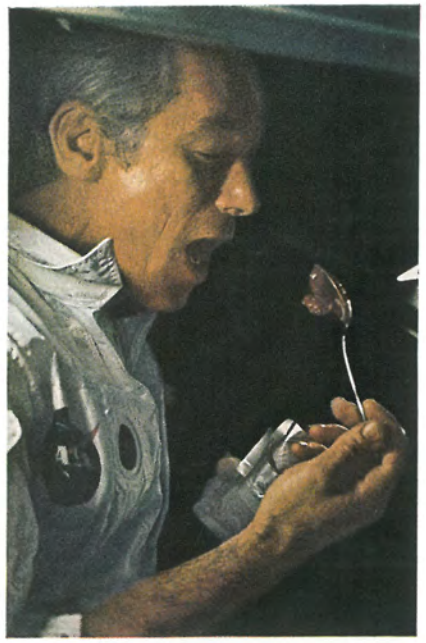
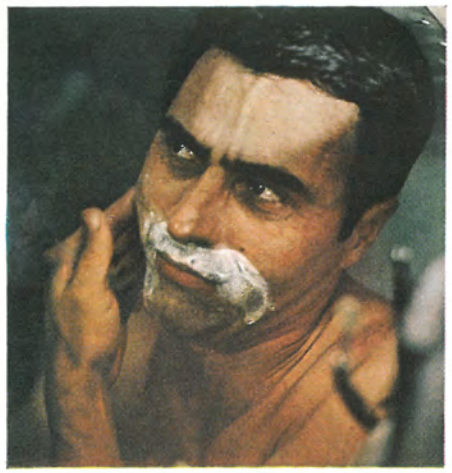
Time to relax on the long road home





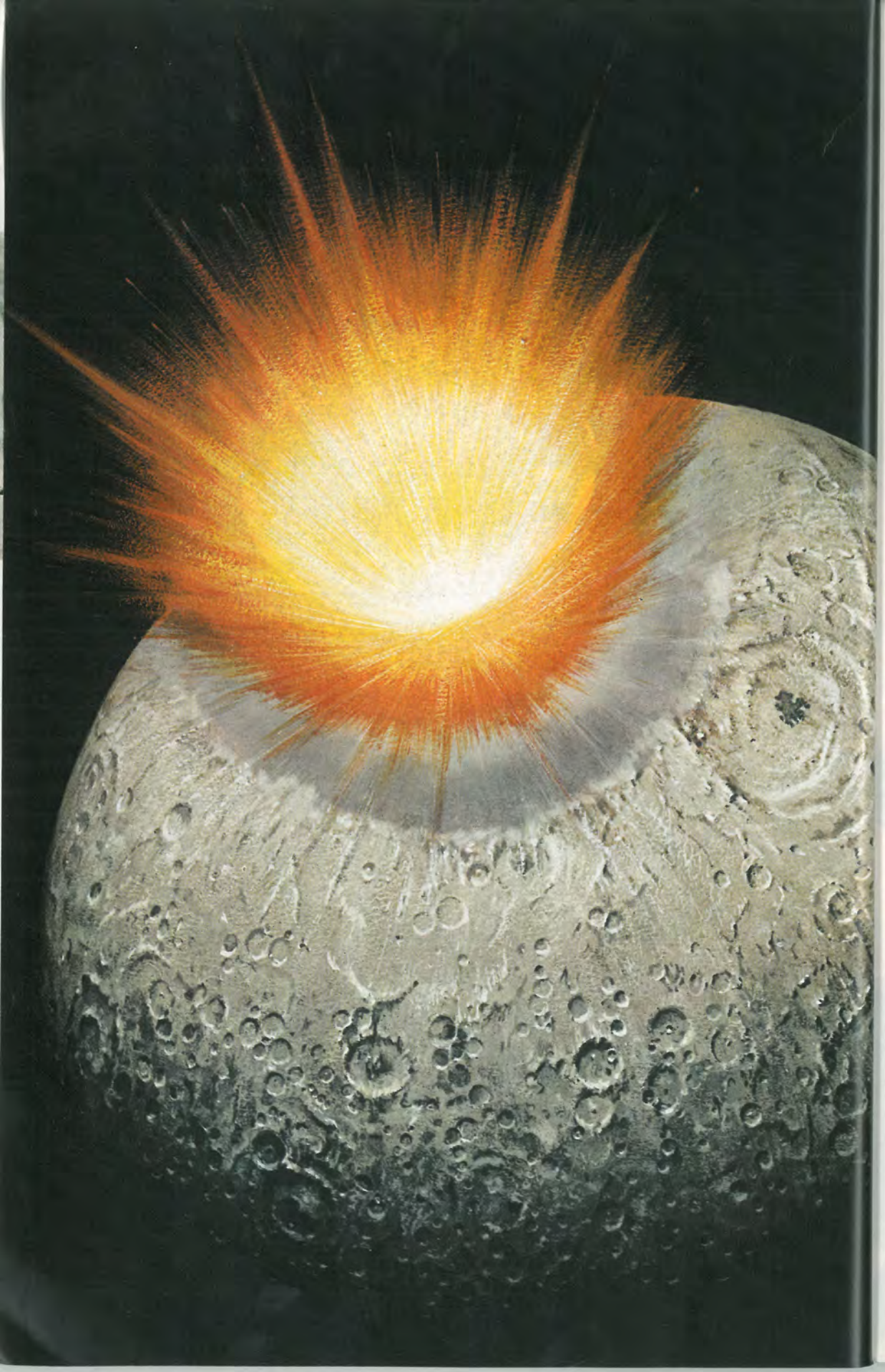


HARRISON H. SCHMITT (TOP LEFT AND LOWER RIGHT); RONALD E. EVANS (TOP RIGHT AND LOWER LEFT); APOLLO 17 CREW (OPPOSITE)

DEPARTING THE MOON as flawlessly as we landed, Gene and I rendezvous with Ron in *America,* then jettison the faithful *Challenger.* After further lunar observations and Ron's space walk to recover exterior film cannisters, we settle down for the relatively relaxed trip home.

Gene (left), and Ron debate what is up and what is down (**top left**). Weightlessness affects everything—canned fruit sticks to Gene's spoon no matter how he holds it (**top right**), while Ron demonstrates the squeezable "glass" (**bottom right**) that enables us to drink in zero gravity. Then comes a time of reckoning: the painful shaving of a fledgling beard (**bottom left**).

For more than six days earth has been our friend in the lunar skies (**right**). That fragile piece of blue with its ancient rafts of life will continue to be man's home as he journeys ever farther in the solar system. □



HAVE WE SOLVED

The Mysteries of the Moon?

By KENNETH F. WEAVER
ASSISTANT EDITOR

Paintings by WILLIAM H. BOND
NATIONAL GEOGRAPHIC STAFF ARTIST

NO MAN KNOWS how big that celestial traveler was. A dozen miles across, at least; perhaps twenty, even fifty. It rushed toward its rendezvous with the moon at relentless speed—an estimated ten to twenty miles a second—yet soundlessly, without flash or fire.

Then, in one awesome instant, cataclysm wrenched the moon. In that moment, as the shock wave penetrated the surface, the monstrous missile disintegrated and vaporized. The frightful energy of its headlong flight—equal to that of billions of hydrogen bombs—was perhaps almost enough to split the moon asunder. Part of the energy turned into a vast, searing fireball that momentarily rivaled the light and heat of the sun itself.

Torn loose by the blast, thousands of cubic miles of rock shot outward—some vaporized, some molten, the remainder pulverized and broken. As the hard-flung fragments arced back into the surface, they gouged myriads of craters and excavated additional rock.

The swift chain reaction reached at least 1,000 miles in every direction. It laid a carpet of ejecta as much as a mile thick, tapering off to a score of feet or less at the outer edges. Some of the displaced moon stuff reached a velocity that overcame lunar gravity and escaped into space.

On the lunar surface a sea of molten rock and newly created rings of mountains marked the scar of the shattering blast. Earlier collisions had left their heavy marks, but none so vast as this. About 650 miles across, it was the largest (and almost the last) of the huge ringed basins to be formed by impacts on the face of the moon.

It was Imbrium, whose lava-filled bowl we see today—some four billion years later—as the right eye of the man in the moon.

In understanding the mysteries of the moon, few features are more important than Imbrium. Apollo 14 landed directly on its ejecta blanket, and many of the rocks brought back to earth are souvenirs of that lunar cataclysm. Significantly, the ages of many lunar rocks cluster around that four-billion-year mark, leading most lunar scientists to conclude that the Imbrium collision, and perhaps several other major events, occurred about the same time. And so the Imbrium

Slamming into the moon with the power of billions of H-bombs, an exploding meteorite blasts out the Imbrium basin, largest scar on the ravaged lunar face.

event is a major landmark in the history of the moon, a history that is slowly taking shape in the massive flood of data from Apollo.

Man's desire to know about the moon has produced a formidable effort going back to 1958. Consider these statistics:

More than 50 spacecraft, U. S. and Soviet, have flown near or landed on the moon. Of 24 Americans who have observed the moon close up, 12 have walked on its surface. There they spent 160 man-hours, traversing 60 miles afoot and by Rover. Thirty thousand photographs from Apollo alone have captured the moon in intimate detail.

On the moon's surface, nearly 60 major scientific experiments were performed by Apollo; in orbit, some 30 more. Five of the six scientific stations left by Americans on the moon continue to transmit information. And, until last May, an unmanned Soviet rover, Lunokhod 2, roamed Mare Serenitatis, telemetering its intelligence to earth.

All told, more than 1,000 scientists in 19 countries have been studying the Apollo samples—a priceless trove of 841 pounds of lunar rock and soil. And a third of a pound of lunar soil brought to earth by Russia's unmanned Luna 16 and Luna 20 spacecraft has added importantly to the growing body of knowledge because it came from areas not sampled by Apollo.

