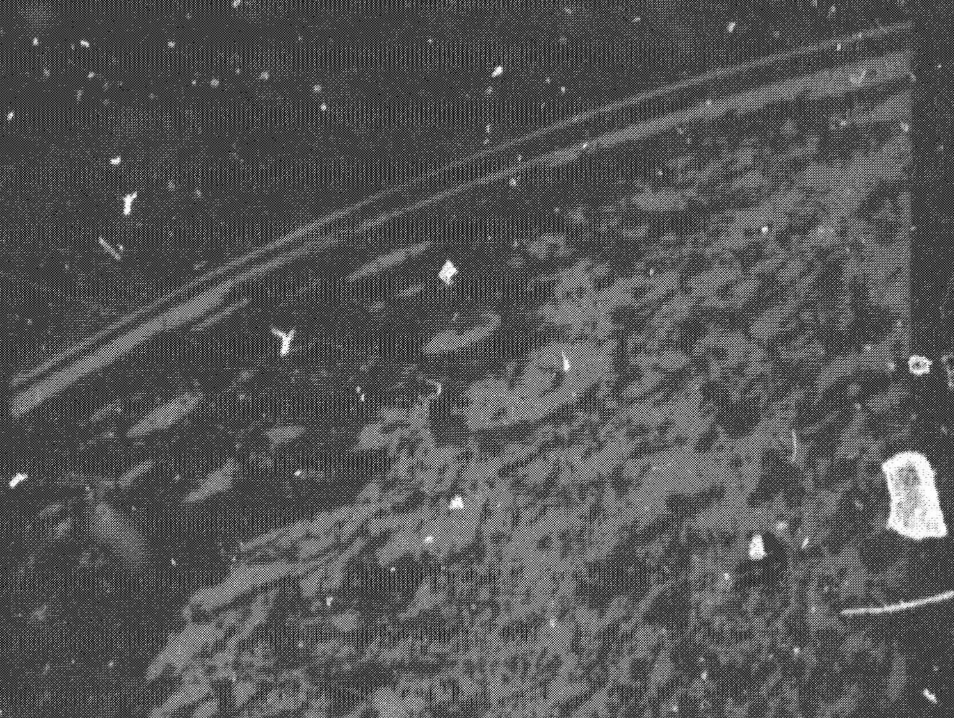
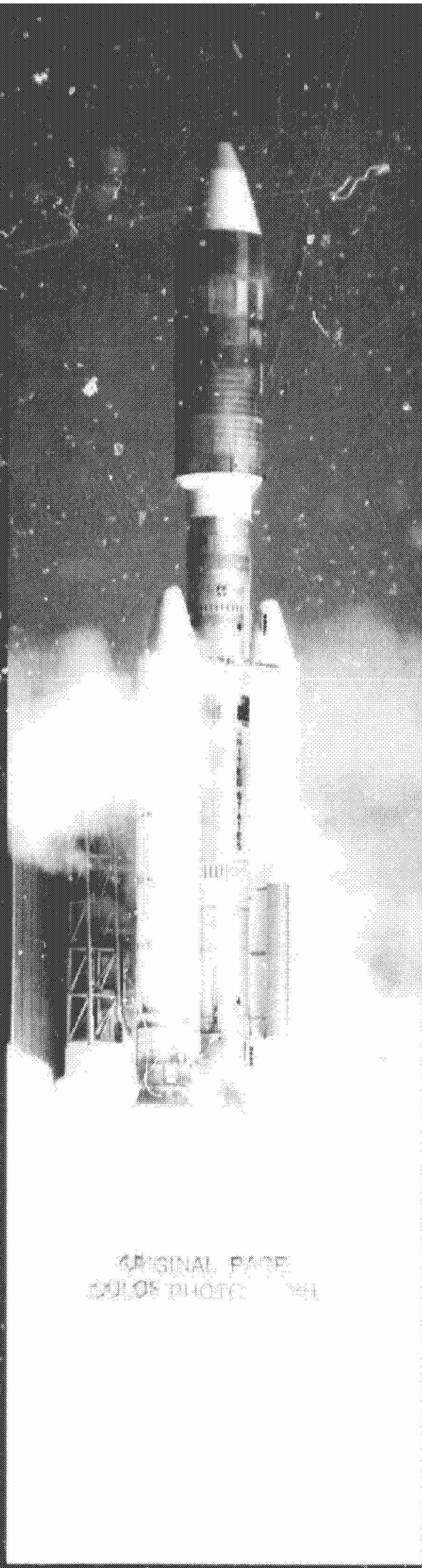
Viking

THE EXPLORATION OF MARS





The voyage of the Viking 1 spacecraft begins spectacularly on August 20, 1975 (right). Launched from Cape Canaveral, Florida, aboard a Titan Centaur 3 booster, Viking 1 would arrive at Mars the following June 19 and send its lander to the Martian surface on July 20. Not to be outdone (left), Viking 2 makes an equally fiery exit on September 9, 1975, on its way to a Mars arrival on August 7, 1976, and a lander touchdown on September 3. Specifications called for the Vikings to operate for only 90 days after landing, but in reality the last message would be sent from Mars to Earth in November 1982, more than six years later.

The slow unveiling of Mars by NASA spacecraft began in 1965 with 21 vague photographs (startling in their time) from a spacecraft called Mariner 4, one of a series of Mariners that ranged the inner solar system from 1962 to 1974 exploring Mercury, Venus, and Mars.

The Mariner 4 photographs were transmitted to Earth at a painfully slow rate of 8-½ bits of data per second. Each photograph contained 240,000 bits and required more than eight hours to send. Only eleven years later, the Viking spacecraft sent their data to Earth at 134,000 bits per second.

Mariner 4's data revealed craters, a haze layer in a thin carbon dioxide atmosphere, and a sparse helping of other findings to be pored over by planetologists for the smallest clues to the nature of a planet once thought to be populated by intelligent beings.

Two more Mariners flew past Mars in 1969, this time sending 201 photographs and other information to add to the slender store of hard data.

The Moon-like photographs gave no hint of a history of geological upheaval or of a living planet that had pulsed with inner heat. "Mars is dead," was the conclusion reached by many scientists.

But when Mariner 9 orbited Mars for a year in 1971, it revealed a new Mars not seen by earlier spacecraft. They had only looked at the areas of ancient terrain on the planet, which were indeed Moon-like.

But the astonishing discoveries of Mariner 9 did not come easily. As the spacecraft approached Mars a small dust storm in the southern hemisphere grew to envelop the entire planet in a thick reddish shroud. In November, Mariner 9 was captured by Mars' gravity field in an orbit above a planet that was totally hidden from view.

The shroud persisted through November and into December before slowly dissipating. Then the electronic eyes of Mariner 9 peered down at a new Mars—an awesome Mars.

The previously unseen surface was cleft by a great canyon thousands of miles long. A volcano towered 17 miles high, dominating a dozen lesser volcanic piles. Long mysterious grooves slashed the dry, desert terrain, and a restless wind had scarred and sculpted great cliffs into majestic forms. And Mariner 9 revealed the greatest mystery of all—evidence that once there had been running water on a planet drier than the Sahara desert.

Low atmospheric pressure on Mars forbids the existence of water except as a solid or a gas. But the photographs clearly showed wandering riverbeds reaching for hundreds of miles. It was difficult for scientists to believe in riverbeds on a waterless planet; but to a geologist's eye it was indeed water that had carved the reddish crust of Mars. (Too small to be seen by telescopes from Earth, these water channels were not the famous canals of Mars.) These channels had been cut by flowing water on a planet without flowing water—and although an explanation was demanded, the issue is yet to be settled.

The fourth mission to Mars was Viking, which consisted of two orbiters carrying two landers. Lander 1 settled down in Chryse Planitia on July 20, 1976, and Lander 2 in Utopia Planitia on September 3, 1976.

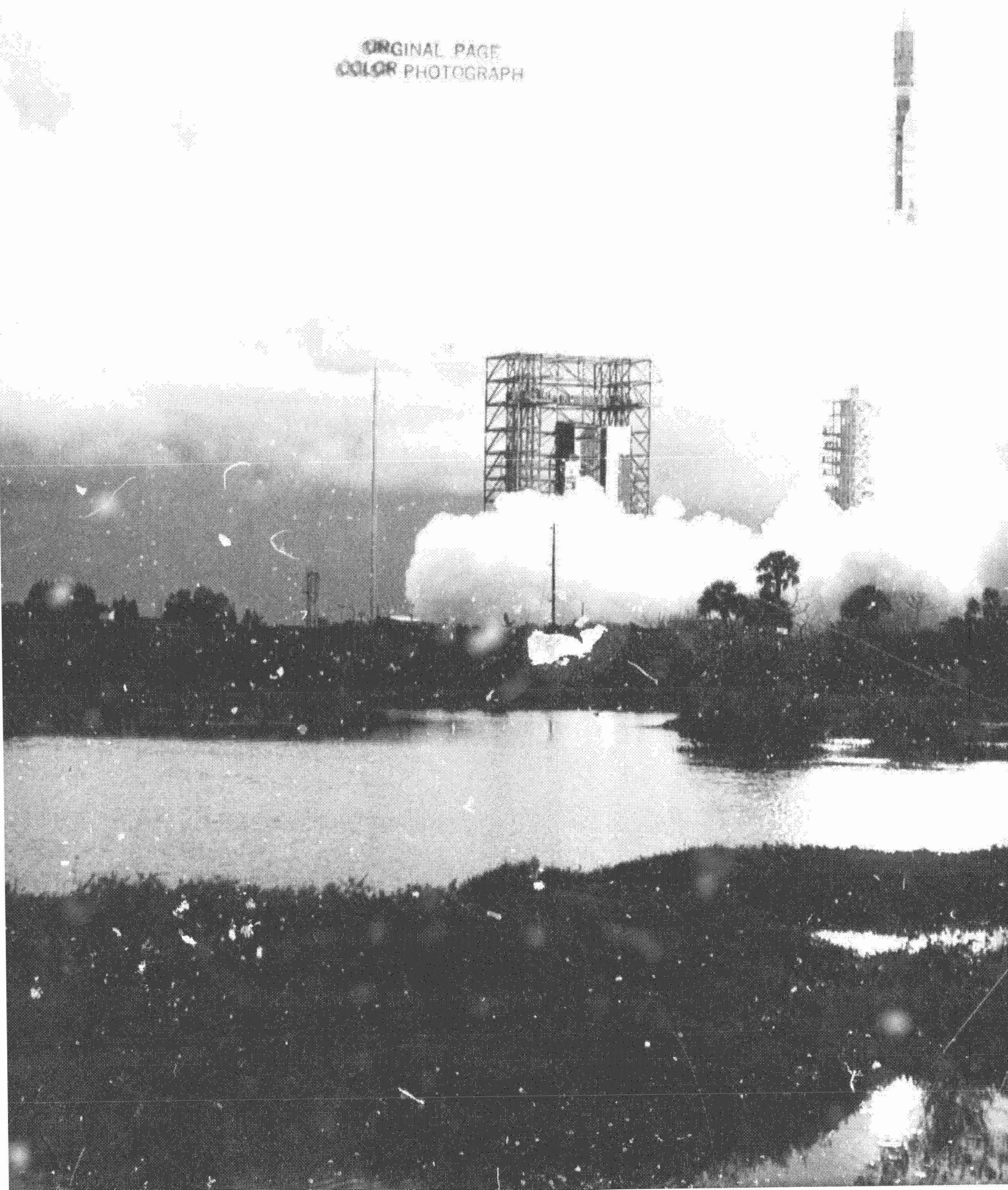
As these robotic outposts of the exploration of our solar system photographed the rocky terrain, measured the wind and temperature, and dug into the red soil, the orbiters began a systematic photographic survey of the planet.

The landers were also charged with the experiment that drew worldwide attention and was the prime focus of the mission—a search for life forms in the Martian soil. They did not find life, although an unexpected chemistry of the soil tantalized scientists by closely mimicking the very reactions they sought as proof of life.

Today, after the last of the four Viking machines has fallen silent, we are heir to billions of bits of scientific data on Mars, and the custodian of more than 50,000 photographs from the Viking mission alone.

But the questions remain. Is there still a possibility of life in some crevice of that strange world? Did life once begin and then die out? And how did climatic conditions change so radically that great floods of water, raging over the Martian plains, vanished to leave the dry, barren desert we see now, a desert changed only by the relentless winds?

In these pages you will see what Viking saw and share with the scientists, engineers, and technicians of the Viking mission their exploration of Mars, the alien beauty of Mars, and its mysteries.



"'Touchdown minus seven, six, five, four, three, two, one, zero.' There was a long silence. It seemed like minutes. Over the loudspeaker came a muffled prayer, 'Come on, baby.' Nothing. I looked down at my shoes. I remember thinking, 'You always wondered what a failure would feel like. Now you know.' I mentally composed some remarks for friends standing nearby. Finally, the silence was broken. 'We have touchdown.'"

—Thomas A. Mutch

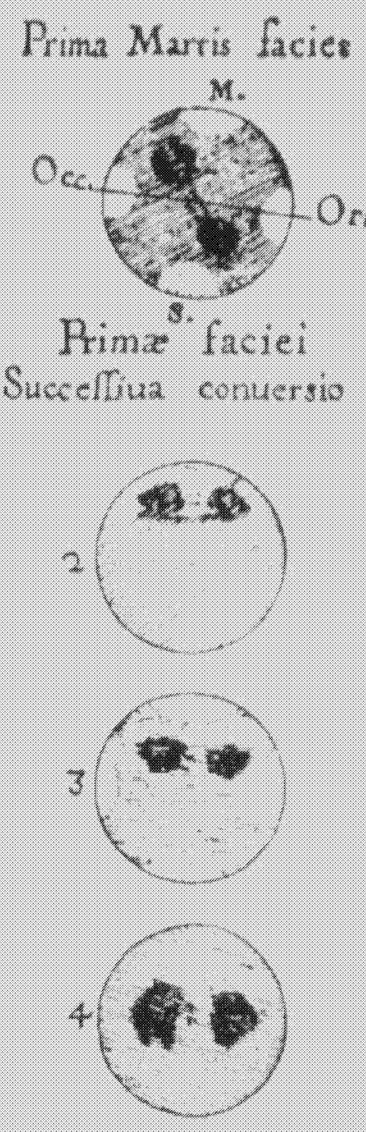
"In Viking, we're after the facts whether they are ugly or beautiful and whether they reinforce or tear down existing theories on the Martian atmosphere."

Seymour L. Hess

"July 19, Monday. The 11 a.m. press briefing produces no suspense; everything is nominal. Read that 'okay' or 'as expected.' Can it be nominal when we're looking to the climactic moment of this most exquisite, mind-boggling venture? The universe is about to grow larger, and it's nominal." Roy Calvin

"If you want to appreciate these pictures fully, you have to travel with us as the Viking Project is transformed slowly and painfully from an idea to a durable spacecraft, propelled on its long journey to Mars."

Thomas A. Mutch



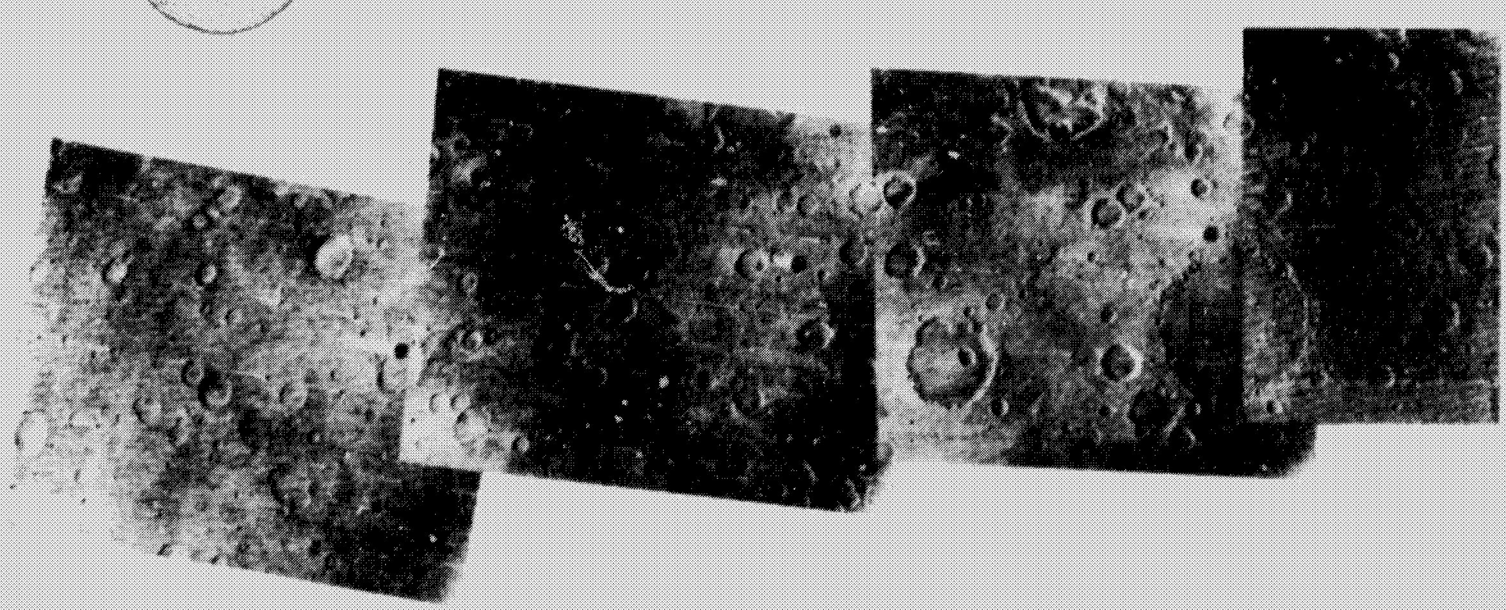
Astronomers began to explore Mars hundreds of years ago, as soon as telescopes could resolve its disk. Imperfect observations and vivid imaginations manufactured a fairy-tale planet, populated by strange creatures, a race older and more intelligent than the humans of Earth. The myths were shattered in A.D. 1965, when a small spacecraft from Earth named Mariner 4 flew past Mars and took 21 photographs of a small fraction of Mars—a desolate, barren waste. The photographs ended thoughts of civilizations on Mars. Two more spacecraft, Mariners 6 and 7, flew past Mars again, in the summer of 1969. They told the same story: Mars was dead and cold, inactive since its birth 4.6 billion years ago.