There is a particular fascination in comparing some of our pre-Apollo ideas about the moon with what we know today. I recall, for example, a prominent scientist who told me in 1968, "I see no evidence for lava flows on the moon." Another predicted that the moon material would explode the instant an astronaut's boot touched it. A third asserted confidently that we would find water on the moon. Still others firmly maintained that the moon has always been a cold, dead body, a simple relic of the primitive solar system.

And the possibility of life on the moon led the National Aeronautics and Space Administration for a time to quarantine both the returning astronauts and their lunar rocks, lest pathogenic organisms infect the earth.

Today none of these ideas is tenable. We have come a long way in understanding our satellite. And yet, as Dr. Robin Brett at NASA's Lyndon B. Johnson Space Center near Houston notes, "The more we see of the moon, the more complicated we know it is." For every question answered, new ones spring up.

Complex sensors installed by Apollo astronauts busily "bug" the moon

WITH INSTRUMENTS of increasing sophistication, six Apollo landings on the moon set up a network of miniature laboratories. Exceeding their life expectancies, most of the devices—here drawn to scale—still send torrents of data to earth.

SUBSATELLITE (1): Deployed from the orbiting command module, this unmanned satellite radios data on solar wind, cosmic rays, the moon's weak magnetic field, and its irregular gravitational field.

ACTIVE SEISMIC EXPERIMENT (2): After the lunar module departs, a mortar hurls grenadelike charges as far as 3,000 feet. Detonations send seismic signals to geophones, revealing subsurface differences.

HEAT-FLOW EXPERIMENT (3): Probe planted eight feet in the lunar soil holds sensors that measure heat flowing from the interior.

SOLAR WIND SPECTROMETER (4): This measures the number of electrons and protons streaming from the sun, as well as their velocity, direction, and temperature.

SUPRATHERMAL ION DETECTOR (5): Registers the rate at which ions are created in the moon's tenuous atmosphere and detects ions from space.

COLD CATHODE ION GAUGE (6): Capturing particles of the moon's thin atmosphere, the gauge monitors its constantly changing density.

LUNAR SURFACE MAGNETOMETER (7): Sensors at the ends of three booms record the moon's slight magnetic field.

CHARGED PARTICLE LUNAR ENVIRONMENT (8): This device records the flow of particles hurled outward by the sun, including those that cause earth auroras.

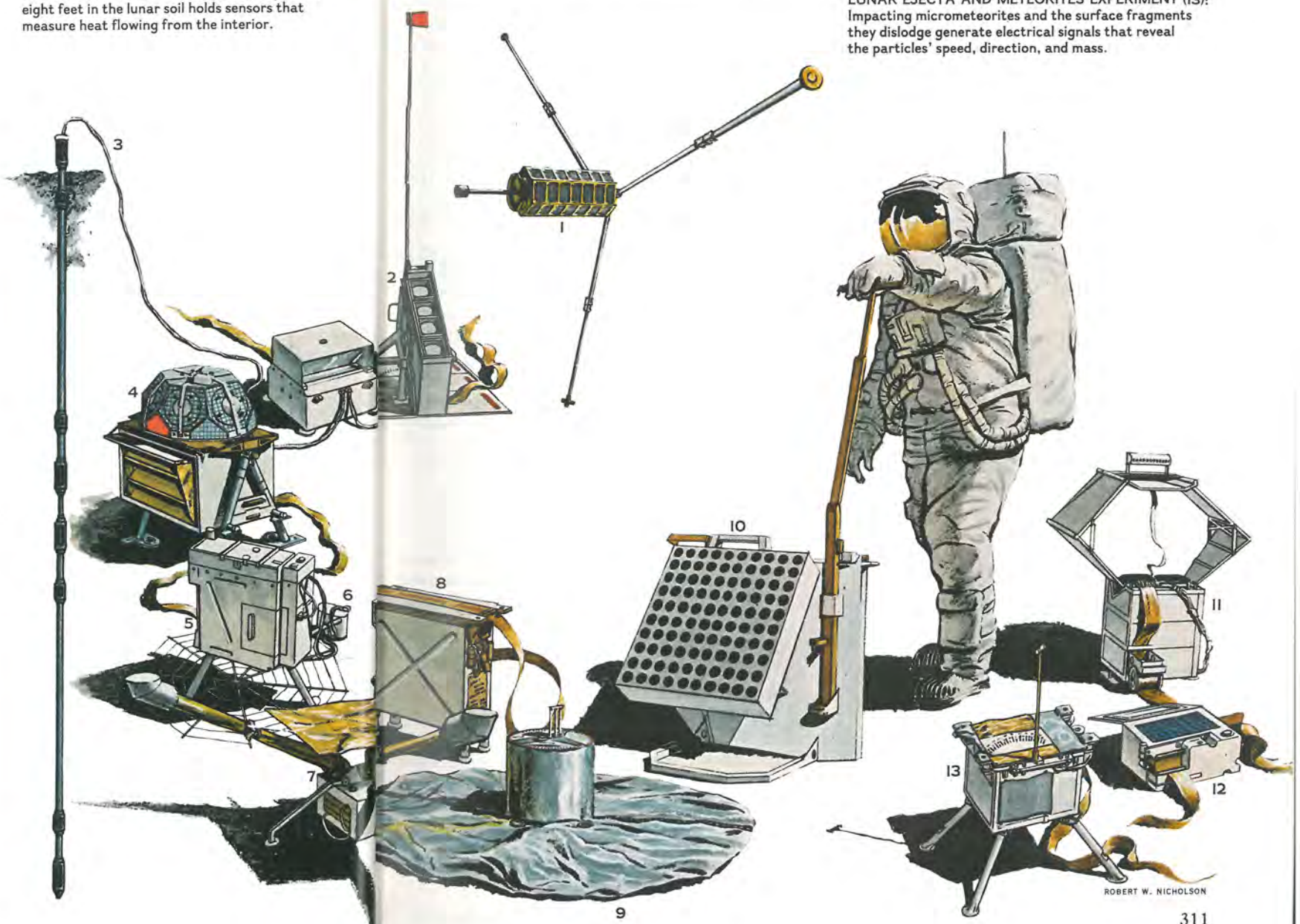
PASSIVE SEISMIC EXPERIMENT (9): Recording moonquakes and meteorite impacts, the seismometer enables scientists to draw profiles of the lunar interior.

LASER RANGING RETROREFLECTOR (10): Bouncing laser pulses back to earth, the reflector measures earth rotation, polar motion, and continental drift, as well as aspects of lunar physics. It gauges earth-moon distances to an accuracy of less than six inches.

LUNAR SURFACE GRAVIMETER (11): Detecting changes as small as 1/10 billionth in the force of the moon's gravity field, this experiment is searching for the gravitational waves predicted in Einstein's theory of relativity.

LUNAR ATMOSPHERIC COMPOSITION EXPERIMENT (12): This sophisticated analyzer of lunar gases was carried only by Apollo 17, as were devices 11 and 13.

LUNAR EJECTA AND METEORITES EXPERIMENT (13): Impacting micrometeorites and the surface fragments they dislodge generate electrical signals that reveal the particles' speed, direction, and mass.



ROBERT W. NICHOLSON

What we know—and what we still do not know—can perhaps best be summed up in six questions, six mysteries of the moon:

1. Is the moon like the earth?

Yes, more so than many scientists thought before Apollo. Like the earth, it is layered, with a crust and mantle and possibly a core, and it "burns" with internal heat. Like the earth, it has had a dynamic history, although volcanic violence has given way to an occasional burp and the shivers of small quakes.

But in more obvious ways, the moon is unlike the earth. No hint of life has shown up in the moon samples, although some analysts find small quantities of substances that they consider the forerunners of amino acids, the building blocks of life. There is no free oxygen. The moon is dry, even though three of its flat maria, or "seas," are named Humorum (moisture), Imbrium (rains), and Nubium (clouds). Rust stains in some Apollo samples may well have been caused by melted ice from comets or water in meteorites falling on the moon, although some scientists blame contamination within the spacecraft.

Apollo's instruments detect tiny amounts of the gases argon, neon, and helium, much of which comes from solar wind. So the moon has an exceedingly tenuous atmosphere, though it is a high vacuum by earth standards.

As Dr. John H. Hoffman of the University of Texas points out: "If you took all the molecules in a cubic centimeter of the moon's atmosphere and lined them up end to end, they would fit on the tip of your pen. But if you did the same thing with the air you are breathing, the chain of molecules would reach to the moon and back with some left over!"

2. Of what is the moon made?

For an answer to this question, I visited some of the laboratories where lunar samples are being analyzed. Scientists twirled the dials on safes, then proudly lifted out little vials of moon dust and rock fragments to show me. I saw bits of orange glass, green glass, red glass, pieces of pitted gray basalt, and speckled chunks of breccia—aggregates of many materials welded together in a single rock.

At the Johnson Space Center I saw sections of moon rocks ground thinner than the page you are reading. Under polarized light in a microscope these now-transparent slices glowed in psychedelic colors, giving ready identifications of minerals.

In an adjoining laboratory automation is being applied to chemical analysis with an instrument called an electron microprobe. Electrons striking a rock sample cause it to give off X rays. The precise wavelengths of the X rays are a kind of fingerprint for identifying the elements in the sample. Driven by computer, the instrument can automatically scan a one-inch disk with a thousand moon particles embedded in it, analyzing each particle in turn within ten minutes.

Some of the tiny orange spheres from the Apollo 17 mission were being analyzed by the microprobe as I watched, and Dr. Arch Reid showed me the readout on an oscilloscope. A series of peaks traced by a rapidly moving dot on the screen revealed the chemical elements present. The scientist pointed to the magnesium peak, then aluminum, then a very high silicon peak, then calcium, titanium, and iron.

"Even with the computer, it's an enormous amount of work," said Dr. Reid, "but we're taking the lunar soils apart, piece by piece."

Analyses like these tell us that the moon is made of the same chemical elements as the earth and the rest of the solar system, but in quite different proportions. The moon is rich in refractory elements—those with high melting points, such as calcium and titanium—that apparently condensed early in the solar nebula from which the moon came. But the moon is poor in volatiles—those elements that vaporize easily, such as sodium or lead.

Carbon, that backbone of living things as we know them, is rare on the moon. Much of what we do find probably came from gases continually escaping from the sun—the solar wind—and from meteorites.

The moon as a whole has much less iron than the earth, though metallic iron—rare on the earth's surface—is common in lunar samples. Some of it shows up as nickel-iron pellets—splashed remnants of meteorites.

The late Dr. Paul W. Gast, head of the Planetary and Earth Sciences Division at the Johnson Space Center, summarized in this way our knowledge of the kinds of rocks found on the moon:

"The moon lacks the large outcrops of granite so common on earth's continents. Also, since the moon has had no oceans or streams, it has no water-laid sedimentary deposits.

(Continued on page 317)

Earth and moon differ greatly, despite similarities

NO LONGER do scientists regard the moon as a celestial cinder pile, cold and inert. Today, thanks to Apollo's seismic and geochemical advances, the moon and earth appear more similar than previously had been believed—both hot internally, divided into layers, and even sharing the same birth date—4.6 billion years ago.

Yet important differences abound. From surface to center, the moon measures only 1,080 miles—a fourth of earth's radius. The moon's density is only about three-fifths that of earth, and its variable magnetic field derives solely from magnetized rocks on the surface. Moonquakes, though frequent, are fewer and weaker than earthquakes, and they occur at greater depths. Perplexingly, the chemistry of the moon tells that it was formed of the same elements as earth but in different proportions—contributing to a theory that the moon could have been born in a different part of the solar system.

Earth

SURFACE FLUIDS: A dynamic atmosphere sweeps the earth, and great oceans wash 71 percent of its surface.

CRUST: Averaging 10 miles thick, earth's mobile outer shell drifts and contorts as it rides atop the shifting mantle. Lava periodically squirts to the surface through volcanic vents.

MANTLE: Some 1,800 miles thick, earth's mantle consists of rock heated to temperatures that may reach 7,000° F. The lithosphere, a more rigid outer layer, slides slowly on the hotter, plastic asthenosphere, carrying the continents.

CORE: Liquid on the outside, solid in the center, earth's iron-nickel core extends inward the final 2,200 miles and seethes at temperatures that may range around 7,500° F.

Moon

SURFACE FLUIDS: A thin, scarcely measureable atmosphere and the absence of oceans hint that the moon never had the kinds of gases that formed earth's atmosphere and oceans, or that they escaped because of weak lunar gravitation.

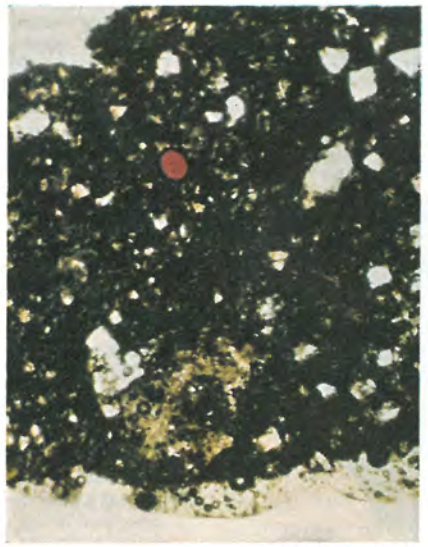
CRUST: The moon's outer layer, almost four times thicker than earth's, where measured, presents a lifeless panorama of craters, fractures, and ancient lava upwellings. No proof exists of recent volcanism.

MANTLE: Still little understood, a lunar mantle apparently extends almost 600 miles, with temperatures possibly as high as 3,000° F.

CORE: Seismic soundings suggest a partially molten outer zone in the lunar center, which extends inward the final 480 miles. But the material does not resemble earth's iron-nickel core. As with earth, heat from decaying radioactive elements probably fuels this inner furnace.

168 TIMES ACTUAL SIZE

Like an empty bird's nest, elongated feldspar crystals mix with blue, red, and yellow pyroxene grains in highland basalt brought back by Apollo 14. Such a basalt, unknown on earth, is rich in radioactive elements that may account for the moon's "hot spots" (page 320). It is called KREEP—for potassium (K), rare earth elements, and phosphorus.



31 TIMES ACTUAL SIZE

Glassy mixture of particles from both highland and mare—or lunar "sea"—harbors a bead tinted red by titanium. This Apollo 15 breccia is typical of the moon's meteorite-churned surface.

59 TIMES ACTUAL SIZE

Kaleidoscope of crystals marks mare basalt from Apollo 17. Whites and grays are feldspar. Black armalcolite is named for Armstrong, Aldrin, and Collins of Apollo 11, who first brought back the mineral. Rainbow hues are pyroxene; olivine adds a touch of green.

Moon's history sought in gaudy slivers of rock

AFTER APOLLO spacecraft freighted a mounting treasure of moon rocks to earth, technicians at NASA's Johnson Space Center near Houston sliced and ground many into wafers less than half the thickness of this paper. Then they exposed them to the light of a polarizing microscope, outlining striking patterns in brilliant hues that identify the rocks' mineral components. Knowing the conditions of heat and pressure that produce such minerals on earth, petrologists will construct a picture of the forces that created these samples of the lunar crust.

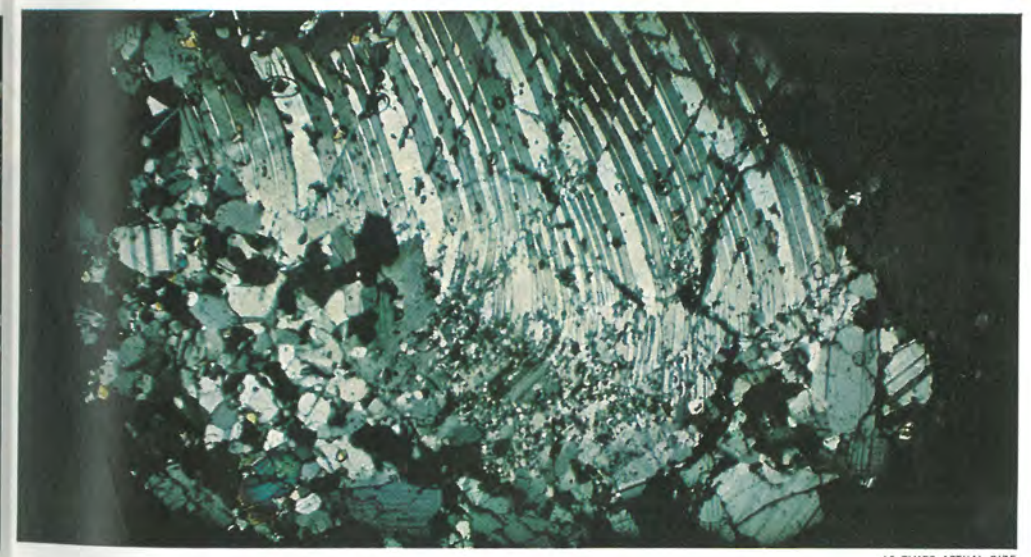
The intriguing sections shown here, photographed and interpreted by Dr. A. E. Bence of State University of New York in Stony Brook, add colorful new pages to the moon's ever-unfolding biography.

83 TIMES ACTUAL SIZE

Beak-shaped growth of pyroxene nestles among feldspar needles. Apollo 12 collected this sample of basalt.

Dark cavity, formed by gas, hides in a vivid matrix of Apollo 15 mare basalt. The hollow originated when molten basalt containing dissolved gas reached the surface. The drop in pressure allowed the gas to expand, just as bubbles flash up when a soft drink is opened.

31 TIMES ACTUAL SIZE



40 TIMES ACTUAL SIZE

Bent bands in the mineral plagioclase indicate deformation of a crystal that felt the shock of a meteorite impact. This bit of rock, known as anorthosite, was collected at Stone Mountain by Apollo 16.

APOLLO 12: Nov. 14-24, 1969 This second mission to land on the moon alighted on a ray, or band of ejecta, blasted from the crater Copernicus, 250 miles to the north. The ray lies atop Oceanus Procellarum, composed of layers of dark mare basalt that welled upward from the mantle some 3.2 billion years ago.

APOLLO 14: Jan. 31-Feb. 9, 1971 Ejecta thrown up by the Imbrium impact, 700 miles distant, formed the Fra Mauro hills of Apollo 14. Mission samples give a date for the cataclysm: about 4 billion years ago. Basalts of Oceanus Procellarum lap against the hills, proving that the uplands predate the lava flows.