Two years later another machine set off, this time to orbit Mars for a full year of study. Mariner 9 revealed a far different planet: a Mars spotted with gigantic volcanoes and a great series of parallel canyons etched across 3,000 miles, trenches in which the Grand Canyon would be a mere scratch. Most surprising of all, on this dry and dusty planet where scientists could find no liquid water, were the relics of ancient river beds, clearly carved in the surface. Since water is essential for life, scientists' hopes rose for Viking's prospects of finding living things or some proof of life in the past.

Those early flights to Mars were preface and prologue to Viking. Viking wrote the definitive text and it is to Viking's results that scientists turn today to study Mars.

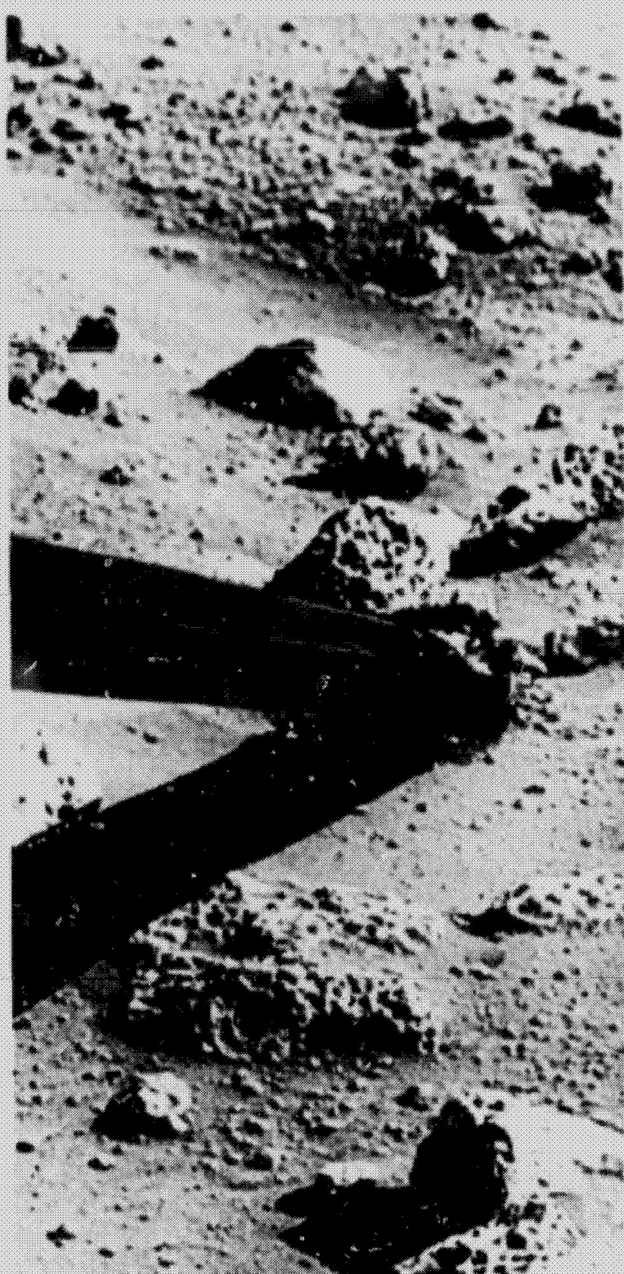
(Opposite page) Mariner 9 telephoto images revealed variable features in Promethei Sinus. In particular one spade-shaped dark marking (to the right of the crater) was seen to change shape dramatically over time. The ragged edges of this and other nearby features are characteristic of windblown deposits.

(Below) This mosaic of Mariner 6 images shows cratered terrain in the area of Deucalionis Regio. The sunset terminator lies at the right edge of the mosaic, which was processed to enhance small-scale contrasts.



THE SEARCH FOR LIFE

The primary objective of Viking was to determine whether life exists on Mars. The evidence provided by Viking shows strongly that it does not.



Three of Viking's scientific instruments were capable of detecting life on Mars:

★ *The lander cameras could have photographed living creatures large enough to be seen with the human eye and could have detected growth changes in organisms such as lichens. The cameras found nothing that could be interpreted as living.*

★ *The gas chromatograph/mass spectrometer (GCMS) could have found organic molecules in the soil. Organic compounds combine carbon, hydrogen, nitrogen, and oxygen and are present in all living matter on Earth. The GCMS searched for heavy organic molecules, those that contain complex combinations of carbon and hydrogen and are either precursors of life or its remains. To the surprise of almost every Viking scientist, the GCMS, which easily finds organic matter in the most barren Earth soils, found no trace of any in the Martian samples.*

★ *The Viking biology instrument was the primary life-detection instrument. A one-cubic-foot box, crammed with the most sophisticated scientific hardware ever built, it contained three tiny instruments that searched the Martian soil for evidence of metabolic processes like those used by bacteria, green plants, and animals on Earth.*

The three biology experiments worked flawlessly. All showed unusual activity in the Martian soil, activity that mimicked life. But biologists needed time to understand the strange chemistry of the soil. Today, according to most scientists who worked on the data, it is clear that the chemical reactions were not caused by living things.

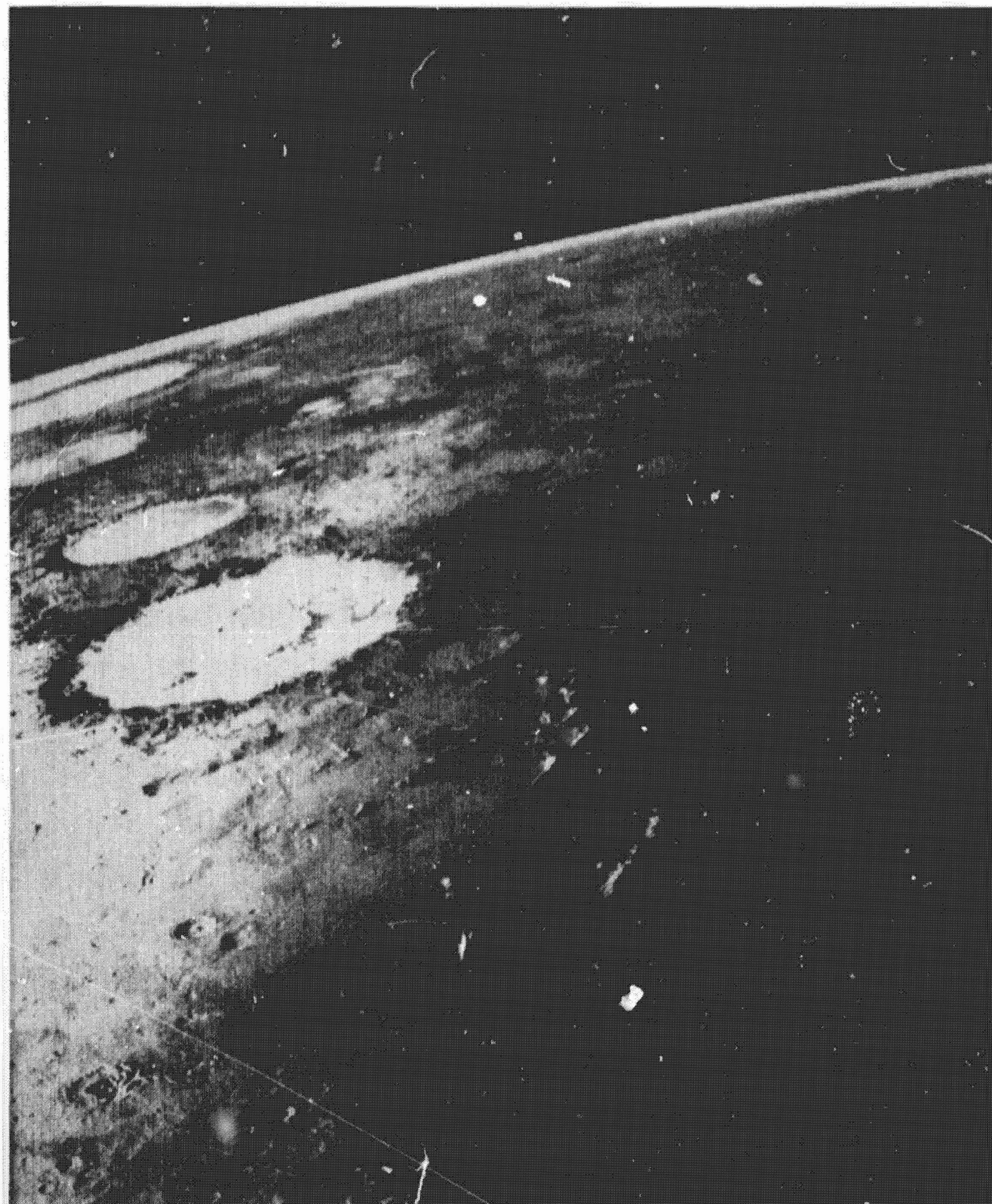
Furthermore, the immediate release of oxygen when the soil contacted water vapor in the instrument, and the lack of organic compounds in the soil, indicate that oxidants are present in the soil and the atmosphere. Oxidants—such as peroxides and superoxides—are oxygen-bearing compounds that break down organic matter and living tissue. Therefore, even if organic compounds were present on Mars, they would be quickly destroyed.

Analysis of the atmosphere and soil of Mars indicated that all the elements essential to life on Earth—carbon, nitrogen, hydrogen, oxygen, and phosphorus—are present on Mars. Liquid water is also considered an absolute requirement for life. Viking found ample evidence of water in two of its three phases—vapor and ice—and evidence for large amounts of permafrost. But it is impossible for water to exist in its liquid phase on Mars.

The conditions now known to exist on and just beneath the surface of Mars do not allow carbon-based organisms to exist and function. The biologists add that the case for life sometime in Mars' distant past is still open.

(Left) Viking's soil-collector arm pushes aside a rock named "Mister Badger" by flight controllers. Scientists believed that possible life forms on Mars might seek shelter from the Sun beneath rocks.

(Opposite page) This orbiter photograph reveals the thin carbon dioxide atmosphere that envelopes Mars. Several high-altitude cloud layers are visible on the horizon. The large basin in the foreground, named Argyre Planitia, was left by an asteroid impact.



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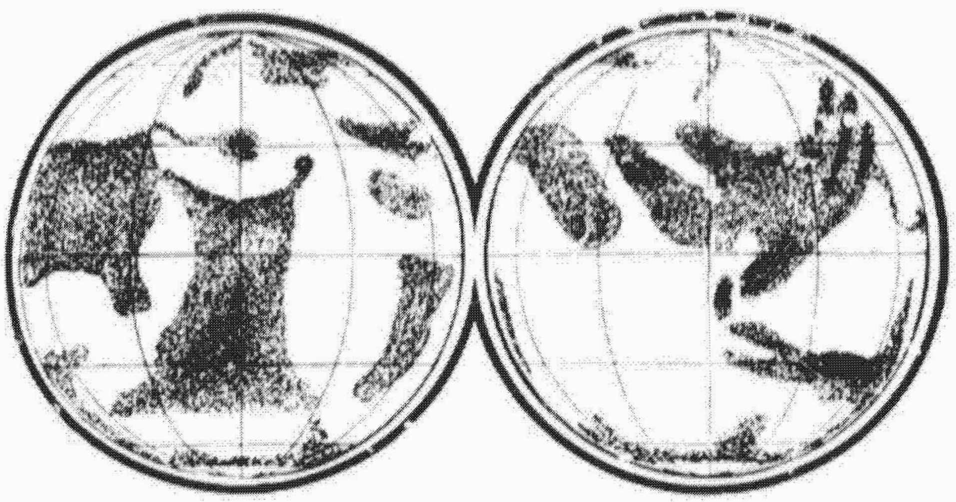
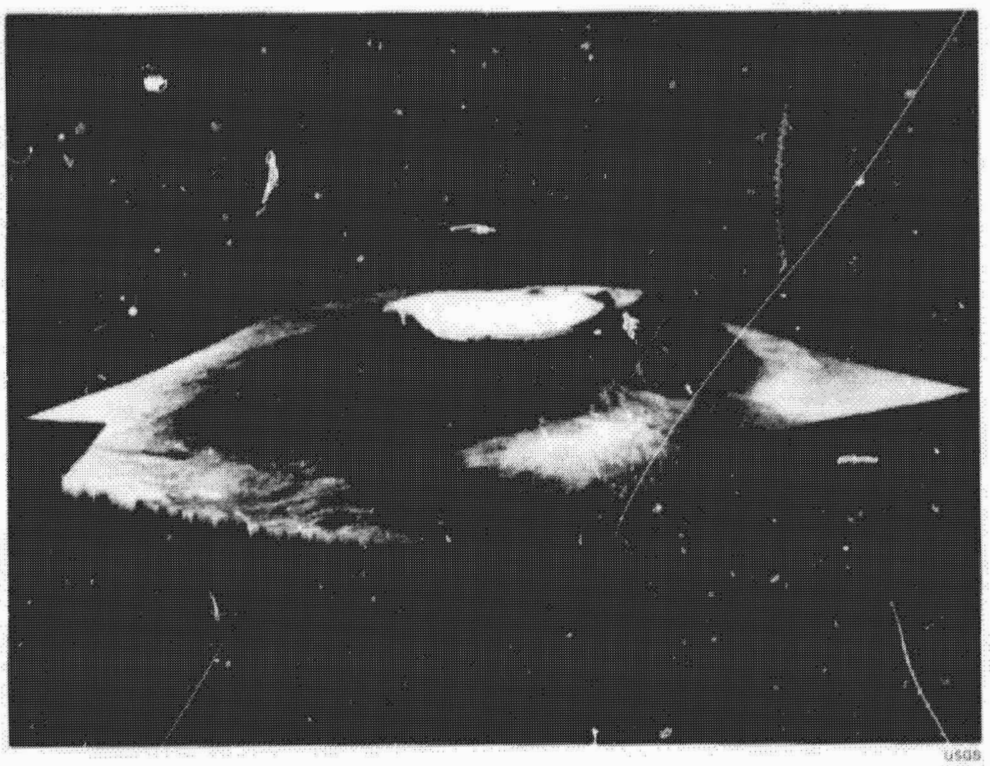
COLOR PHOTOGRAPH

Mars is pear-shaped, like Earth. Viking's radio-occultation experiment found that most of the southern hemisphere is higher than the average surface, and most of the northern is lower. There are exceptions: the large, deep basins called Argyre and Hellas in the south lie far below the mean surface. The north has three raised areas:

- *The region west of Syrtis Major Planitia, where old, cratered terrain extends to 45 degrees north of the equator between longitudes 290 and 20.*
- *The volcanic province around Elysium Mons at 25 north latitude, 213 longitude.*
- *The enormous crustal bulge called Tharsis Ridge, southeast of Olympus Mons. The center of Tharsis Ridge is at latitude 14 south, longitude 101. The bulge extends at least 2,500 miles north to south and 1,900 miles east to west. What some scientists call the Tharsis Province covers about one-fourth of the entire surface of Mars. The Tharsis Bulge probably began to rise about 3.3 to 4.1 billion years ago, but its volcanoes formed much later. Olympus Mons began to erupt 2.5 to 3 billion years ago. All the dates are inferred from the density of cratering on different areas of the surface.*

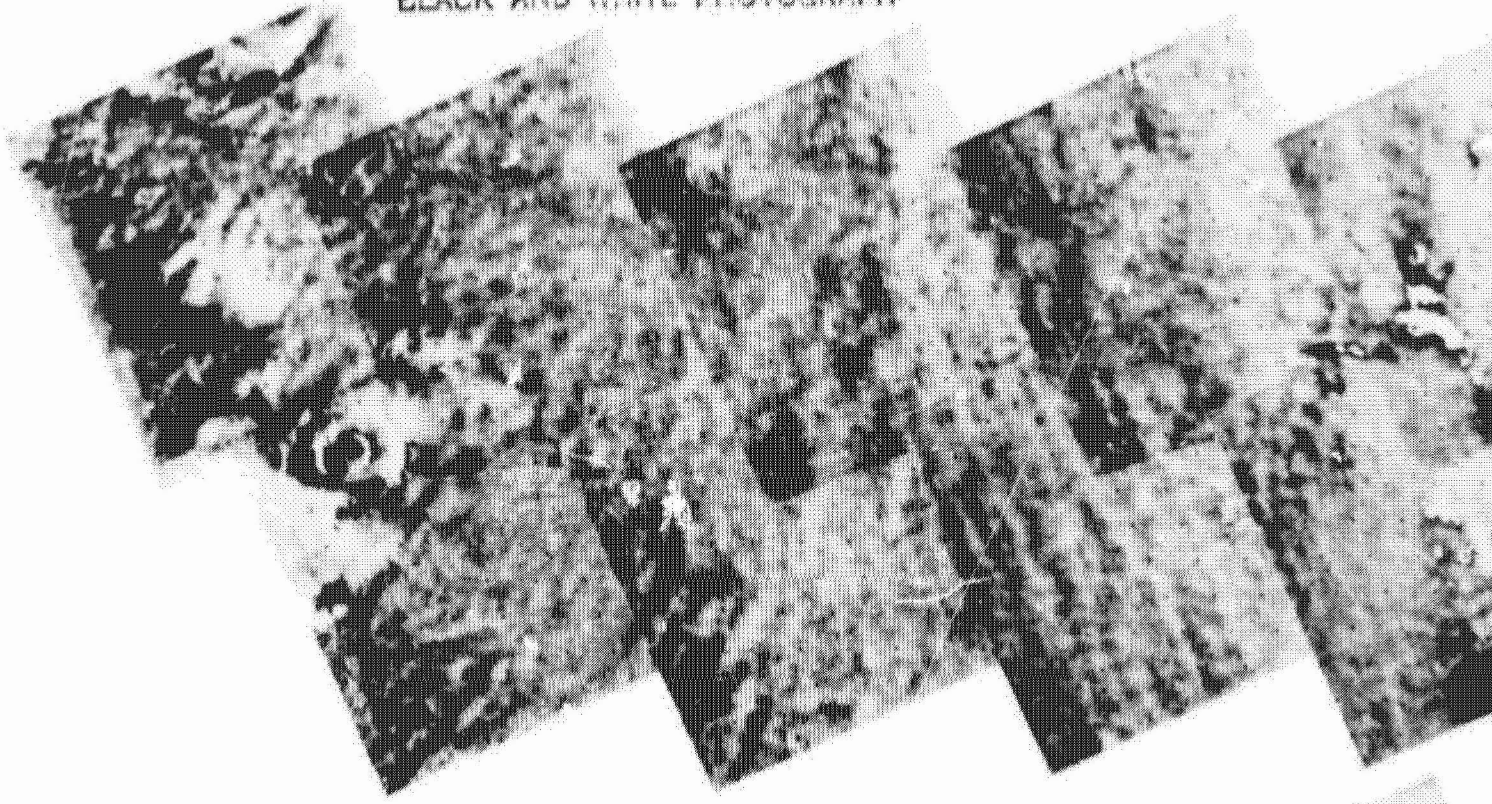


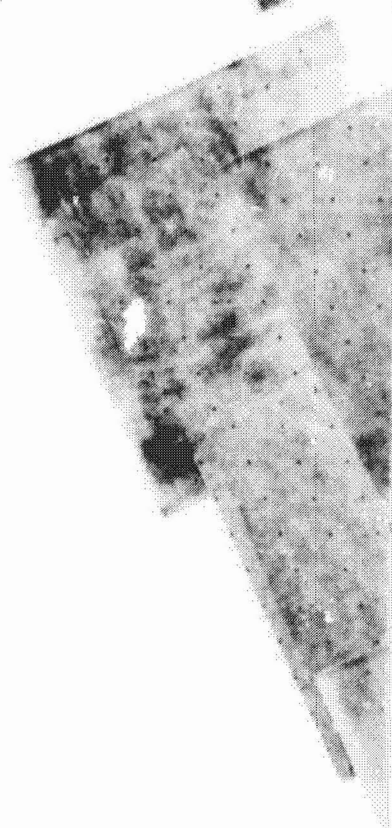


USGS

(Opposite page) The giant volcano Ascreaus Mons is visible in this view of Mars from Viking Orbiter 2. Below the volcano, the canyon Valles Marineris stretches across the Ridged Plains.

(Le...) Computers and stereo photogrammetry contributed to the creation of this oblique view of Arsia Mons, one of the four great volcanoes on Mars. A great rift zone cuts the mountain's flank, providing escape for volcanic rocks and lava that poured from the summit crater. The white haze in the caldera is a cloud that was present when the pictures were taken. Clouds that form around Mars' high mountains have been observed for almost a century from Earth. Percival Lowell called them "W clouds," and he watched them change on a daily basis for many years. The stripes on Arsia Mons' flanks are many small lava flows.





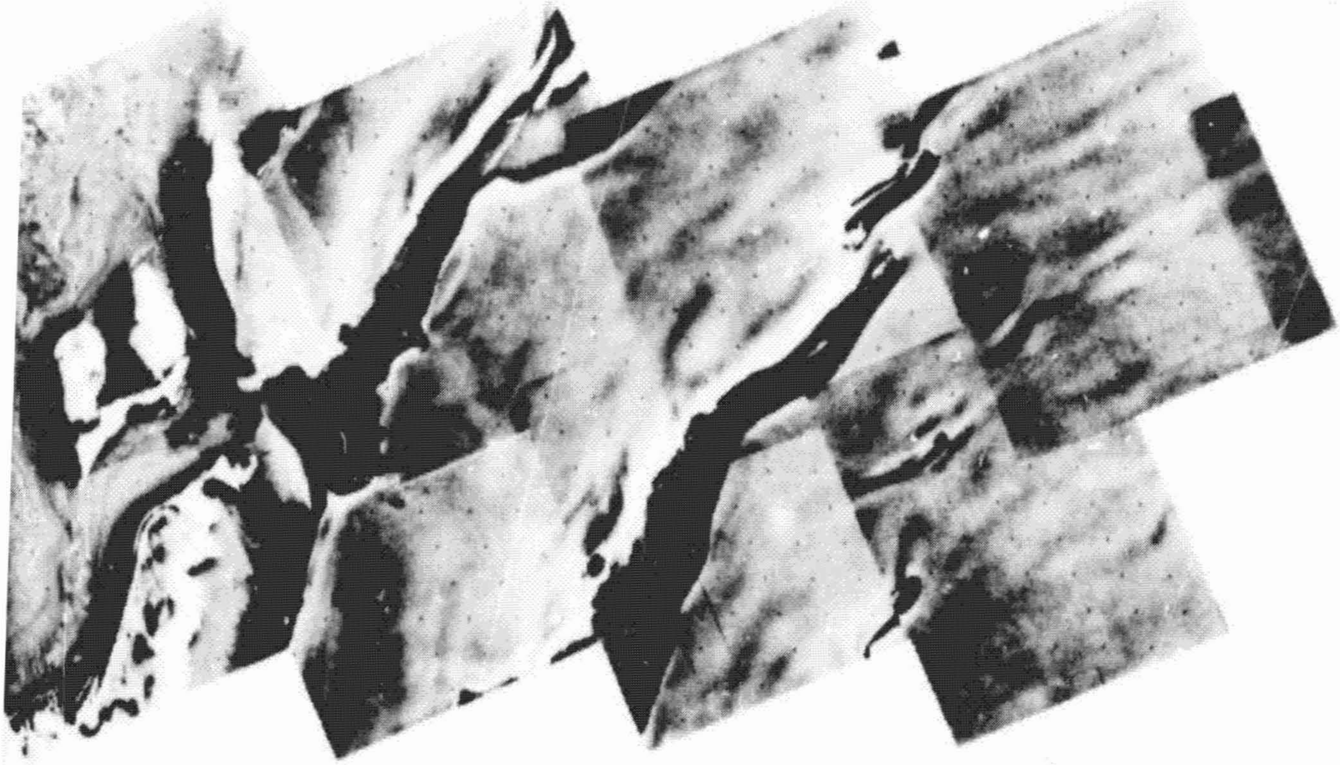
The northern and southern hemispheres of Mars differ also in that the north is primarily plains and the south mostly cratered. The boundary is distinct, a great circle cutting across the equator at 35 degrees, slicing through Isidis Planitia and passing north of the Tharsis Bulge.

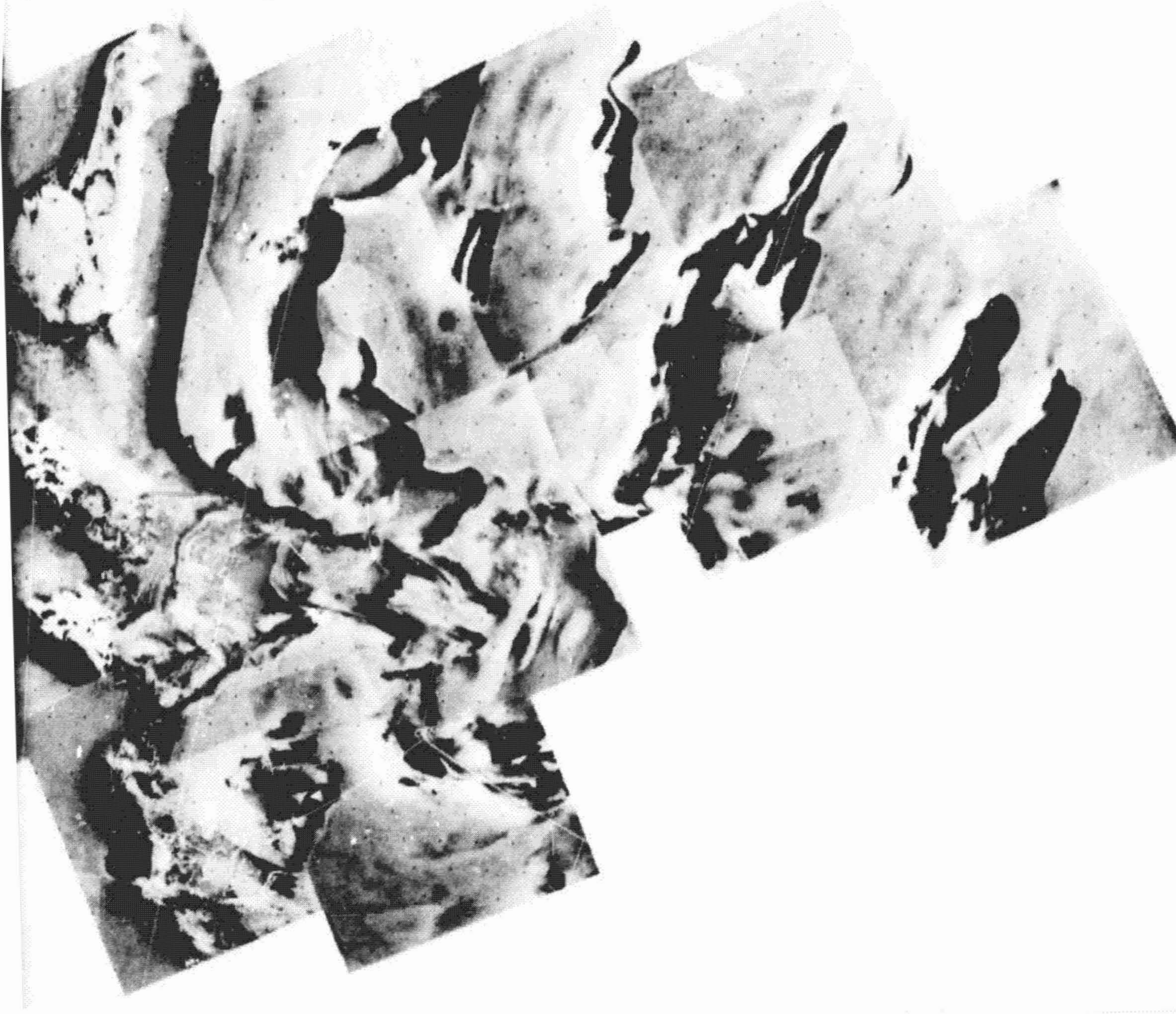
The planet's surface features range in size from those large enough to be seen from Earth, down to others that can be seen only by a Viking lander. The polar ice caps and the great volcanoes are the most conspicuous features of Mars.

Astronomers observed the polar caps for more than two centuries and believed they were water ice. Then Mariner 4 measured the temperatures of the caps and found them to be −113 degrees Fahrenheit, far too cold to be frozen water. That temperature indicated dry ice, frozen carbon dioxide—a partial truth, scientists would learn from Viking.

Measurements by the Viking orbiters of the temperature and humidity of the Martian poles revealed an important difference between them. The southern cap is, indeed, frozen carbon dioxide the year round. But the summertime remnant of the north polar cap is water ice, covered each winter by layers of carbon dioxide that freezes out of the atmosphere.

The mosaic on this and the opposite page shows layered deposits near the north pole. The deposits are partially covered by frost, as can be seen in the right half of the image. The strange appearance of the surface can be attributed to the confusing effects of the frost and topography. Bright areas are frost-covered, whereas the dark areas are mostly frost-free.





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COLOR PHOTOGRAPH

(Right) This type of layered terrain in Mars' polar regions represents layers of ice and dust that have been deposited by the Martian winds. These layers suggest a repetitive history of climatic changes. Scientists believe such terrain may hold clues to the mechanisms that trigger ice ages on Earth.

(Below) At midsummer in the northern hemisphere of Mars, the melting north polar icecap has receded to its smallest size. In this mosaic, the solid white area toward the top (north) is ice containing both frozen carbon dioxide and frozen water. The dark bands are devoid of ice and spiral in toward the cap's center. The reason so little ice occurs in these bands is uncertain, but may be related to winds blowing away from the center of the cap.

Water is frozen in the Martian north-polar ice cap. The dark grooves are troughs and [illegible] cut in the ice by a combination of solar heating and wind scouring. They show the layering of dark and bright ice that contains a record of the planet's climatic history.

"Being a geologist, I have an interest in the origin of Earth and the evolution of the Earth. But I cannot consider the Earth alone. I am concerned with the solar system, the origin of the solar system and its evolution through what we call geologic time."

—Robert B. Hargraves

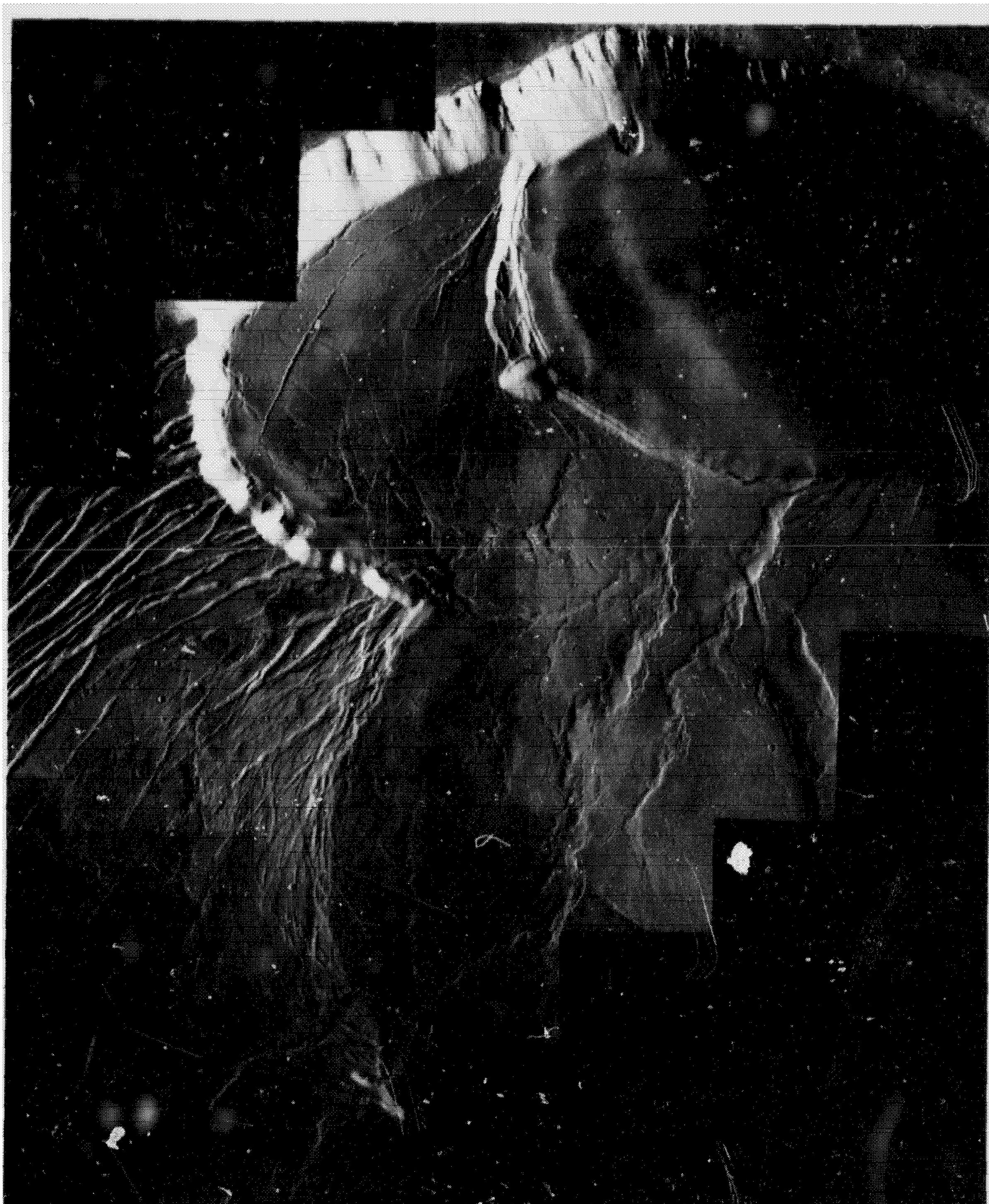
Nearl- all the great volcanoes lie along ..ree parallel lines that run southwest to northeast. The largest volcanoes are Olympus Mons, at latitude 18 north, longitude 133; and Alba Patera, 1,100 miles to the northeast.

Olympus Mons is a great shield volcano, the largest volcano in the solar system. It is similar to Hawaii's Mauna Loa but many times larger. Olympus Mons alone contains more lava than the entire Hawaiian Island chain. Its summit rises 16.7 miles above the mean surface—the Martian equivalent of sea level. The great mountain covers an area about 435 miles across, and would cover the State of Montana. It is bounded by a huge escarpment, a near-vertical cliff, 3.7 miles high. Lava repeatedly flowed over the cliff, dropped nearly four miles to the plain below, and splashed far beyond. The upper slopes of Olympus Mons are terraced by the lava flows. Ridges that appear to be lava channels and roofed-over lava tubes course down the lower slopes. Impact craters are extremely rare on Olympus Mons, indicating that the volcano was active in recent geologic time, to cover the cratering that surely occurred long ago.

(Below) Dust clogs the lower atmosphere in this oblique view of Olympus Mons, the solar system's largest volcano. The mountain has a complex summit caldera and a scarp around the base nearly four miles high.

(Opposite page) Olympus Mons' summit caldera comprises a series of craters formed by repeated collapses after eruptions. The volcano towers over 15 miles above the Martian surface. By contrast, Hawaii's Mauna Loa, the largest comparable feature on Earth, rises a mere 5 miles above the ocean floor.