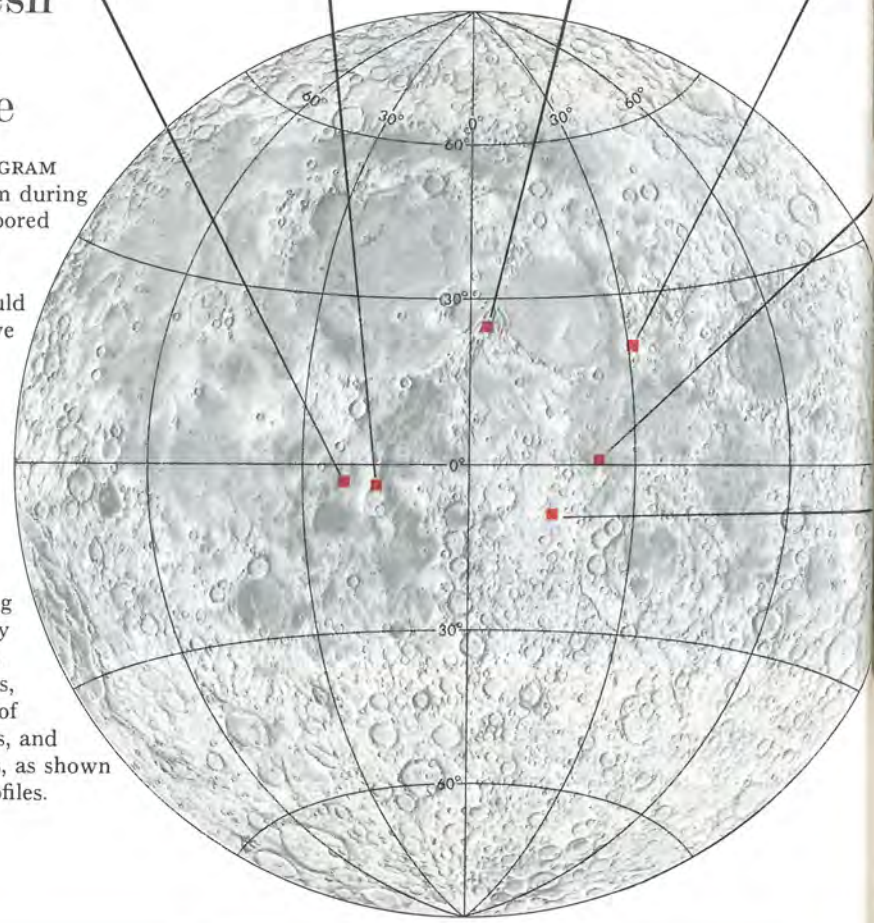
APOLLO 15: July 26-Aug. 7, 1971 The Apennine Mountains soar nearly three miles, and enigmatic Hadley Rille slashes a 1,000-foot canyon at the spectacular site of Apollo 15. This mission and Apollo 16 collected highland rock dated as being more than 4 billion years old.

APOLLO 17: Dec. 7-19, 1972 Massifs created by the impact that dug the Serenitatis basin guard the valley of Taurus-Littrow, scene of the final Apollo landing. After lava filled the valley some 3.7 billion years ago, an avalanche brought down highland rock, putting it handily in reach of the lunar explorers.

Landing-site profiles flesh out the moon's face

As THE APOLLO PROGRAM gained momentum during the 1960's, scientists pored over lunar maps and photographs to select landing sites that would be the most productive scientifically. Successive moon flights reconnoitered for missions to come.

Today, by putting together the voluminous surveys of the six Apollo landings, scientists gain a growing understanding of the moon's anatomy —its vast level maria, or "seas," its highlands, rilles, craters, regions of overlapping landforms, and its subsurface features, as shown in these schematic profiles.



APOLLO 11: July 16-24, 1969 Jumbled boulders ejected from whitish West crater threatened this first lunar landing with disaster; only seconds of fuel remained when Neil Armstrong, clearing West's debris, found a level area for setting down. The site lies in Mare Tranquillitatis, which filled with lava 3.7 billion years ago.

APOLLO 16: April 16-27, 1972 Seeking rocks from loftier terrain, Apollo 16 visited the Descartes highlands. Debris hurled from North Ray crater, right, and nearby South Ray crater strews the surface, while beneath lie deposits from more ancient meteorite impacts. These highlands and those of Apollo 14, 15, and 17 abound with breccias — rock fragments and soil that have adhered because of the heat and pressure of impacts.

"In the areas we have been able to sample, four kinds of moon materials predominate. First, basalts in the maria that are rather like the most common volcanic rocks on earth. Second, feldspar-rich rocks, especially a type called anorthosite, that are found in the highlands. Third, an enigmatic rock type named KREEP* that is relatively high in radioactive elements; it is found chiefly in the regions of Mare Imbrium and Oceanus Procellarum, but is not known on earth. And finally, a recently identified basalt type that I've called VHA, for 'very high aluminum,' found in the Descartes region by Apollo 16."

Jack Schmitt, the geologist-astronaut of Apollo 17, points out that "anorthosites on earth are uncommon and sometimes extremely old. They are of special interest for that reason, and also because earth's anorthosites, such as those in the Adirondacks, are frequently associated with titanium deposits."

This suggests, in fact, a real value of moon exploration. Although we have found no lunar resources worthy of exploiting, the knowledge we have gained from another celestial body enhances knowledge of our own earth, and—some geologists say—may lead to more efficient exploration of our own resources.

3. Is the moon hot or cold?

Before Apollo, few questions roused more raging controversy among scientists. Cold moon adherents were numerous. But today, as Dr. David Strangway at the Johnson Space Center puts it: "We've changed the question. Now we ask: How much of the moon was hot, and when, and for how long?"

Many scientists today agree that some of the moon was hot for at least a time. We see abundant evidence in the rocks from the moon that they were once melted.

The surface itself gives no hint of the heat that may now lie underneath. No active young volcanoes or fumaroles have been found.

Surface temperatures near the equator, as Apollo measurements show, fluctuate violently, depending on the sun's position. They range from about 230° F. at lunar noon to as low as minus 290° F. just before dawn.

But the Apollo temperature probes, a series of ultrasensitive thermometers sunk eight feet deep, show that these surface variations disappear completely only about three feet down.

*K for potassium, REE for rare earth elements, and P for phosphorus.

Below the three-foot level, temperature increases with depth, the result of a flow of heat from the interior. According to Dr. Marcus G. Langseth, Jr., who is in charge of the heat-flow experiment, the measured rate of loss indicates a lunar heat production per unit of volume nearly twice that of earth. This suggests melting conditions somewhere in the moon.

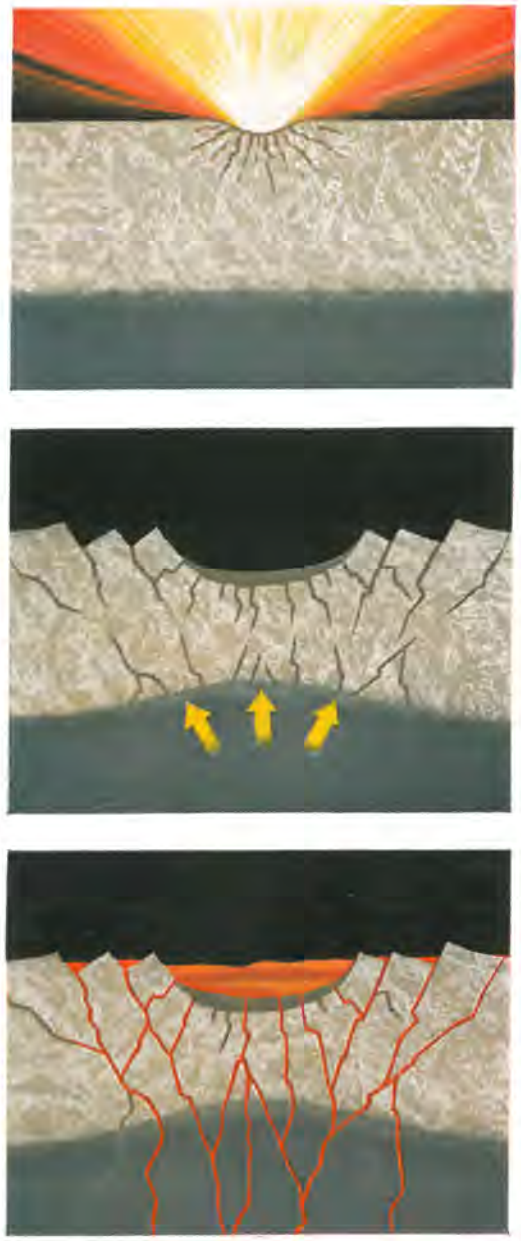
Oddly enough, strong additional evidence for heat in the moon's deep interior comes from the quake-sensing seismometers, of which there are now four operating on the moon. By measuring the various kinds of seismic waves from quakes and meteorite impacts as they pass through the moon, we get a rudimentary picture of the lunar interior.

The jittery lines on the seismograms show a sudden change in velocity of seismic waves at a depth of about 35 miles—at least in the region of southeastern Procellarum. Such a change implies that the material of the lunar surface has given way to rock of different composition, in which seismic waves travel faster. So, in the view of Apollo's chief seismologist, Dr. Gary Latham, "This discontinuity may well mark the end of the lunar crust and the beginning of the mantle."

Below the 35-mile boundary, seismic waves seem to travel with fairly constant speed all the way up from the deep moonquakes that trigger them. Since most of the quakes detected by Dr. Latham (and he records as many as 3,000 a year) come from two long belts 500 to 600 miles deep, the material in the mantle seems to be fairly homogeneous to that depth.

But what lies below? Is there a core, possibly iron? Is it in part molten, like earth's? These questions have been a source of prolonged speculation. But no one had an inkling of the facts until July 17, 1972, when the seismograph recorded a startling event on the far side of the moon—the crash of a meteorite estimated to weigh more than a ton.

Some vibrations from this event passed through the interior of the moon and were recorded by the Apollo network on the other side. But one type, known as shear waves, was absorbed by something in the interior. It happens that shear waves pass through solids but not through liquids, so the conclusion may be that the moon has at least a partly molten center! Dr. Latham puts the beginning of the melting at about 600 miles down, or 480 miles from the center of the moon. Here,



Mighty wounds, slow in healing, shaped the moon early in its history, as an Imbrium-type impact demonstrates. Disintegrating and vaporizing as it strikes, a meteorite blasts debris outward (**top**), while a shock wave creates fractures in the rock. A pool of rock melted from shock heat solidifies in the crater (**middle**), and the slightly plastic mantle adjusts to the loss of mass above it by pushing upward, causing additional fractures. The blast has hurled up mountain rings around the crater. Later, interior heat from radioactivity causes partial melting, and basaltic material rises along fractures, filling the basin layer by layer to form a mare (**bottom**).

temperatures for melting rock must be at least 2,600° F.

Since about a third of the earth's mass is iron, and since much of this metal is in a large molten core, the question naturally arises as to whether the zone of melting within the moon could also be iron. If there were iron in the moon originally, and the moon had been sufficiently hot, the dense metal presumably would have sunk to the interior.

The moon presents a magnetic mystery that might be solved if indeed there is an iron core. No magnetic field is being generated in the moon today, yet lunar rocks show a weak magnetic field, unmistakable evidence that they were magnetized long ago. One explanation might be that a liquid core, rich in iron, acted as a dynamo early in the moon's history and created a magnetic field that has since dissipated.

The entire question of iron in the center raises controversy. It is generally agreed that the low density of the moon (about 3/5 that of earth) would not permit a large dense core. But perhaps the core is small, or holds a low percentage of iron. Some experts argue that a molten iron core would require such a high temperature (about 3,000° F. at that depth and pressure) that much of the moon would melt. But others, notably Dr. Brett, suggest that the iron may be mixed with sulphur, which would permit a melting temperature as low as 1,800° F.

In summary, then, we have reason to speculate that the moon is hot today in its deep interior. In the distant past, it must also have been hot much closer to the surface. Vast sheets of lava in the maria, such as Serenitatis, Tranquillitatis, and Imbrium, testify to widespread volcanism long ago. Such flows, scientists say, could easily have come from depths of as much as 300 miles, finding their way to the surface through the massive networks of fractures caused by the impacts that created the circular basins.

Scientists conclude that the moon's heat engine seems to be cooling, at least in its upper levels. About the only hint of contemporary volcanism comes from suspected venting of gases. Orbiting instruments in the Apollo spacecraft have detected radon, a radioactive gas, possibly seeping from the vicinity of the craters Aristarchus and Grimaldi. Such gases may be linked to elusive bright spots sometimes seen on the moon.

As far back as the 1500's, observers reported brief sightings of such spots, sometimes glowing with color. Just ten years ago at Lowell Observatory, three reddish patches were seen near Aristarchus, and they remained visible for more than an hour.*

These transient phenomena seem to be closely connected to tidal forces which are many times more powerful than those affecting earth. Actually, the distortions caused by these forces are also believed to be the chief source for Dr. Latham's quakes.

4. Why is the moon lopsided?

The moon displays a number of peculiar anomalies, or irregularities. For one thing, its mass is mysteriously off center.

When a Ranger spacecraft plunged into the moon on a photographic mission in 1964, scientists monitoring its passage were perplexed because it crashed slightly later than expected. Careful analyses of radar measurements, photographs, and spacecraft orbits showed that the center of the moon's mass and the geometrical center were not the same. In fact, the center of mass is displaced toward the earth, and the near side of the moon is about two miles farther away from earth than expected, as confirmed by Apollo's laser altimeter. Small as it seems, it is significant to geodesists.

No one has a certain explanation of this anomaly. However, some scientists believe that the crust on the moon's far side may be thicker than the 35 miles indicated by seismometer readings in Oceanus Procellarum. If so, the two irregularities probably have some connection.

In several other ways the near and far sides of the moon exhibit remarkable differences. The front side, as the most casual glance at the full moon reveals, displays vast flat stretches of dark maria, many of which, scientists believe, are enormous impact basins filled with lava. These are interspersed with heavily cratered highlands, the brighter areas of the moon's face.

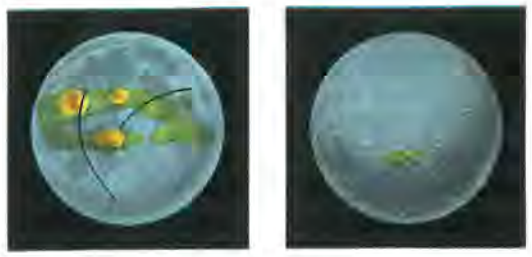
By contrast, the far side, which we never see from the earth, is almost entirely highlands. Only a few of the far-side basins and craters, such as Moscoviense and Tsiolkovsky, have been filled with lava.

Why is this? Why did lava in enormous quantities rise to fill the big basins on one side

*See "That Orbèd Maiden . . . the Moon," by Kenneth F. Weaver, NATIONAL GEOGRAPHIC, February 1969.

Near and far sides wear different faces

Vast mare areas, composed of dark basalts, smudge the familiar near side of the moon (**left**). Brighter highlands dominate the far side, where a suspected thicker crust may have checked the flow of mare material to the surface.



Lunar "hot spots"—areas rich in radioactive rocks—pattern the front side, while the back is largely "cool." Red indicates greatest concentrations of radioactive elements in the fifth of the lunar surface that has been tested. Yellow and green chart areas of lesser radioactivity. Lines show where most moonquakes occur.

of the moon but not on the other? Perhaps a thicker crust on the back made it harder for lava to break through.

Another anomaly: Radioactivity on the surface seems to concentrate in a few near-side areas, as shown in the adjoining diagram. Again, explanations are inconclusive.

Finally there are the mascons, those strange concentrations of material that are detected in the largest circular basins on the face of the moon.

Mascons were discovered by two scientists at the Jet Propulsion Laboratory in Pasadena, California—William L. Sjogren and Paul M. Muller. While analyzing the radio-tracking data from Lunar Orbiter 5, which circled the moon in 1967, they found that when the orbiting vehicle passed over each of the large ringed basins, the spacecraft speeded up temporarily. That increase, Mr. Sjogren tells me, was only about a quarter of a mile an hour out of some 3,000 miles an hour, but such a difference is highly significant.

The best scientific guess about mascons is that the moon reacts after being struck by a very large object, pushing upward to replace all the mass that has been lost by the impact, reducing the depth of the newly created crater. Later, lavas from the mantle break through and partly fill the basin. This additional material tugs with extra gravity on the spacecraft and thus alters its velocity.

5. What is the moon's origin?

A veteran student of the moon once said that it would be easier to explain the nonexistence of the moon than its existence.

Time, and all the evidence from Apollo, has not altered the truth of that statement. All the classic theories about the origin of the moon, plus several recent variations, have their proponents and detractors; there is no consensus.

Traditionally, three theories have competed for attention. The fission, or daughter, theory argues that the moon was born from the earth. The sister, or twin-planet, theory suggests that the earth and the moon were born together at the same time from the same cloud of gas and dust. And the spouse theory holds that the moon was born elsewhere in the solar system, then captured by earth's gravity and forced into eternal wedlock.

Severe problems beset each theory. The marked chemical differences between earth and moon make it very difficult to see how the satellite could have been torn from the earth, or how the moon and earth could be twin planets. And problems of orbital dynamics argue that earth's gravity could not easily have captured the moon and swung it into its present orbit.

Yet, as a Lunar Science Institute study says, "The lunar studies of the last decade have not produced conclusive evidence against any of the theories of the Moon's origin."

And, as Professor George W. Wetherill of the University of California at Los Angeles remarked to me, "I personally would guess that some kind of capture is the proper theory, but I would give it only a 20 percent chance compared to 10 percent for each of the others. The other 60 percent represents things we haven't thought of yet!"

6. What is the moon's history?

The plaque on the door said "Lunatic Asylum," but there was nothing lunatic inside. It was a model of order and cleanliness, in which dedicated scientists from several countries were doing ultraprecise dating of moon rocks. I was visiting the geochronology laboratory of Professor Gerald J. Wasserburg at the California Institute of Technology.

At the door I removed my shoes, then stepped onto a squishy pad to clean lint and dust from my socks. From the hall inside I could peer through windows into sparkling rooms where white-garbed scientists worked. Heavily filtered air under slight pressure flowed outward from the rooms, so that contamination could not come in.

I was not allowed into the holy of holies, where lunar samples were being prepared for analysis, but I observed that surgical standards prevailed. Stainless-steel bone chisels and tweezers that had extracted a small fragment from a rock were immediately discarded for electro-cleaning; for the next operation new tools were taken from a plastic box marked "clean." Surfaces not in use were covered with special paper. In some areas Teflon was used to cover metal surfaces. And, Professor Wasserburg told me, the floors are regularly scrubbed down with distilled water.

The reason for such scrupulous cleanliness is that the laboratory works with infinitesimal quantities of material—as little as a hundredth of a gram. Contamination would seriously distort the results.

Professor Wasserburg is a past master at measuring radioactive materials in rocks and determining how long radioactive decay has been going on. This gives him a rock's age.

The technique of radioactive dating is complicated, but a simple analogy helps explain it. If you know the size of a log and the rate it is burning, you can tell how long it has been burning by measuring the amount of ash.

In effect, Professor Wasserburg measures the proportions of strontium or lead or argon, which are the "ashes," or decay products, as compared to their radioactive parents—rubidium, uranium, or potassium, respectively. Thus he can calculate with considerable accuracy when the rock was last crystallized from a melt. Or, as scientists put it, he determines when the radiometric "clock" was reset.

Before Apollo no one had any way of knowing how old moon rocks would be. When Professor Wasserburg and others began dating the actual moon samples, they made a surprising discovery: The youngest rock, a piece of basalt brought back by Apollo 12, was 3.16 billion years old, far older than many people had expected. That fact becomes all the more remarkable when you consider that 99 percent of the earth's surface is less than 3.1 billion years old. That is, most of the earth's surface rocks have been melted, recrystallized, or deeply covered by younger rocks since that time.