"That is what exploration is. You don't always find what you are looking for, but you almost always find something of value to you even though the value may not be recognized until the next generation."—Richard S. Young



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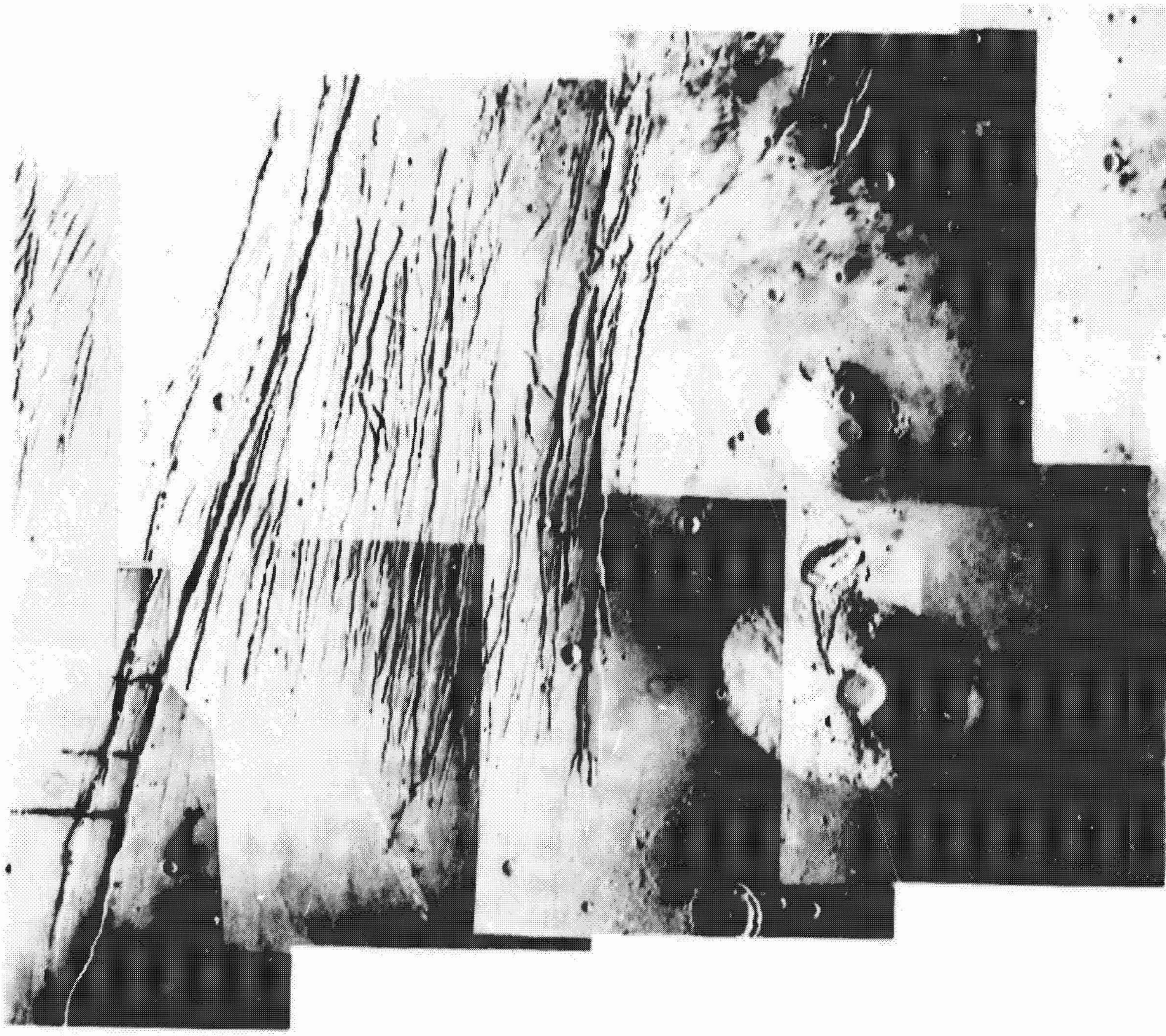
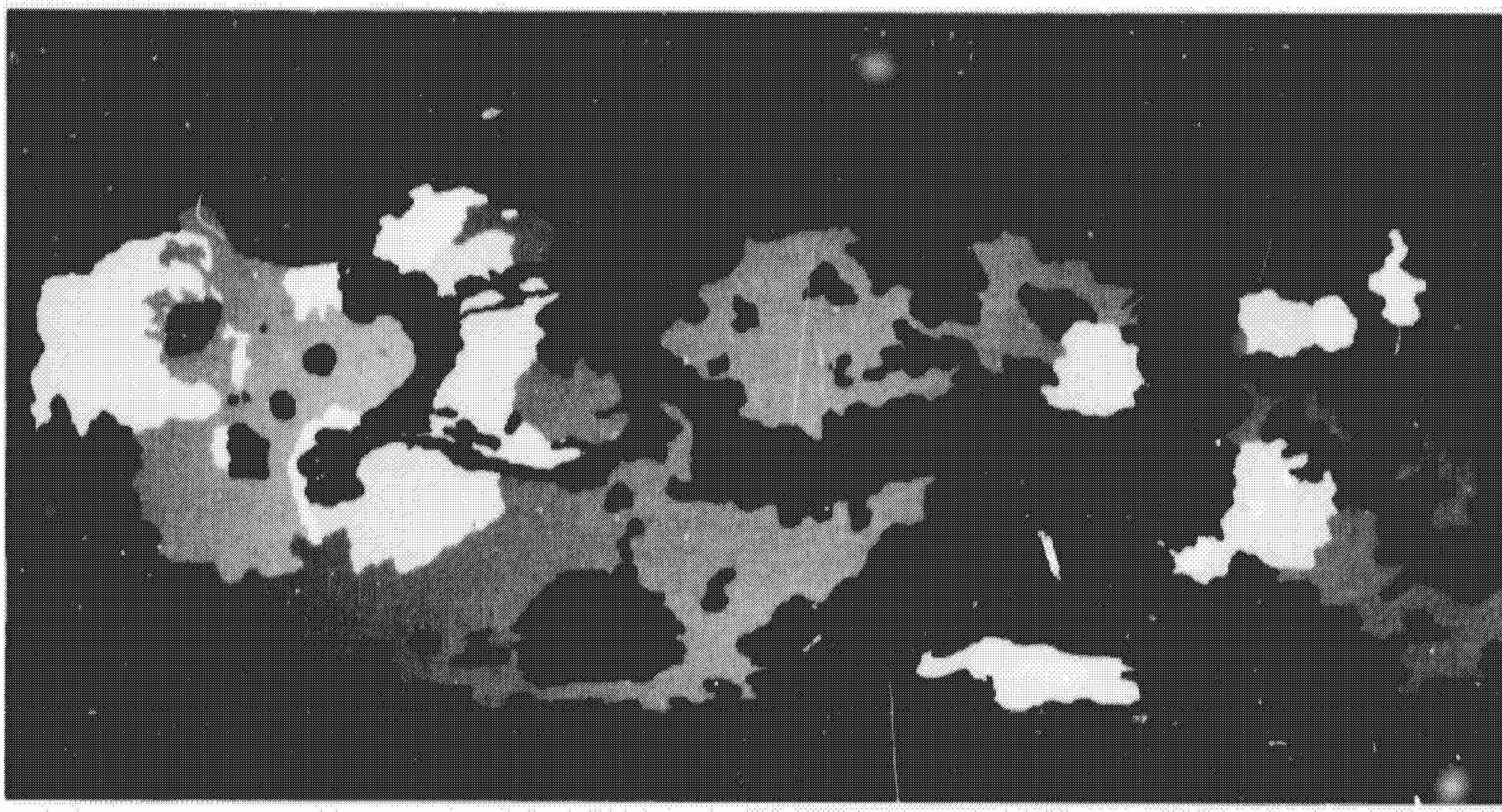


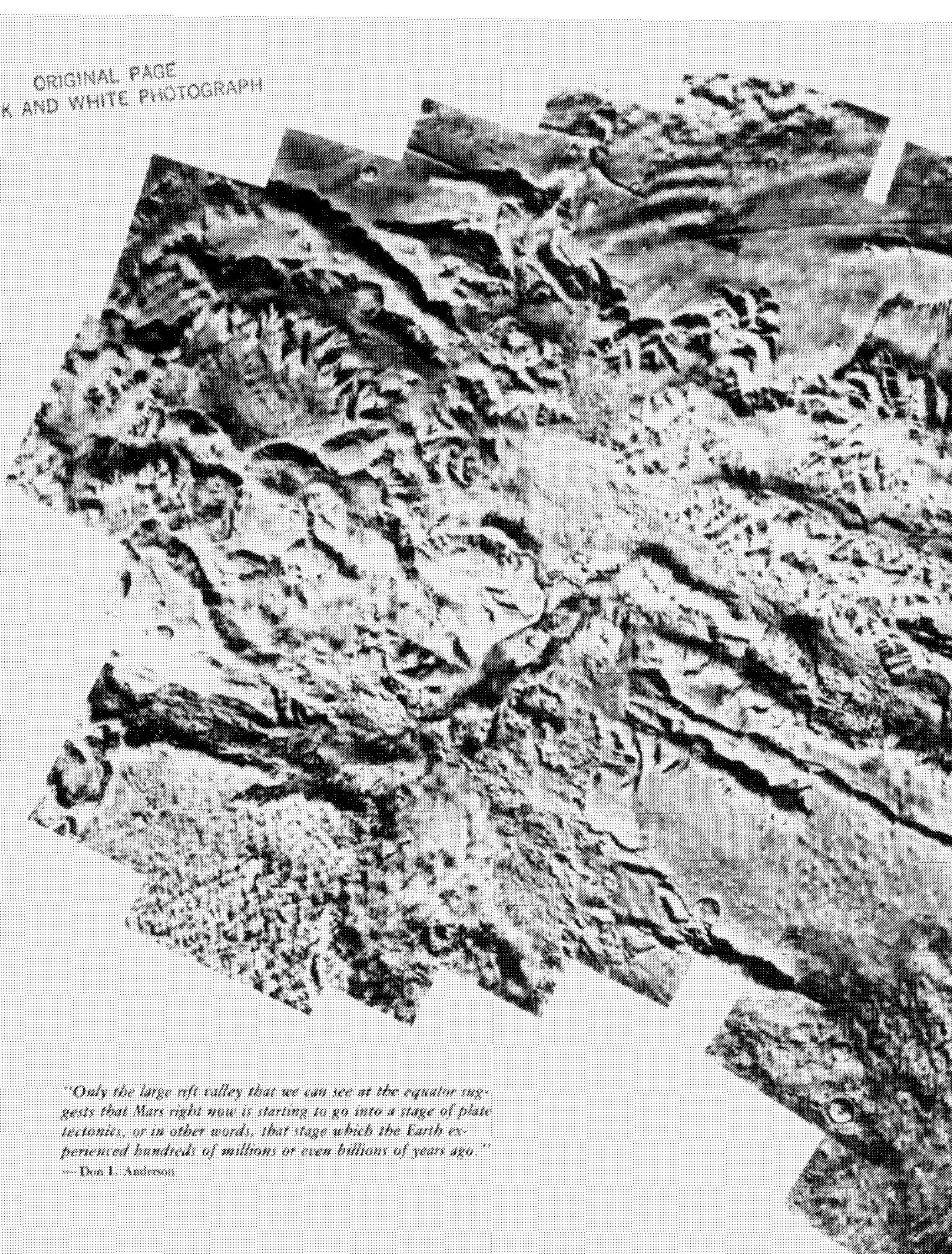


A row of huge shield volcanoes lies about 1,000 miles southeast of Olympus Mons: Arsia Mons, Pavonis Mons, and Ascraeus Mons. Their structure is similar to that of Olympus Mons, and their summits are almost as high; they stand atop a huge bulge in the Martian crust more than six miles high. Crater densities on and around all the volcanoes suggest a long history of eruptions, perhaps lasting billions of years.

Mars has such great volcanoes because the planet's crust is thick and rigid. This thick Martian crust does not drift, as Earth's continents do, even when the Martian surface lies above a pool of molten rock. On Mars, the surface above an interior pool remains stationary for billions of years while magma rises through vents to build mountains. And the thick Martian crust is strong enough to support the great weight of these massive volcanoes.

(Opposite page) The Tharsis Ridge is the youngest volcanic region on Mars. This mosaic of the ridge's northeast margin shows an area of intense faulting at the left and a pair of volcanoes with prominent summit craters at the right. Channels, crater chains, and individual lava flows can be seen on the flanks of the volcanoes.

(Above) This computer-generated map shows the major geologic units of Mars. Although generalized, the map allows a rapid understanding of the distribution and relationship of various rock types. The small red spots at left and at right represent the large volcanoes. The yellow-orange areas are volcanic plains; the brown areas show regions of heavy cratering.

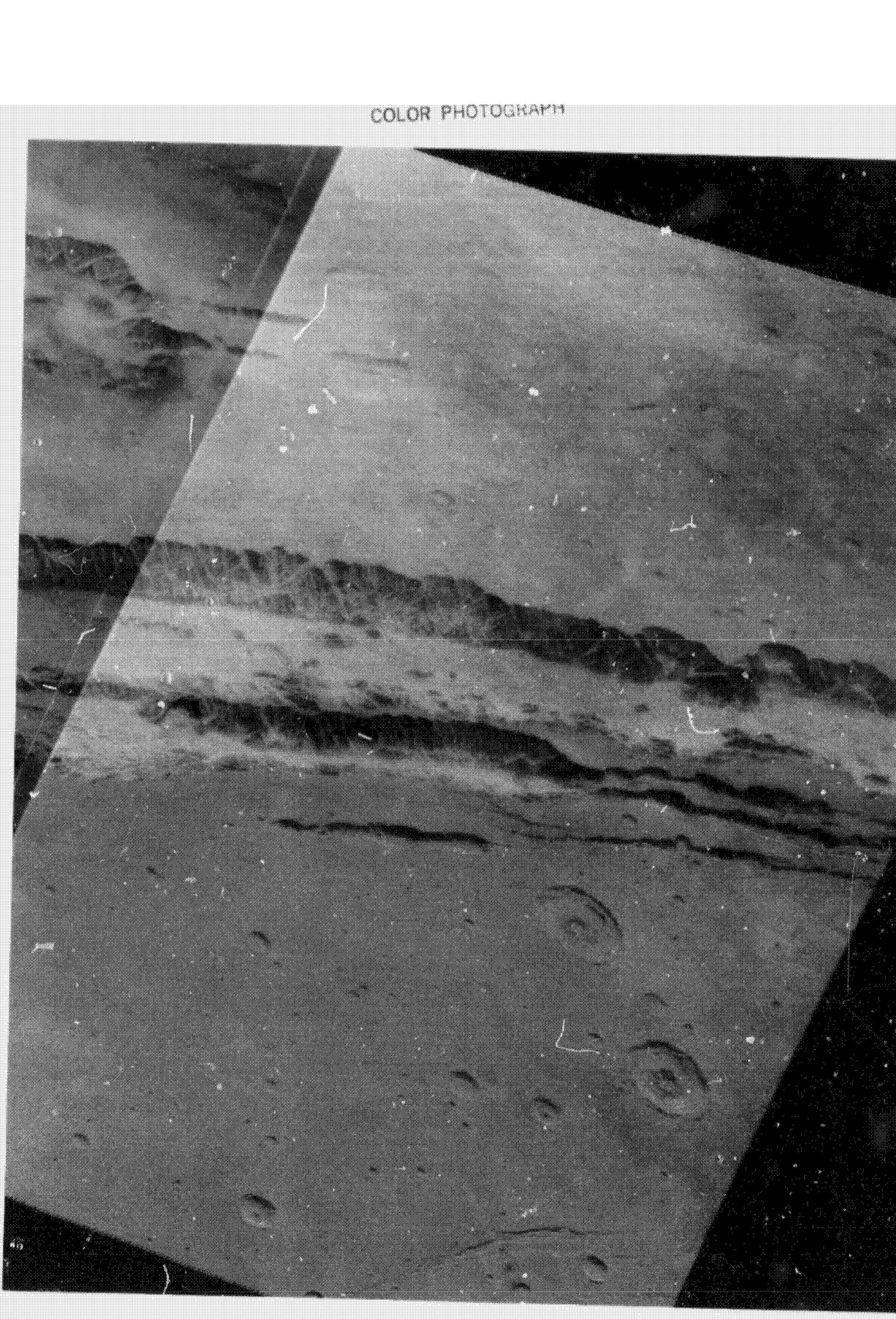


"Only the large rift valley that we can see at the equator suggests that Mars right now is starting to go into a stage of plate tectonics, or in other words, that stage which the Earth experienced hundreds of millions or even billions of years ago."
—Don L. Anderson

In addition to its great mountains, Mars has a deep rift that extends for more than 3,000 miles across the planet's face. Valles Marineris is an immense network of valleys that dwarfs the Great Rift Valley of Africa, which extends from Capetown to the Middle East. The steep sides of Valles Marineris are torn by landslides that crash down and roar across the valley floor. Around Valles Marineris is a complex system of parallel fractures in the surface of the planet, where the crust of Mars split open in the distant past. Erosion carved the network ever larger.

More than 100 individual Orbiter 1 pictures form this mosaic of Valles Marineris. Extending over 3,000 miles in length, this huge complex of equatorial canyons displays a wide range of canyon types, including areas where the walls appear to have been modified by great landslides. In some places, erosion has formed integrated tributary systems; elsewhere, faulting appears to have predominated.

COLOR PHOTOGRAPH



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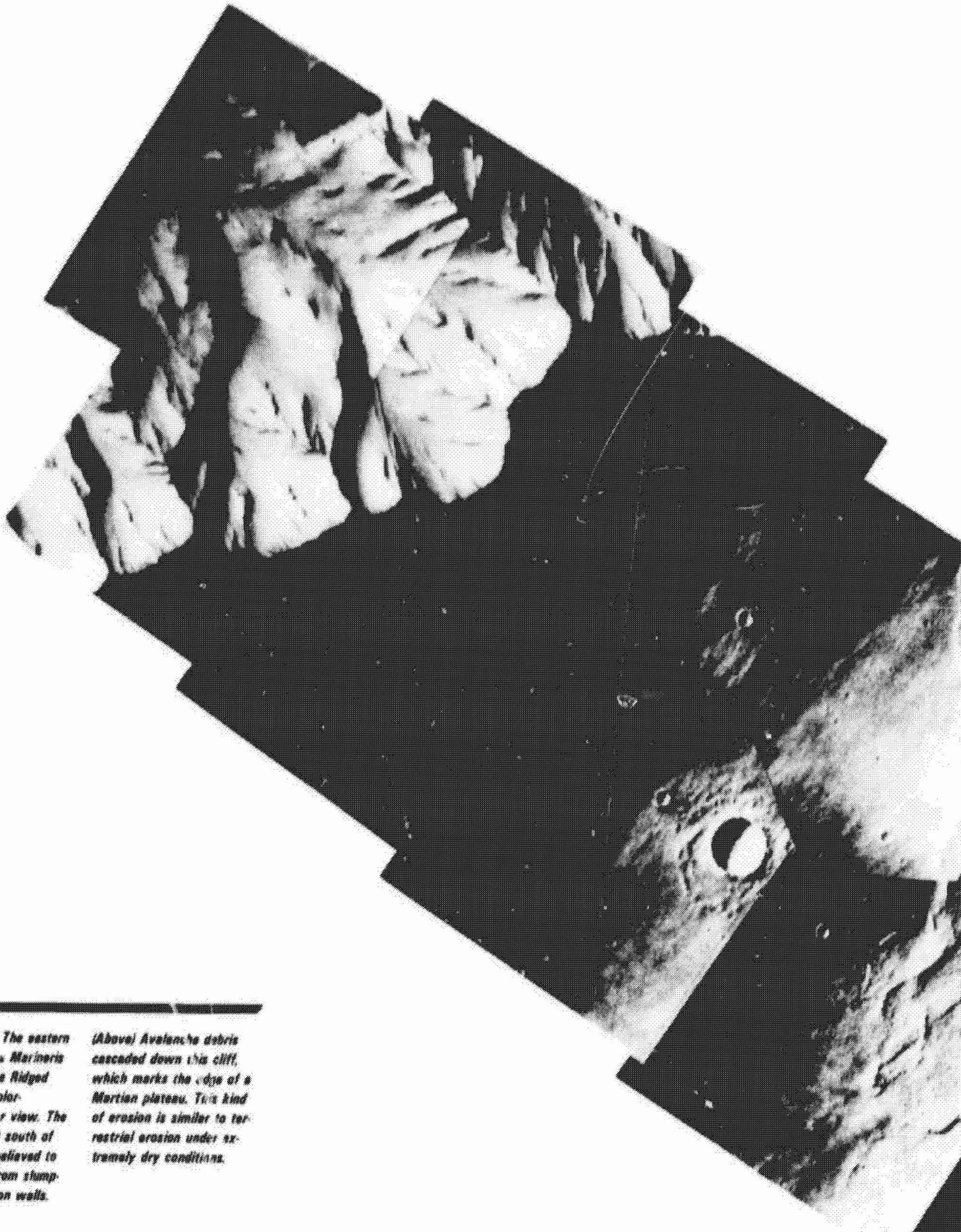

(Opposite page) The eastern portion of Valles Marineris cuts through the Ridged Plains in this color-enhanced orbiter view. The faults lying just south of the valley are believed to have resulted from slumping of the canyon walls.

(Above) Avalanche debris cascaded down this cliff, which marks the edge of a Martian plateau. This kind of erosion is similar to terrestrial erosion under extremely dry conditions.

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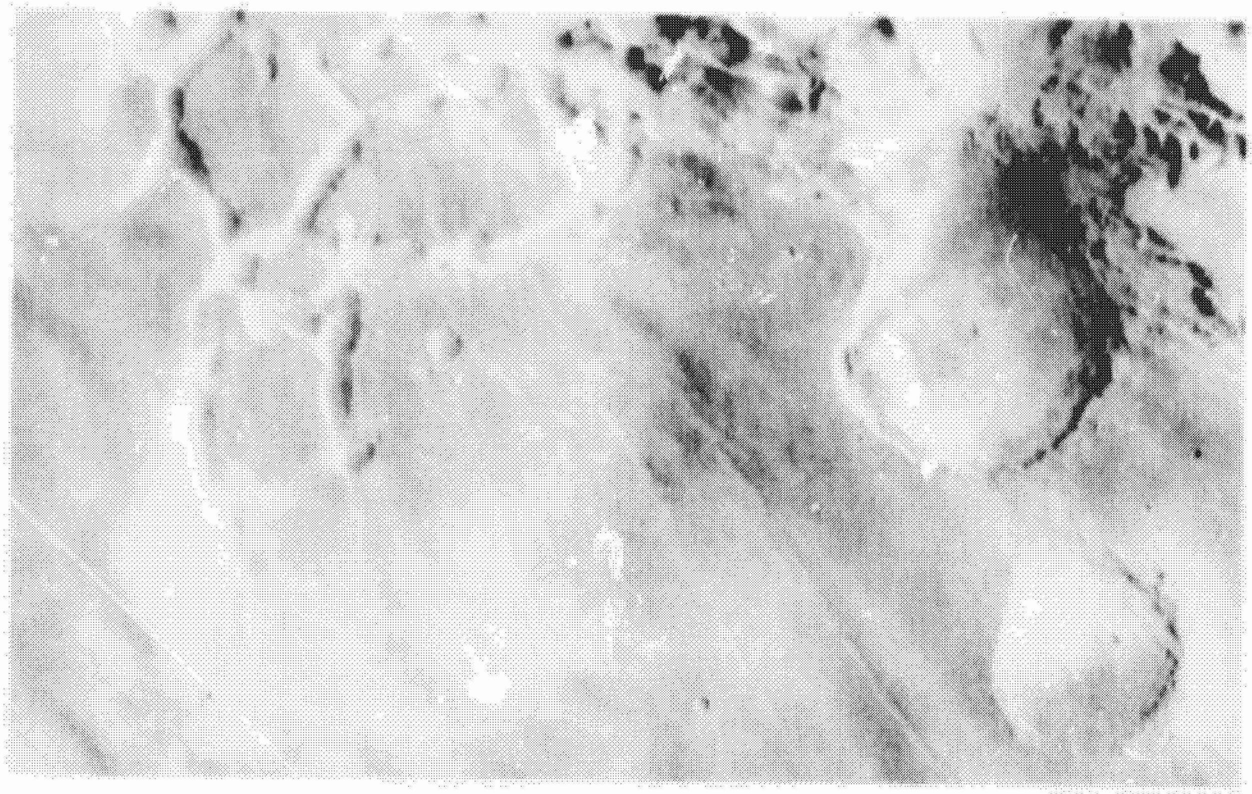
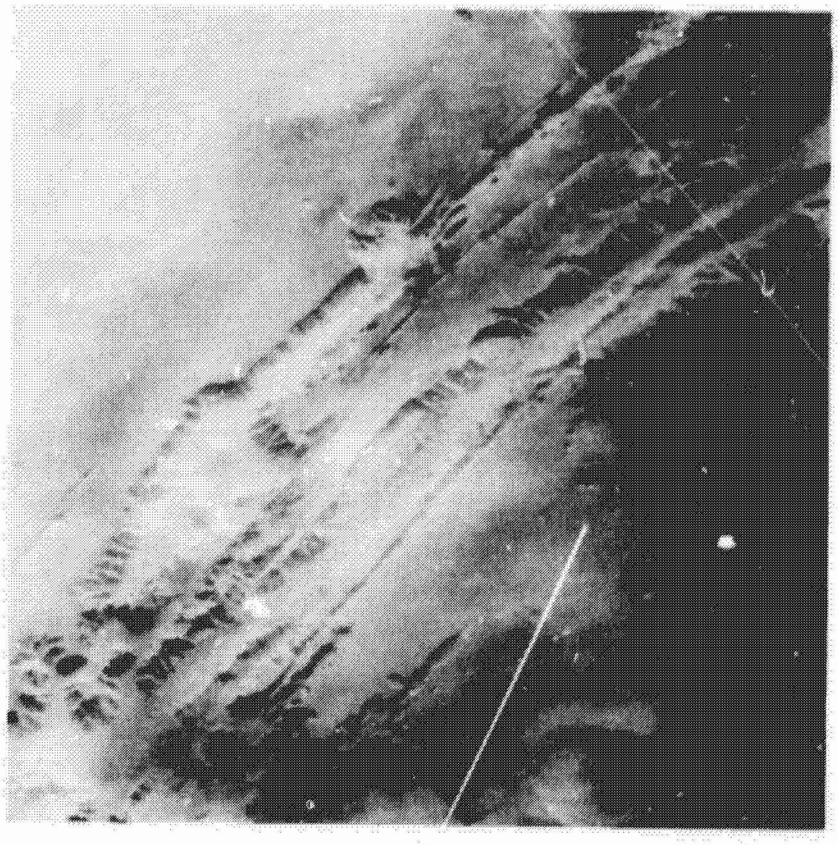
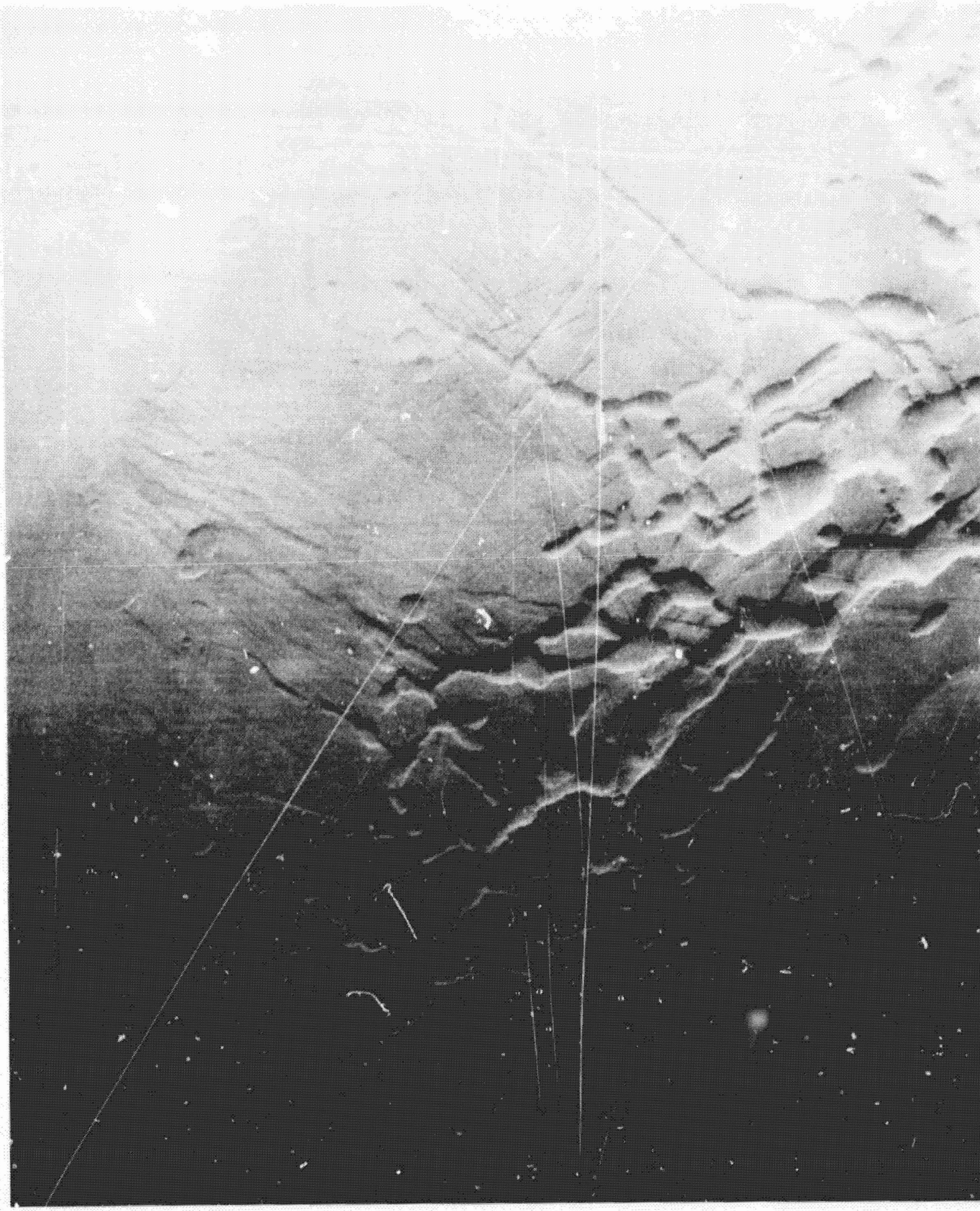




(Above and opposite page) The origin of Martian canyons by faulting is most apparent in Noctis Labyrinthus at the western end of Valles Marineris. In many canyons the upland plain surface is preserved on the valley floor. Other canyons are more irregular in form and have rough floors. The image on the opposite page depicts an area to the northwest of that in the image above.

(Left) Another orbiter gives a broader look western end of the g complex of equatorial canyons.



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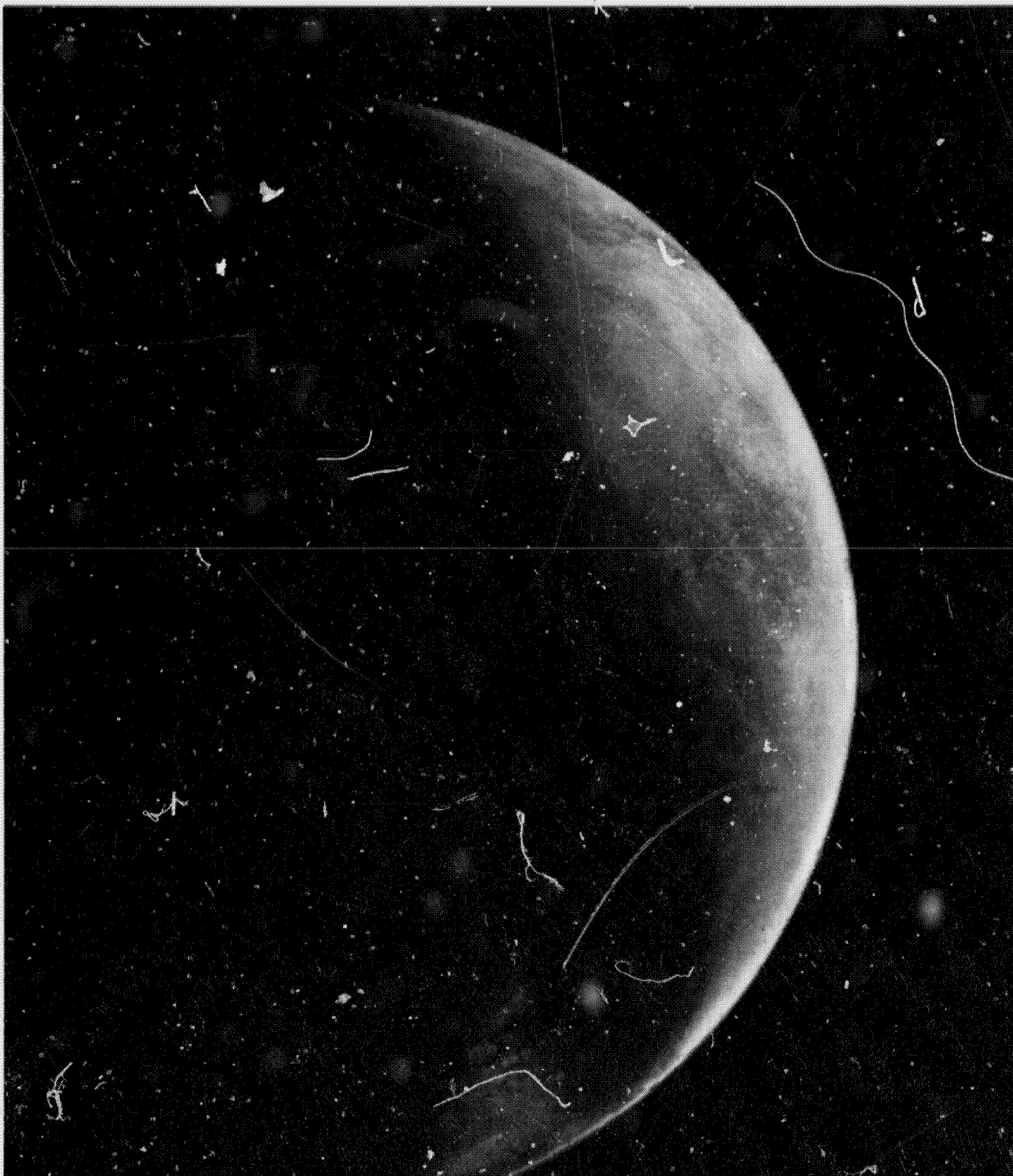
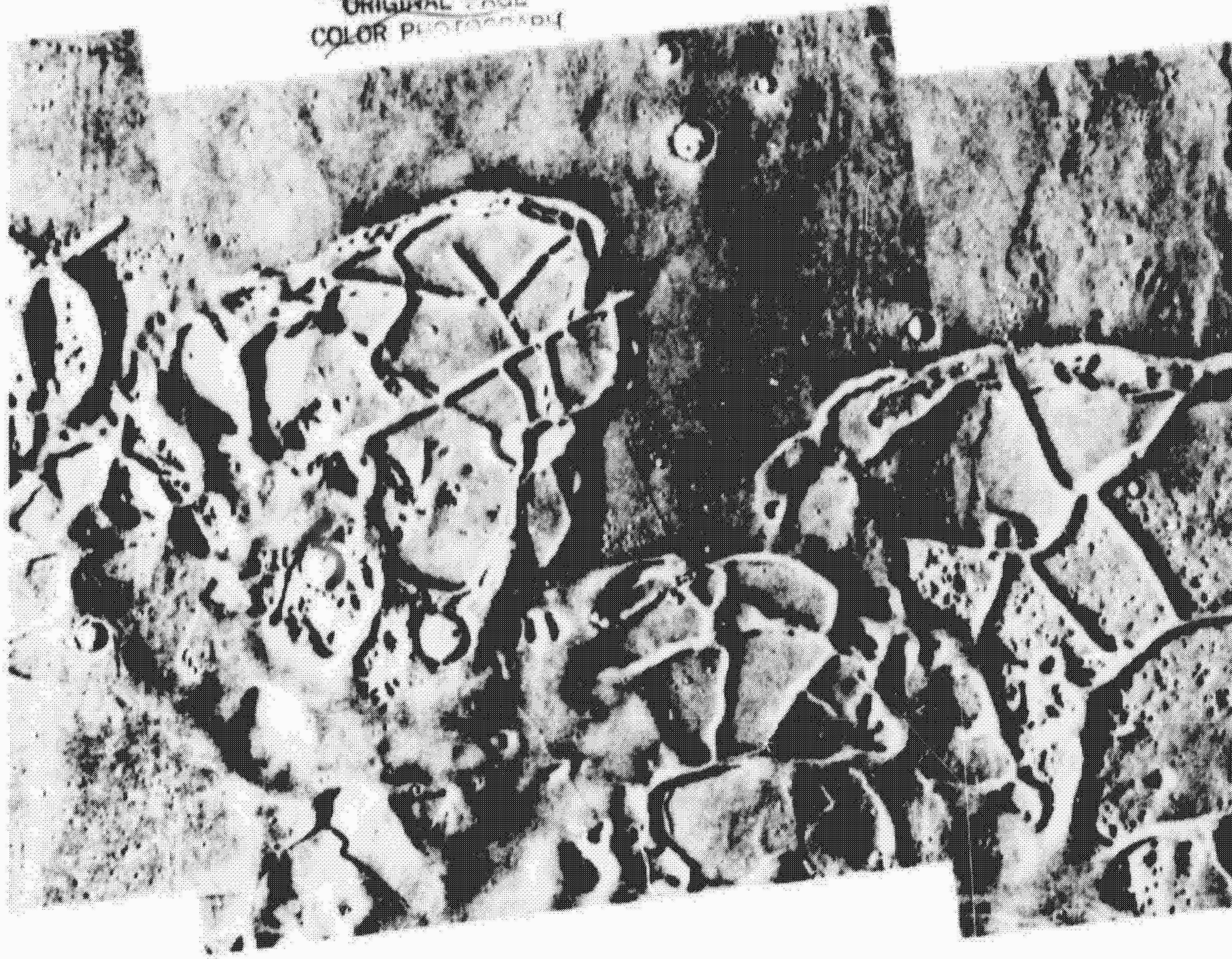
The lowest point on Mars is the bottom of a great, circular impact basin called Hellas Planitia, centered at 45 degrees south latitude. The floor lies 3.7 miles below the mean surface. Hellas is surrounded by concentric rings, similar to the mountain rings around major impact basins on the Moon. The Moon's ringed basins have changed very little over time, while Hellas' rings are heavily eroded. Geologists believe a meteor or asteroid crashed into Mars and created Hellas about 4 billion years ago.