The very oldest moon rock that Professor Wasserburg's group has dated—also from Apollo 12—is just four billion years old. So many rocks have been dated at nearly that same time that some scientists have attributed them to the Imbrium event.

Other laboratories have reported older dates for several lunar rocks—4.2 to 4.3 billion years ago. It is not yet clear whether these variations in dating result from differences in the methods of measurement or in the type of rocks, but they have triggered a lively discussion among lunar scientists.

Is this, then, the age of the moon? Not at all, for we believe from calculations about the original radioactive materials in the lunar rocks that the moon began forming about 4.6 billion years ago. That age coincides with the ages of meteorites, which some authorities regard as debris left over from the birth of the solar system.

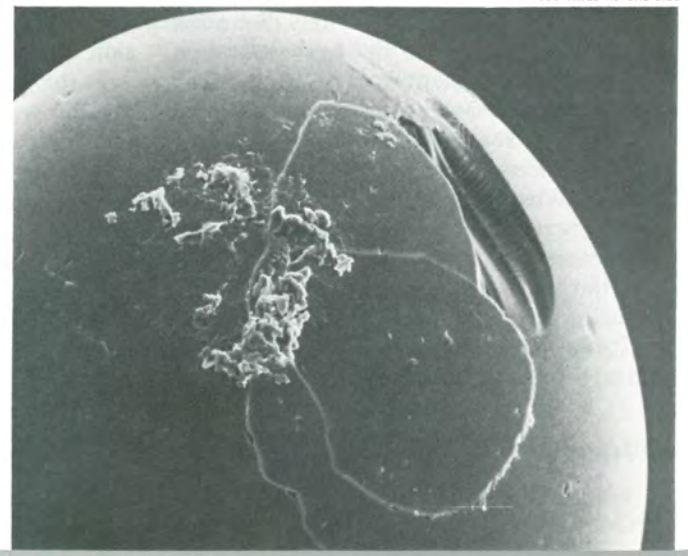
Similarly, on earth the very oldest rocks that have been dated are found near

(Continued on page 325)

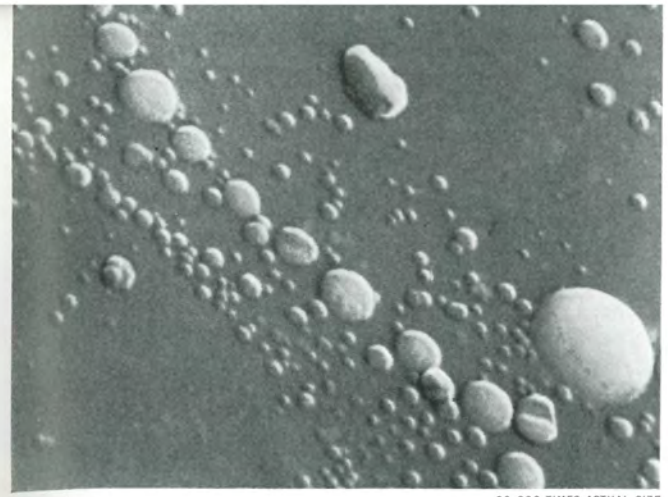
From microscopic worlds, bold lunar vistas: Studying a scanning electron microscope's enlargements of minute moon fragments, Dr. David S. McKay, left, and Dr. Uel S. Clanton of the Johnson Space Center near Houston gain clues to great events that wracked the moon. Tiny glass particles such as those of the Apollo 17 "orange soil" (page 303), enlarged 2,500 times in the mosaic behind them, suggest that lava fountains similar to Hawaiian volcanoes once belched molten rock.

MARTIN ROGERS (ABOVE)

400 TIMES ACTUAL SIZE

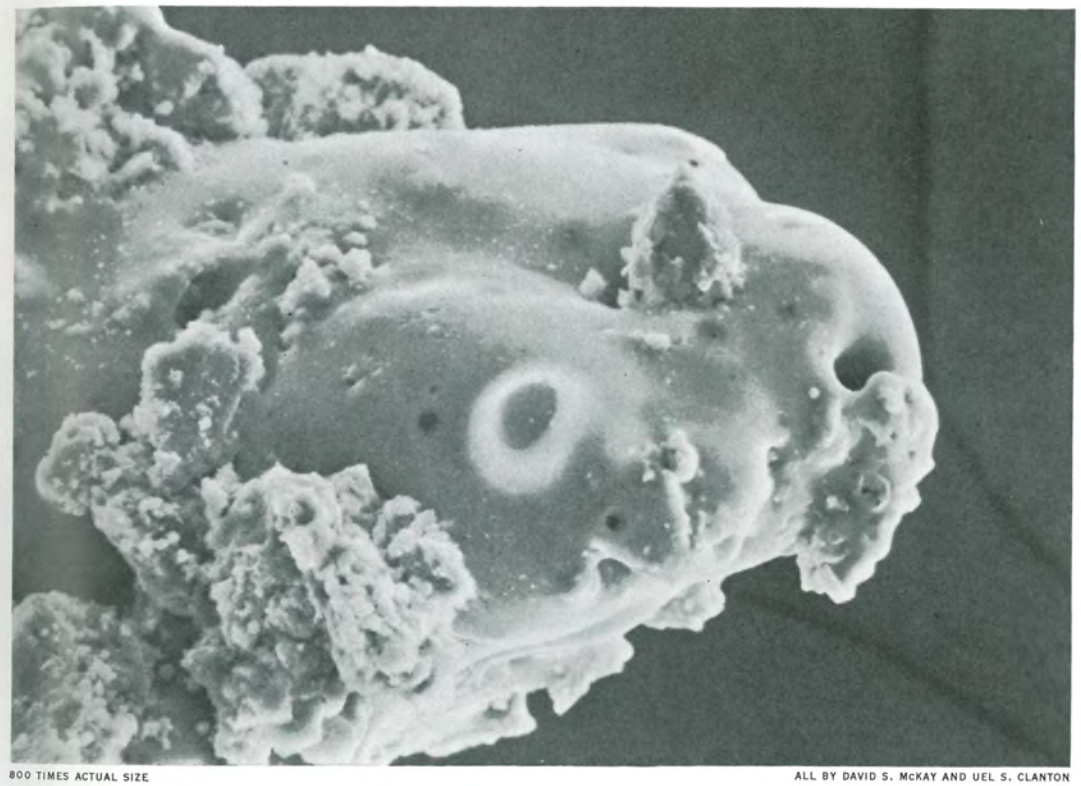


Rigors of birth mark a sphere of glass brought back by Apollo 15. More than 3 billion years ago this droplet may have formed in a lunar volcanic eruption. Molten glass struck it in flight, fracturing and spattering it.



30,000 TIMES ACTUAL SIZE

Offspring of dynamic change, tiny iron droplets, some of them only 1/4,000 the diameter of a human hair, cling to glass formed by micrometeorite impact.



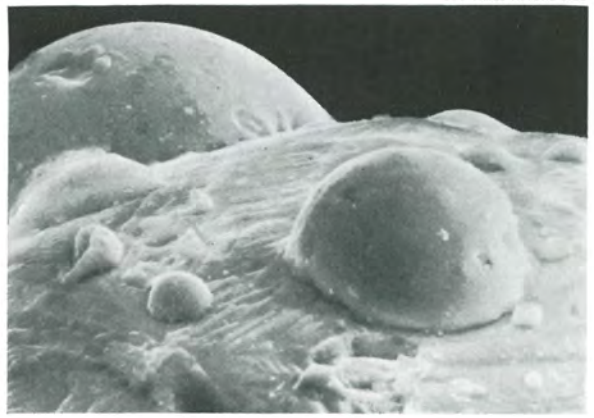
800 TIMES ACTUAL SIZE

ALL BY DAVID S. McKAY AND UEL S. CLANTON

"Parrot's head" emerged when molten glass from a micrometeorite impact captured bits of soil. Such particles, known as agglutinates, are still being formed as micrometeorites continue to bombard the moon.

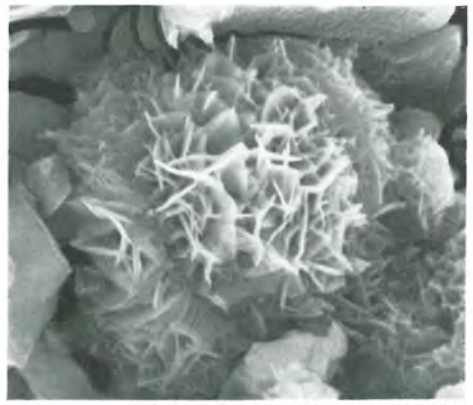
Small glass mounds cling to a larger bead of Apollo 17 soil (**right**). Like the glass at left, the bead's structure suggests that it originated in a lava fountain.

900 TIMES ACTUAL SIZE



Gem from another world, an iron crystal perches on the pyroxene setting where it grew. The crystal formed from an iron-rich vapor during the cooling of a massive blanket of debris thrown out by a large meteorite impact.

Flowerlike iron-oxide crystals of a rusty rock (**right**) collected by Apollo 16 contain water, possibly from a comet, a water-bearing meteorite, or contamination in handling. Apollo's payloads of rocks and data will challenge scientists for decades.



8,000 TIMES ACTUAL SIZE (LEFT); 4,000 TIMES (ABOVE)
DAVID S. McKAY AND UEL S. CLANTON (BOTH PHOTOGRAPHS)

Godthaab, Greenland. Their age has recently been set at 3.75 billion years. Yet we believe that earth, like the moon, is 4.6 billion years old.

So we have never found—and may never find—any of the original crust of either the moon or the earth. But even if the moon's scars and rocks do not date back to the very origin of the solar system, they have opened up an extremely important period in its history and have stimulated our thinking about the earth during this same obscure period.

From all this evidence about rock ages, temperatures, chemical makeup, and interior structure, scientists are beginning to sketch outlines of the possible history of the moon. Here is one such outline.

About 4.6 billion years ago the great solar nebula began condensing to form the bodies of the sun and the planets. Some of this condensed material gathered to form the moon.

The enormous energy of the infalling material melted the outer portion of the moon, perhaps to a depth of 100 miles or more. In a process called differentiation, denser materials settled, and lighter materials floated to form a scum. Thus the moon's crust was developed.

Even after the moon accreted to its present size, it kept sweeping up celestial debris, such as the Imbrium object. The cataclysmic effects of such impacts not only tore out the huge basins but also reset the radiometric clocks of the surface rocks. This process virtually ended with the Imbrium event, about 600 to 700 million years after the moon began to form.

Successive flows of lava, melted by radioactivity in the interior, rose and gradually filled the excavated basins. Meanwhile, smaller meteorites constantly battered the moon, pulverizing the surface and producing the pockmarks we see at every hand. The rate of this meteoritic rain decreased, however, as the leftover debris of the solar system was swept up.

Since about three billion years ago the cooling moon has apparently produced no more substantial volcanism. For all that time its surface has been, in the words of Sir Richard Burton, a "ruined world, a globe burnt out, a corpse upon the road of night."

It was fashionable only a few years ago to regard the moon as the Rosetta stone of the solar system, which was going to lay bare the very earliest beginnings of the solar system. No longer can we say that. Explains Dr. Farouk El-Baz of the Smithsonian Institution: "Maybe the moon is the Stonehenge of the solar system, but not the Rosetta stone. It tells us a great deal, but there are still many mysteries."

That, to me, is an apt comparison. The moon, like Stonehenge, is still in part a riddle from the distant past, a mystery that continues to intrigue the mind of man. □

What Is It Like to Walk on the Moon?

By DAVID R. SCOTT
APOLLO 15 COMMANDER

SIXTY FEET ABOVE THE MOON, the blast of our single rocket churns up a gray tumult of lunar dust that seems to engulf us. Blinded, I feel the rest of the way down "on the gauges." With an abrupt jar, our lunar module, or LM, strikes the surface and shudders to rest. We have hit our target squarely—a large amphitheater girded by mountains and a deep canyon, at the eastern edge of a vast plain.

As Jim Irwin and I wait for the dust to settle, I recall the 12 revolutions we have just spent in lunar orbit aboard our Apollo 15 spaceship *Endeavour*. Each two hours found us completing a full circuit of earth's ancient satellite—one hour knifing through lunar night, then sunrise and an hour of daylight.

As we orbited, I found a particular fascination in that sector of the darkened moon bathed in earthshine. The light reflected by our planet illuminates the sleeping moon much more brightly than moonlight silvers our own night. The mountains and crater rims are clearly seen.

I will always remember *Endeavour* hurtling through that strange night of space. Before us and above us stars spangled the sky with their distant icy fire; below lay the moon's far side, an arc of impenetrable blackness that blotted the firmament.

Then, as our moment of sunrise approached, barely discernible streamers of light—actually the glowing gases of the solar corona millions of miles away—played above the moon's horizon. Finally the sun exploded into our view like a visual thunderclap. Abruptly, completely, in less than a second, its harsh light flooded into the spaceship and dazzled our eyes.

As we looked into the early lunar morning from *Endeavour,* the moonscape stretched into the distance, everything the color of milk chocolate. Long angular shadows accentuated every hill, every crater. As the sun arched higher, the plains and canyons and mountains brightened to a gunmetal gray, while the shadows shrank. At full lunar noontide, the sun glared down upon a bleached and almost featureless world.

Now we have come to rest on the moon, and the last of the dust settles outside the LM. We throw the switches that convert this hybrid vehicle from spacecraft to dwelling. Thus begin our 67 hours of lunar residence.

We are on a still and arid world where each blazing day and each subfreezing night stretch through 355 earth hours. We have landed in the bright morning of a moon day. When we depart, the sun will not have reached zenith.

It is sobering to realize that we are the only living souls on this silent sphere, perhaps the only sentient beings in our solar system not confined to earth. Though we have slipped the bonds of our home planet, we remain earthmen. So we keep our clocks set to Houston time and gear our lives to the 24-hour cycle we have always known.

OPENING THE TOP HATCH for a preliminary reconnaissance, I peer out at a world seemingly embalmed in the epoch of its creation. Each line, each form blends into the harmonious whole of a single fluid sculpture. Craters left by "recent" meteorites—merely millions of years ago—stand out, startlingly white, like fresh scar tissue against the soft beige of the undulating terrain.

I steal a moment and glance straight up into the black sky where the crystalline sphere of earth—all blue and white, sea and clouds—gleams in the abyss of space. In that cold and boundless emptiness, our planet provides the only glow of color.

For 30 minutes my helmeted head pivots above the open hatch as I survey and photograph the wonderland of the lunar surface. The incredible variety of landforms in this restricted area (on the moon, the horizon lies a scant mile and a half from a viewer) fills me with pleasant surprise. To the south an 11,000-foot ridge rises above the bleak plain. To the east stretch the hulking heights of an even higher summit. On the west a winding gorge plunges to depths of more than 1,000 feet. Dominating the northeastern horizon, a great mountain stands in noble splendor almost three miles above us.

Ours is the first expedition to land amid lunar mountains. Never quickened by life, never assailed by wind and rain, they loom still and serene, a tableau of forever. Their majesty overwhelms me.

Eight years' training in lunar geology make me instantly aware of intriguing details. A dark line like a bathtub ring smudges the bases of the mountains. Was it left by the subsiding lake of lava that filled the immense cavity of Palus Putredinis, on the fringes of Mare Imbrium, billions of years ago? Mare Imbrium, on whose edge we have landed, stretches across the face of the moon for some 650 miles. The celestial projectile that excavated it must have been huge—perhaps as much as 50 miles across—and it slammed into the moon with a velocity many times greater than that of a rifle bullet.

WHEN WE DESCEND the ladder of the LM and step onto the moon's surface, Jim and I feel a gratifying sense of freedom. For five days we have been crammed into the tight confines of the spacecraft that brought us here. Now, all at once, we regain the luxury of movement.

But, we quickly discover, locomotion on the moon has its own peculiar restrictions. At one-sixth of earth's gravity, we weigh only a sixth our normal poundage. Our gait quickly evolves into a rhythmic, bounding motion that possesses all the lightness and ease of strolling on a trampoline.

At the same time, since the mass of our bodies and personal gear—and hence, our inertia—remains unchanged, starting and stopping require unusual exertion. I learn to get under way by thrusting my body forward, as though I were stepping into a wind. To stop, I dig in my heels and lean backward.

To fall on the moon—and I did several times—is to rediscover childhood. You go down in slow motion, the impact is slight, the risk of injury virtually nil. Forsaking the adult attitude that regards a fall not only as a loss of dignity but also a source of broken bones, the moon walker—like a child—accepts it as yet another diversion. Only the clinging moon dust, the untoward demand on the oxygen supply occasioned by the exertion of getting up, pall the pleasure of a tumble.

Personally I find the one-sixth gravity of the moon more enjoyable than the soothing weightlessness of space. I have the same sense of buoyancy, but the moon provides a reassuringly fixed sense of up and down.

As we unload and begin to assemble our equipment—including the battery-powered four-wheeled Rover that will carry us across the moonscape at a jaunty six or so miles an hour—I gaze around at the plains and mountains that have become our world. My eyes trace a curiously contoured, totally alien wasteland. I scan the lofty mountains

and feel a strange, indescribable emotion: No naked eye has ever seen them; no foot has ever trod them. I am an intruder in an eternal wilderness.

THE FLOWING MOONSCAPE, unmarred by a single jagged peak, reminds me of earth's uplands covered by a heavy blanket of fresh snow. Indeed, the dark-gray moon dust—its consistency seems to be somewhere between coal dust and talcum powder—mantles virtually every physical feature of the lunar surface. Our boots sink gently into it as we walk; we leave sharply chiseled footprints.

Color undergoes an odd transformation here. Everything underfoot or nearby is gray, yet this hue blends gradually into the uniform golden tan that characterizes distant objects. And this small spectrum moves with the walker.

Most of the scattered rocks share the same gray tint as the dust, but we find two that are jet black, two of pastel green, several with sparkling crystals, some coated with glass, and one that is white.

As we advance, we are surrounded by stillness. No wind blows. No sound echoes. Only shadows move. Within the space suit, I hear the reassuring purr of the miniaturized machines that supply vital oxygen and shield me from the blistering 150° F. surface heat of lunar morning.

Any of a thousand malfunctions in a space suit or the LM could condemn an astronaut to swift death. Yet we have a quiet confidence in our own abilities, and a boundless faith in the engineers and technicians who have fashioned the ingenious devices that transport and sustain us in space. Often, in the course of my stay on the moon, I recall the words of American poet Edwin Markham: "There is a destiny which makes us brothers; None goes his way alone."

At first we experience a troubling deception with perspective. Without the familiar measuring sticks of our native planet—trees, telephone poles, clouds, and haze—we cannot determine whether an object stands close at hand or at a considerable distance, or whether it is large or small. Gradually our eyes learn to cope with the craters—mammoth, medium, and minuscule—that dot virtually every inch of the surface. And gradually the moon becomes a friendlier place. A thought occurs to me: Would human beings born on the moon be able to find their way among the trees and clouds of earth?