(Right) The great Argyre Basin in Mars' southern hemisphere dominates this mosaic that stretches to the limb of Mars and shows clouds high in the atmosphere. In the foreground, impact craters scar an ancient upland surface. Many fault valleys show the crust broken by tectonic movement along faults. The small, sinuous valleys were carved by water that flowed over the surface. The Argyre Basin formed when a huge piece of space debris smashed into Mars soon after the planet formed and cooled. The clouds are probably crystals of frozen carbon dioxide and are about 25 miles above the surface.

(Opposite page) The great 3000-mile-long rift canyon Valles Marineris dominates the center of this image of the dawn side of the planet. The bright south polar region is distinguished by the large impact basin Argyre Planitia.





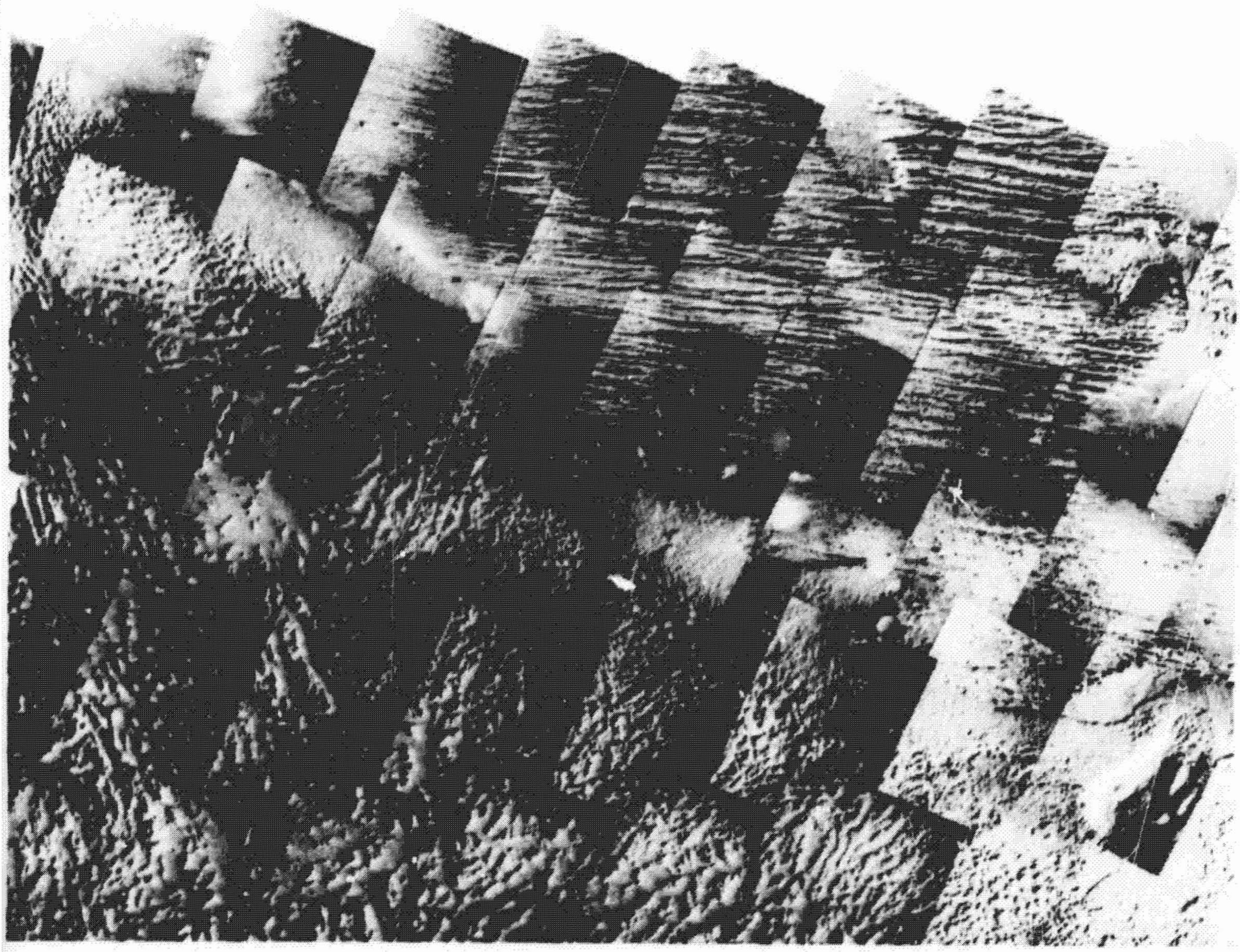
At the near end of the geologic time scale are fresh craters that were made in fairly recent times. All the inner planets—Mercury, Venus, Earth, and Mars—and their satellites have these impact craters, and those on the Moon are studied as the prototypes. Fresh craters on Mars are, however, distinctly different from those on the Moon. The major difference is in the material thrown out of the crater to blanket the surrounding terrain. On the Moon, the soil is extremely dry. But on Mars it contains water or ice that provides lubrication and allows the rock and soil to flow for great distances.

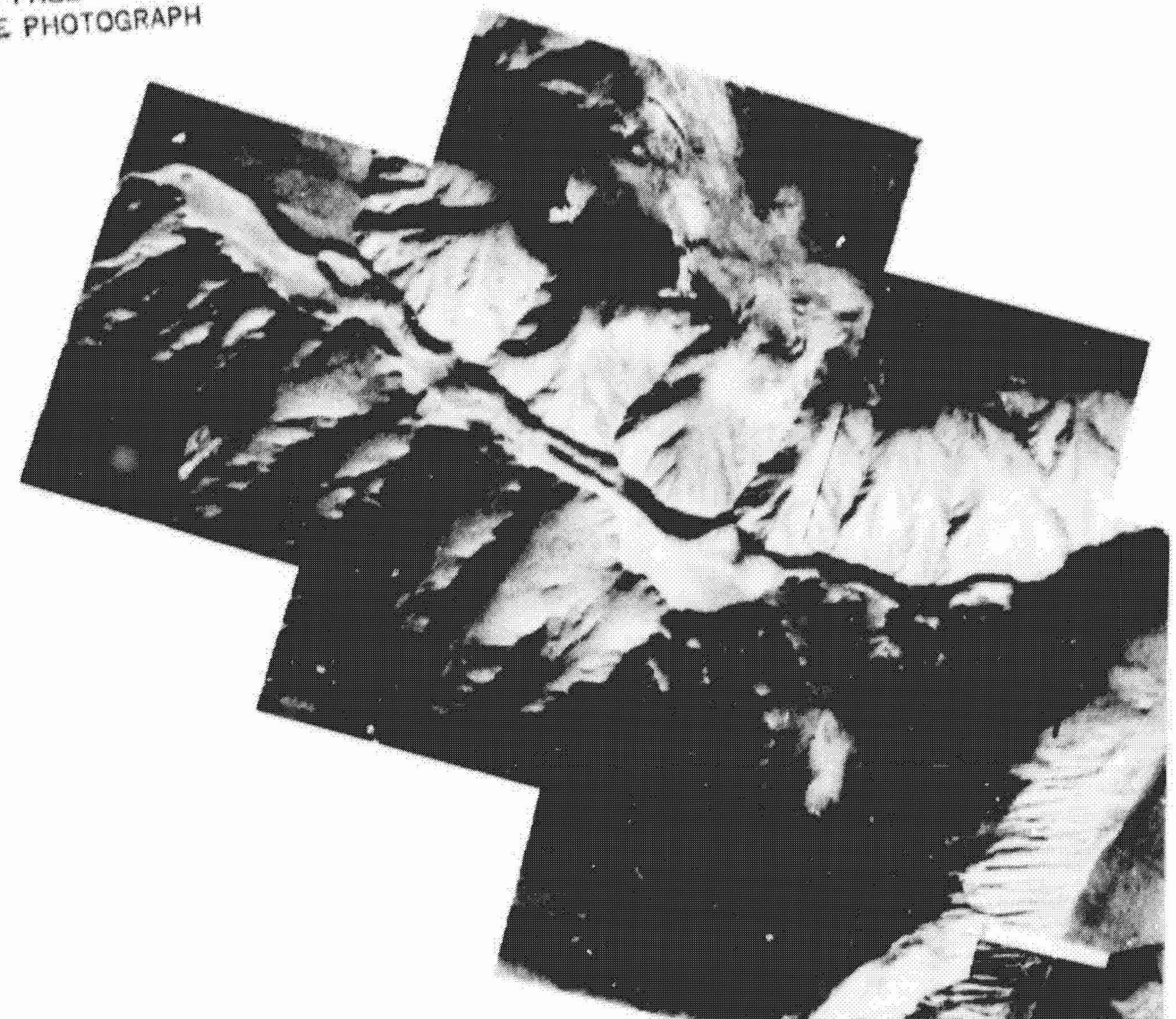
(Above) Permafrost freezing and thawing cycles have broken the Martian surface along faults that intersect. Fine-grained soil in the valleys has probably been carried away by wind. Small landslides contain material borne downhill by gravity. Many small impact craters allow geologists to date the surface relative to the ages of other regions of Mars.

One or more layers of ejected material are visible, each with its own distinct outer edge or rampart. These rocky ramparts prompted the name rampart craters. Geologists believe the ramparts formed when rock that was saturated with permafrost blasted out of the new crater, then flowed great distances after hitting the ground.

Another strange type of crater has been seen over much of Mars' northern hemisphere. Each crater sits atop a pedestal, a small platform that stands above the surrounding terrain. The soil at the base appears to have been stripped away by wind.

(Below) These ancient plains have been so heavily eroded by wind that it is difficult to ascertain their original nature. In one region all the grooves cut by the wind run in one direction, indicating that the prevailing wind has been constant. In other areas, the wind flow has been less consistent.





The wind is a major cause of erosion on Mars. It continues to alter Mars' appearance. Seasonal changes in the planet's colors, which Earth-bound astronomers used to cite as evidence for life, appear to be caused entirely by the wind. Some of the effects of wind were well known even before Mariner 4 visited Mars. Dust storms had been observed through telescopes for decades.

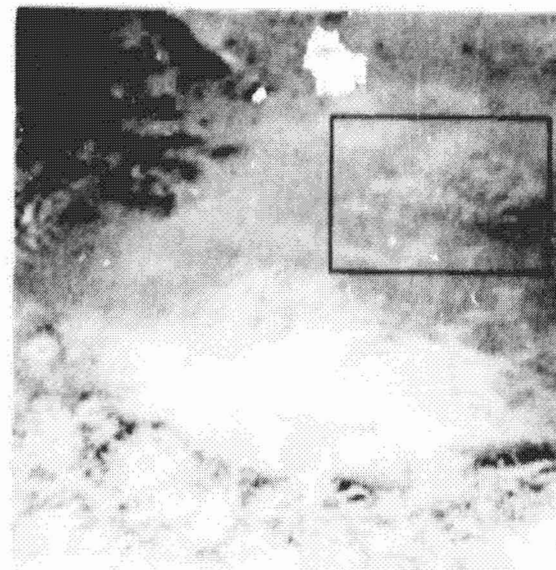
Wind appears to be primarily responsible for one of the planet's most interesting features—the laminated terrain at the polar caps. Layer upon layer of ice and dust have been laid down on the poles by global dust storms and the alternating seasons. Deposits at both poles are similar: thin, horizontal layers of varying thickness that stretch across hundreds of miles. Both poles are nearly uncratered and rest on older terrain. The upper layers are the ice caps themselves.

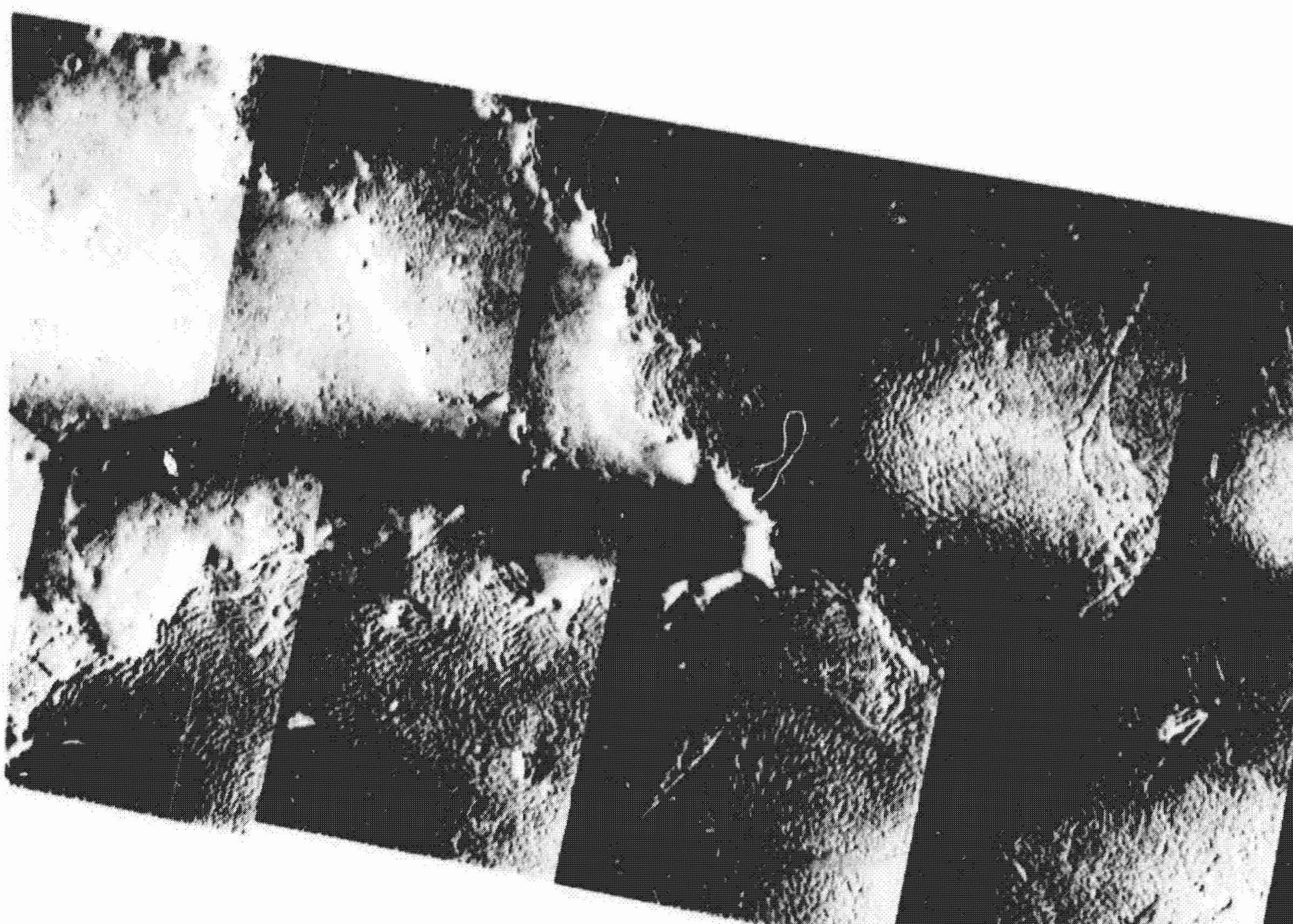
(Above) This region on Mars is a small part of the region called Candor Chasma. Some floor deposits adjacent to canyon walls of these steep Martian hills have been deeply grooved by wind erosion. Some scientists believe the deposits may be remnants of ancient Martian lake beds. The canyon walls themselves have been deeply eroded by mass wasting, the result of any of a number of processes by which rock is decomposed and pulled downhill by gravity. The groove and the smooth tableland represent a preexisting surface that has been progressively eaten away.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

(Below) The erosive power of the wind is evident in grooved terrain that has been overlaid with lava. Both the older terrain and the younger lava flow have been scoured and grooved by the wind. Geologists say it is almost impossible to tell whether the cliff is a result of the lava or activity along an ancient fault.