Each excursion on the lunar surface is planned to last seven hours, almost to the limit of a space suit's life-sustaining capabilities. We dig and drill into the surface, gather rocks and soil, take endless photographs. The photographs, it seems to me, provide us with a testament that transcends time, for we may be photographing the distant past of our own planet.

The Rover functions impeccably as we ride from site to site, accumulating fragments of history. We bounce and pitch across omnipresent chuckholelike craters. The motion exactly resembles that of a small boat in a rough sea; so does the physical effect. Incredible as it seems, in the arid environment of the moon, seasickness could become an occupational hazard.

After each of our expeditions, we climb—sapped of energy—back into the LM. With its oxygen and food and water, it is a tiny artificial earth that comforts us in the void. Removing our space suits and attending to our housekeeping chores consumes two hours. For the first twenty minutes we are conscious of a pervasive odor, similar to that of gunpowder, from the moon dust we have tracked in. Our air-purifying system soon dispels the acrid scent, but the fine, adhesive dust clings to everything. Back on earth, no amount of cleaning will convert our space suits from the gray hue acquired on the moon to their once pristine and sparkling white.

The better to sleep, we create the illusion of night. We place opaque shades over the windows of the LM to exclude the harsh sunlight reflected from the moon's surface. Then we go through all the homey activities of sunset on earth, even to snapping on overhead lights. When finally we switch them off, we settle into hammocks. On earth, I have always found hammocks uncomfortable. But here my 30-pound body adapts marvelously to the canvas crescent, and I easily fall into dreamless sleep.

BOUNCING ALONG IN THE ROVER on our third and final expedition, we begin to feel fully at home in our new habitat. The craters now seem familiar and help us gauge distances. And we venture across the horizon—the first astronauts ever to do so—without anxiety. Should the sophisticated Rover navigation system fail, we have a small cardboard sun compass fashioned by a technician in Houston—a frail instrument much shriveled by the savage lunar sunlight and coated with moon dust—that will give us our bearings. But our newfound confidence stems less from instruments than from the fact that we have come to know and understand our surroundings.

On our return we even dare a shortcut. The Rover bounces between undulations and crater walls that mask our view of the LM for long minutes, but we emerge on target.

Arriving at the LM, I experience a sense of impending loss. Soon I will leave the moon, probably forever. And, in a peculiar way, I have come to feel a strange affection for this peaceful, changeless companion of the earth.

As I mount the ladder for the last time, I halt and glance back at the Rover. It seems poised and ready for its next task. And poised in that same eager attitude it could remain for thousands, perhaps millions of years—a driverless vehicle lost in the loneliness of this lifeless realm. Beside it, like staunch sentinels through the long millenniums, will hulk the LM descent stage and the assorted equipment of our mission. The vacuum of space, which knows only negligible decay, will confer upon all of it—even to the footprints we have left in the undrifting dust—a permanence akin to immortality.

The thought haunts us that the end of the Apollo flights may mark man's last visit to the moon for a long time. American manned exploration of deep space is scheduled for an indefinite hiatus. Most scientists have already suggested that, when it resumes, all effort should concentrate upon reaching Mars and beyond. So our lunar artifacts—bypassed in the race to the planets—could remain undisturbed for eternity.

Clutching the ladder, I raise my eyes from the now-familiar moonscape to earth, glowing in the black heavens—that incredibly vivid sphere, so blue, so beautiful, so beloved. And so bedeviled: by ecological balances gone awry, by scattered starvation, by a shortage of energy that may motivate us to seek sources beyond our earth. Our Apollo crew believes that a technology capable of exploring space can and will help resolve such problems. We feel a sense of pride in the accomplishments of our program, yet we cannot escape a sense of deep concern for the fate of our planet and our species.

This concern has led us to add certain items to the equipment we are leaving on the moon. The sum of these articles, we hope, will form a résumé of our era in the continuing story of the human race.

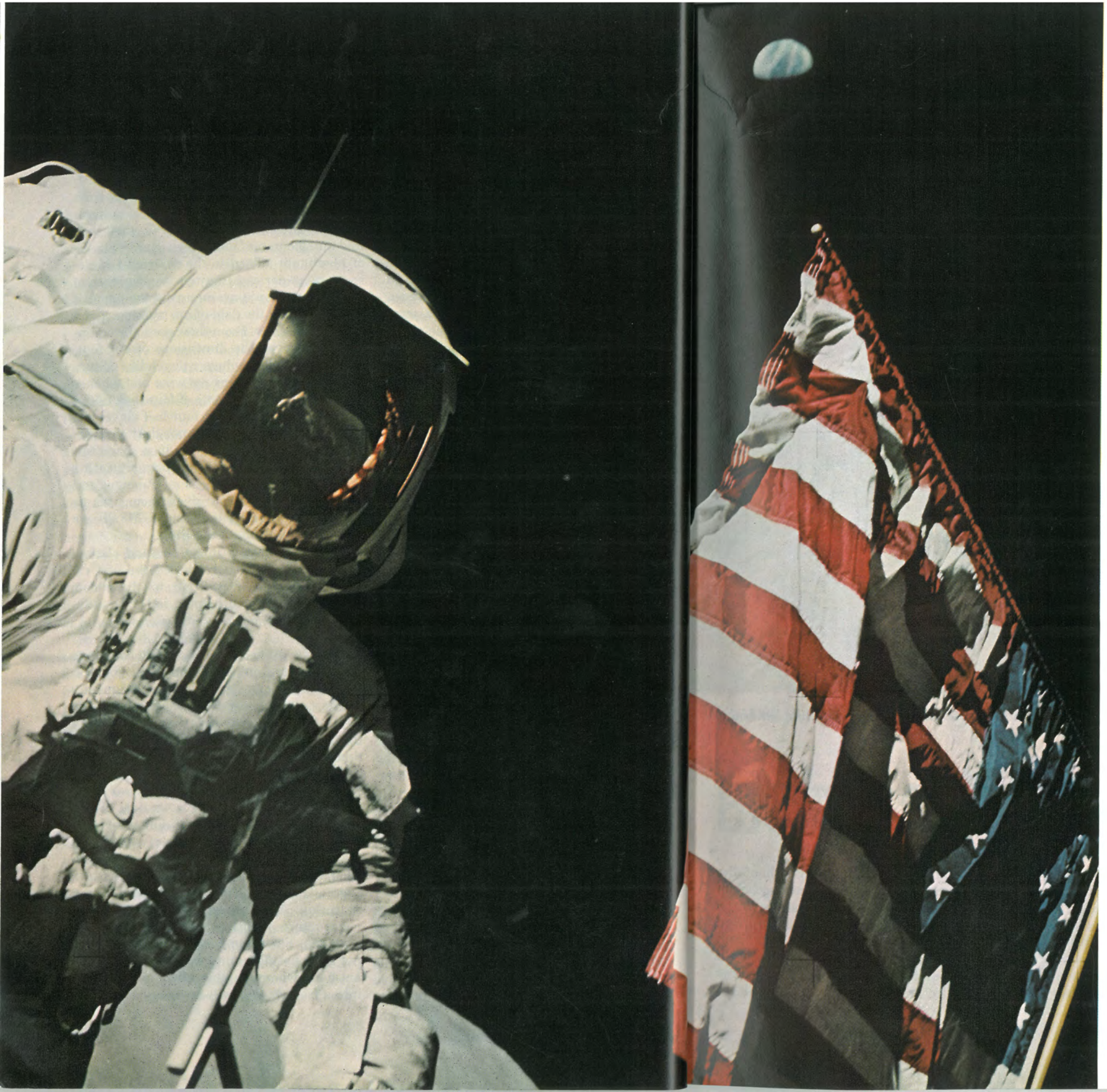
In eons to come, should astronauts from the deeps of space—from other solar systems in other galaxies—pass this way, they may find our spoor, our abandoned gear. A plaque of aluminum affixed to the deserted LM descent stage portrays the two hemispheres of our planet; upon it are engraved the name of our spacecraft, the date of our mission, and a roster of the crew. From these data, the equipment, and even the dimensions of our footprints, intelligent beings will readily deduce what kind of creatures we were and whence we came. We leave a piece of fauna—a falcon feather—and of flora—a four-leaf clover.

In a little hollow in the moon dust we place a stylized figurine of a man in a space suit and beside it another metal plaque bearing the names of the 14 spacemen—Russians and Americans—who have given their lives so that man may range the cosmos. Finally we deposit a single book: the Bible.

Our mission ends in fatigue and elation. Amazing success has rewarded the first extended scientific expedition to the moon. After debriefing and helping in the analyses of our findings, our crew disbands.

NOW, TWO YEARS LATER, I continue to work in the Lyndon B. Johnson Space Center near Houston. Frequently I reflect upon those three most memorable days of my life. Although I can reconstruct them virtually moment by moment, sometimes I can scarcely believe that I have actually walked on the moon.

Occasionally, while strolling on a crisp autumn night or driving a straight Texas road, I look up at the moon riding bright and proud above the clouds. My eye picks out the largest circular splotch on the silvery surface: Mare Imbrium. There, at the eastern edge of that splotch, I once descended in a spaceship. Again I feel that I will probably never return, and the thought stirs a pang of nostalgia. For when I look at the moon I do not see a hostile, empty world. I see the radiant body where man has taken his first steps into a frontier that will never end.



"We came in peace for all mankind."

FROM A PLAQUE LEFT ON THE MOON BY APOLLO 11

Symbolizing man's feat, Apollo 17 Astronaut Harrison H. Schmitt stands on the moon beside the United States flag planted by him and Mission Commander Eugene A. Cernan, whose image reflects in the geologist's visor. A beckoning earth floats nearly a quarter of a million miles away.

EUGENE A. CERNAN