(Right) A turbulent, bright dust cloud more than 185 miles across blows through the great Argyre Basin, moving eastward under the influence of strong winds. This Orbiter 2 image was the first color photograph of a dust storm taken from a spacecraft orbiting the planet.

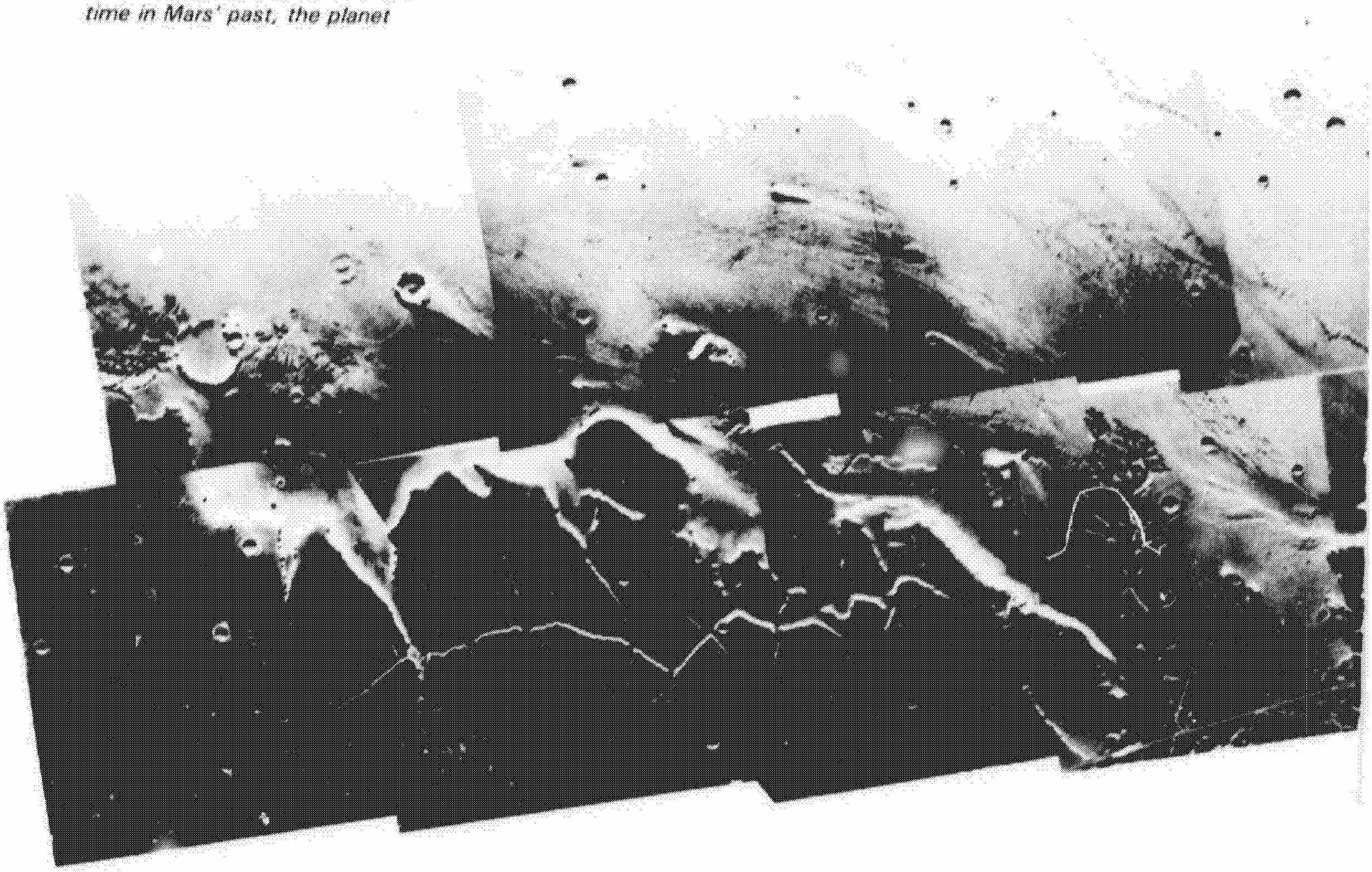




Between the time Mariner 4 looked at Mars and saw only impact craters and Mariner 9's arrival six years later, scientists believed Mars had always been dry, that no liquid water had ever existed on its surface. But Mariner 9 found channels carved in the terrain, channels that most scientists now agree were cut by water flowing across the surface. That poses a problem: Mars' atmosphere is extremely thin, and the low pressure will not allow liquid water. At the low pressure on the surface of Mars, water changes directly from ice to vapor without going through the liquid phase. That was the puzzle: if water cannot exist as a liquid, how can it flow? And how can it flow in such quantities as to create the huge floods that appear to have swept the surface? Scientists believe that, at some time in Mars' past, the planet was warmer, the atmosphere was denser, and water could flow on the surface.

The largest channels are called outflow channels, because they appear to have flowed out of the ground from some subterranean source and then to have poured into several large, deep basins. Other channels, slightly smaller, tend to be sinuous and to have many tributaries. The dry floors of some of those mid-sized channels have braided textures.

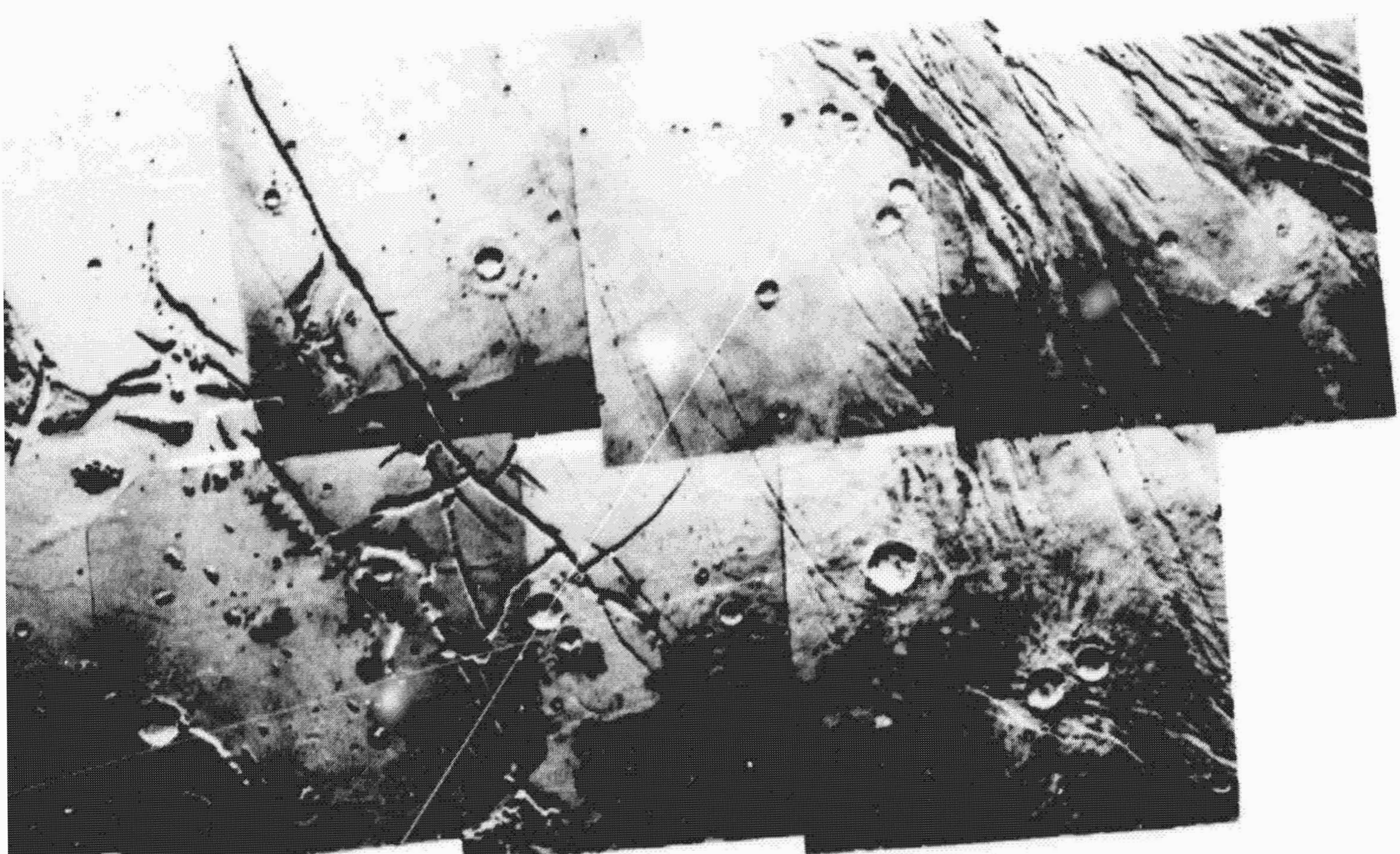
"Where is the water on Mars?"—Hugh H. Kieffer



They look like the stream beds in Earth's deserts that are carved by flash floods.

The smallest of the three kinds of channels were barely visible in Mariner 9's photographs. But Viking found that those channels are the most abundant of all Martian valley networks. At first, scientists thought these small groups of valleys looked like channels that are formed on Earth when rainfall runs down slopes. However, long and careful study of their shapes and patterns led scientists to conclude that they had nothing to do with rainfall, but were caused by underground water flowing onto the surface. The heads of these small valley networks are completely different from the sources of rainfall-caused rivers and streams on Earth.

Both old and young features are present in the ancient uplands and more recent lowlands of Mars. In the mosaic on this and the opposite page, craters dot a landscape cut by flowing water. Tadpole-shaped islands in the channel beds show the direction in which the water flowed.



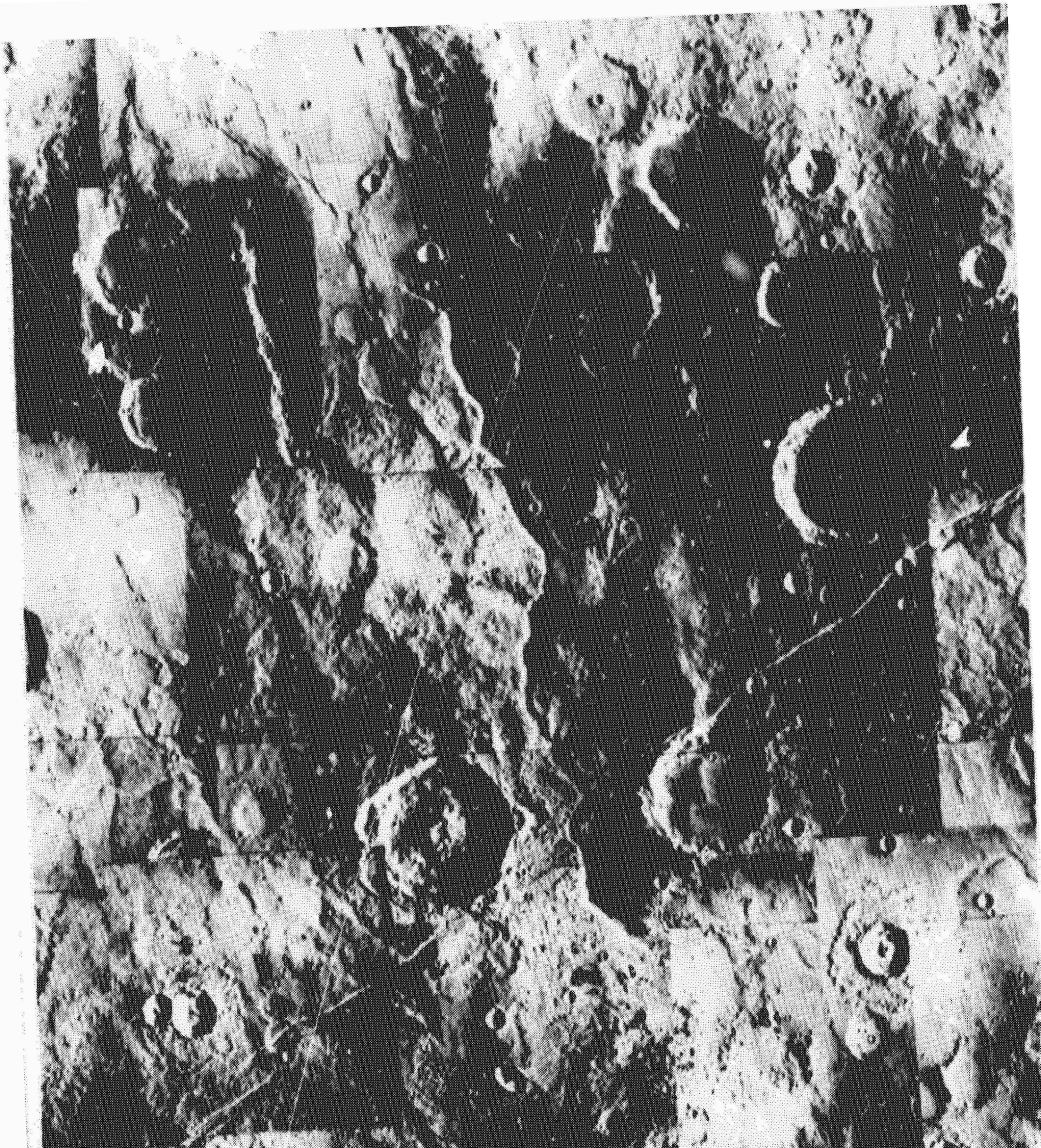
Each Viking lander carried a seismometer to measure quake activity and to provide data on the internal structure of the planet. Lander 1's seismometer had failed by the time it had landed, but the one on Lander 2 worked well. It found not a single definitely confirmed seismic signal in more than 1,200 hours of good data. If Mars quakes, it must do so infrequently. Therefore all information about the interior comes from other sources.

Idiosyncracies in the Martian gravity field exist around the five largest volcanoes and in Valles Marineris. A "mascon," or mass concentration, a region where the rock is denser than average, was found in a depression called Isidis Planitia.

(Opposite page) Strong evidence for large quantities of water flowing across the surface during Mars' past exists among craters of widely varying ages. Wind has eroded the edges of lava flows. Complicated features within some of the channels indicate permafrost activity. The islands and grooves formed after water cut the landscape. Later, wind erosion heavily modified the terrain.

(Below) Stream channels in Kasai Valles have been highlighted by wind erosion that further carved the longitudinal grooves formed by flowing water. After the channels were cut, the region was broken by faults that run in several directions. The floor of the youngest channel is covered with featureless deposits that in turn are dotted with craters. More recently still, landslides cascaded down onto the young channel surface. Small channels offset the youngest flow deposits.

"We may have an opportunity to probe natural laboratories that are undergoing the type of evolution that almost certainly must have occurred on Earth nearly 4 billion years ago."
—Richard S. Young



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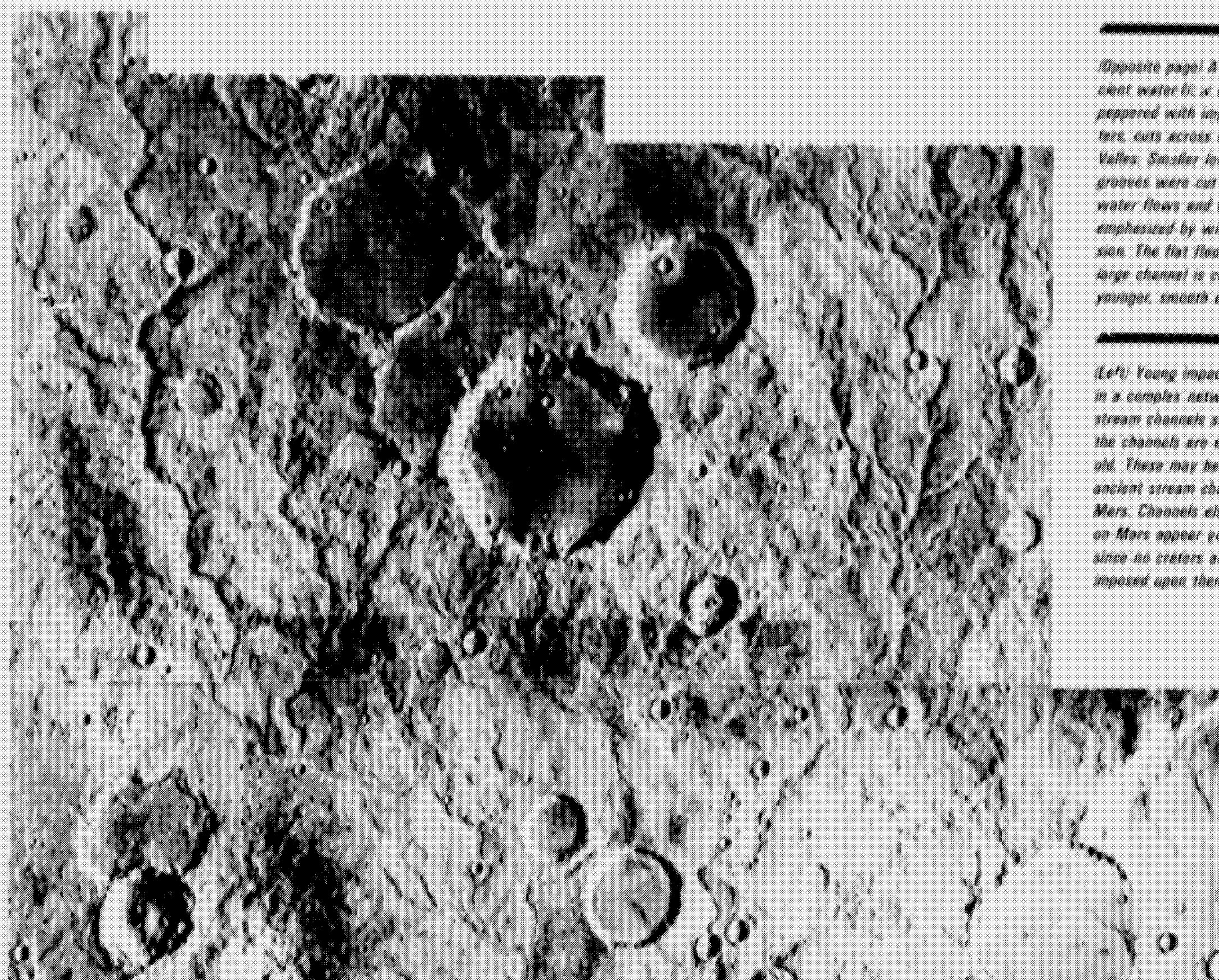


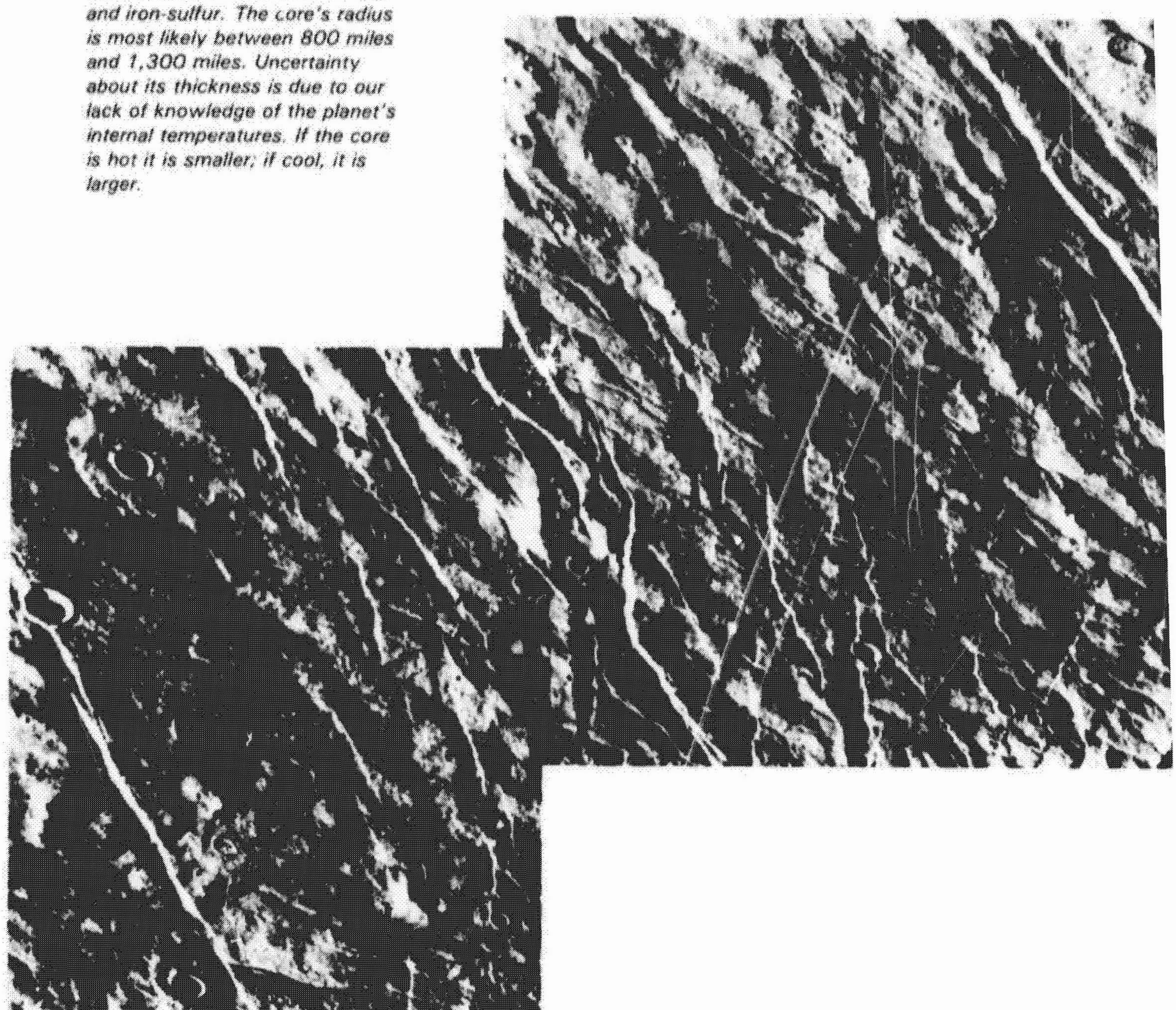
(Opposite page) A large, ancient water-flow channel, peppered with impact craters, cuts across Kasei Valles. Smaller longitudinal grooves were cut by later water flows and then emphasized by wind erosion. The flat floor of the large channel is covered by younger, smooth deposits.

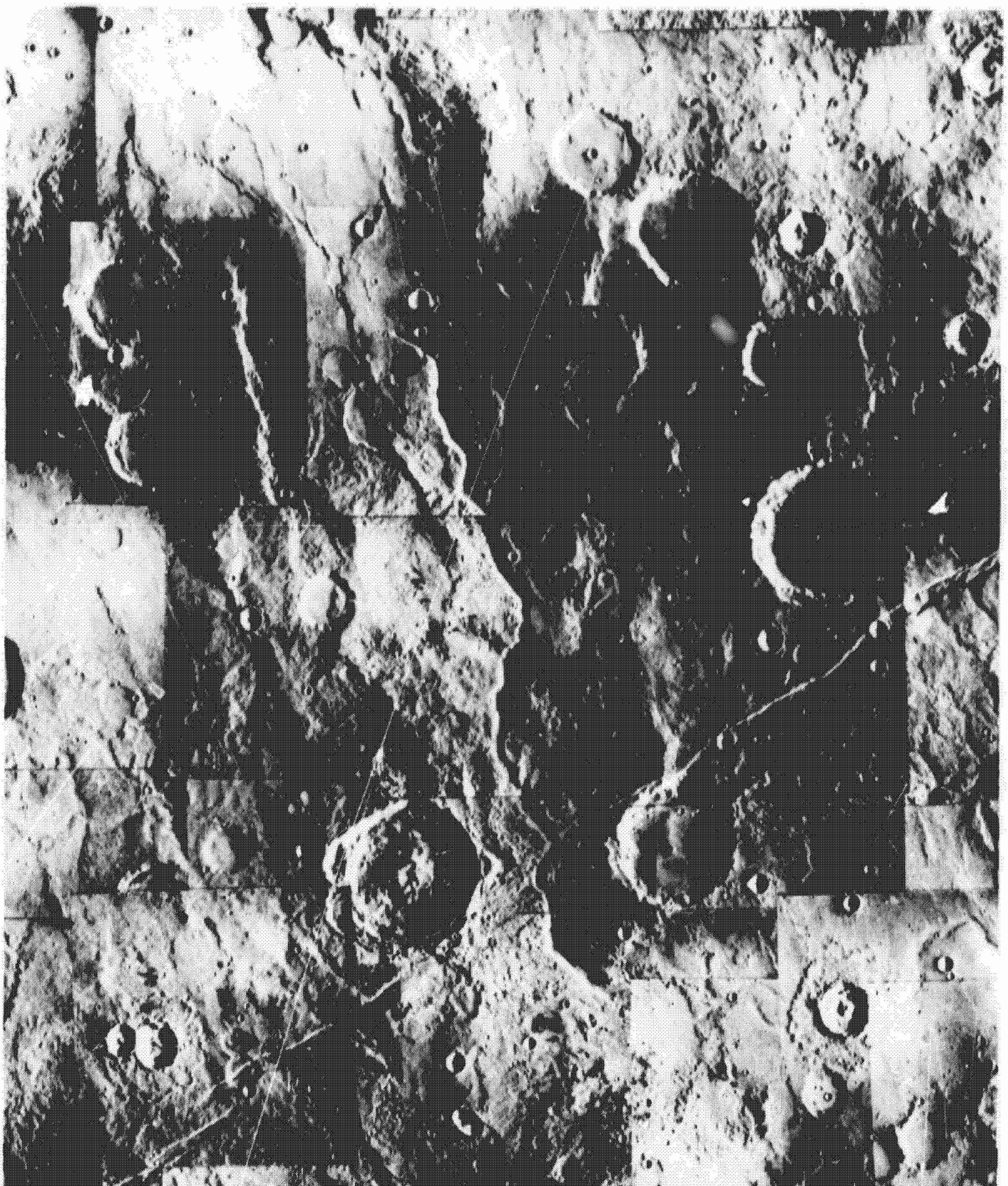
(Left) Young impact craters in a complex network of stream channels show that the channels are extremely old. These may be the most ancient stream channels on Mars. Channels elsewhere on Mars appear younger, since no craters are superimposed upon them.

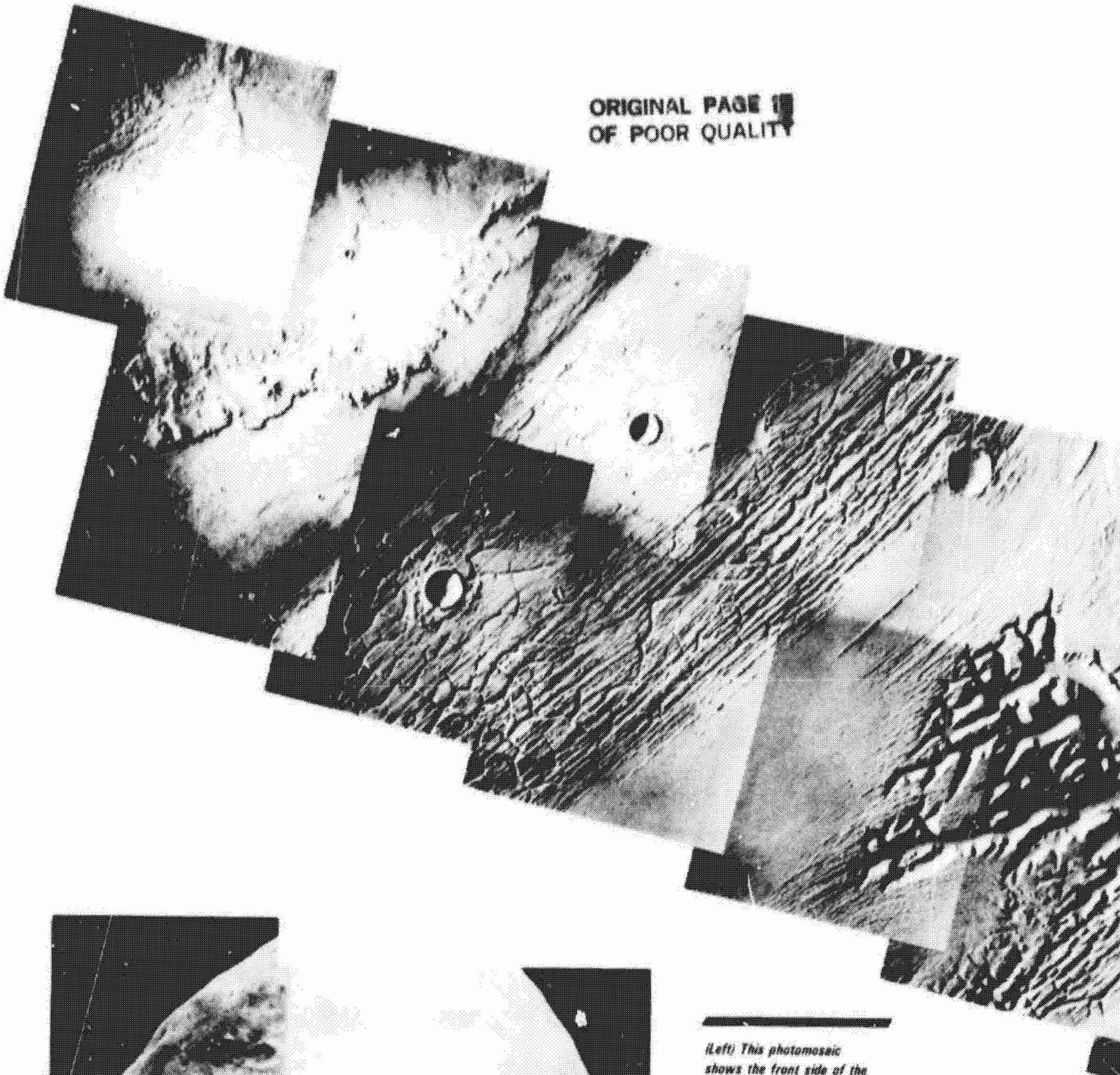
It was the gravity data—derived from changes in the orbits of the Vikings—and the extreme elevations of the volcanoes that indicated a rigid crust about 31 miles thick. Mars' mantle appears cooler and thicker than Earth's. A firm, solid region just beneath the crust is about 125 miles thick. Mars probably has a deep, weak region that is subject to internal stress, a slowly convecting, evenly mixed mantle of basalt, and a molten core of iron and iron-sulfur. The core's radius is most likely between 800 miles and 1,300 miles. Uncertainty about its thickness is due to our lack of knowledge of the planet's internal temperatures. If the core is hot it is smaller; if cool, it is larger.

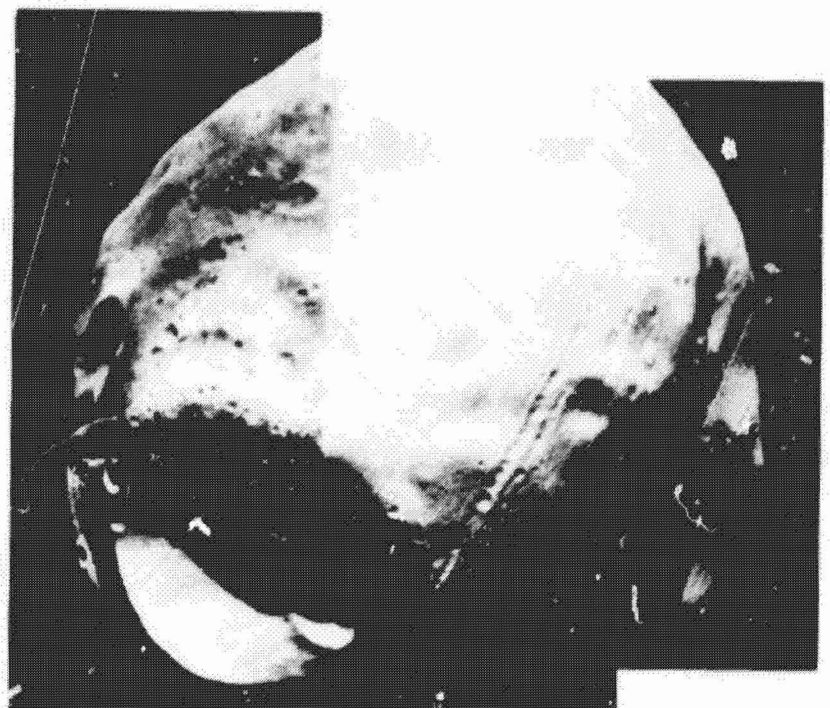
(Below) The western flank of Alba Patera is a volcanic plateau located in the northern lowlands of Mars. Numerous faults break the crust and offset small channels, showing that the channels are older than the faults. Some of the impact craters are older and some are younger than the faults.

(Opposite page) History can be read in this mosaic of an ancient upland region. Very old craters dot the surface. The craters and the rocks around them are cut by younger fault valleys, which contain still younger impact craters. The banks of ancient stream channels have been highly modified by craters and by gravity pulling the rocks downhill.









(Left) This photomosaic shows the front side of the moon Phobos, which always faces Mars. The gaping crater at the lower left is Stickney, the largest crater on Phobos, and is 6 miles in diameter. The linear grooves coming from and passing through Stickney appear to be surface fractures caused by the impact that formed the crater. The deep shadow at the right in the southern hemisphere is cast by Kepler Ridge. Phobos is about 4 miles in diameter and circles Mars every 0.3 days at an altitude of more than 5,800 miles.

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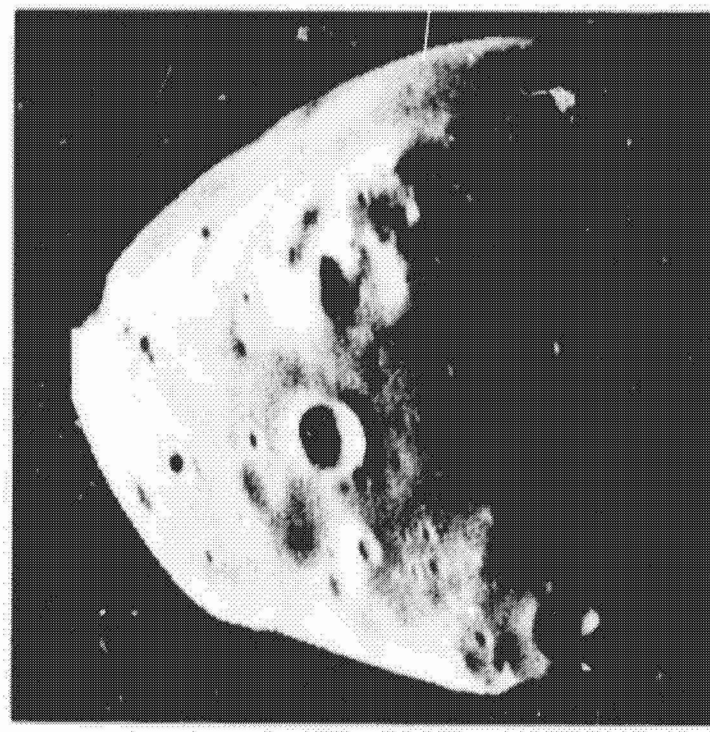
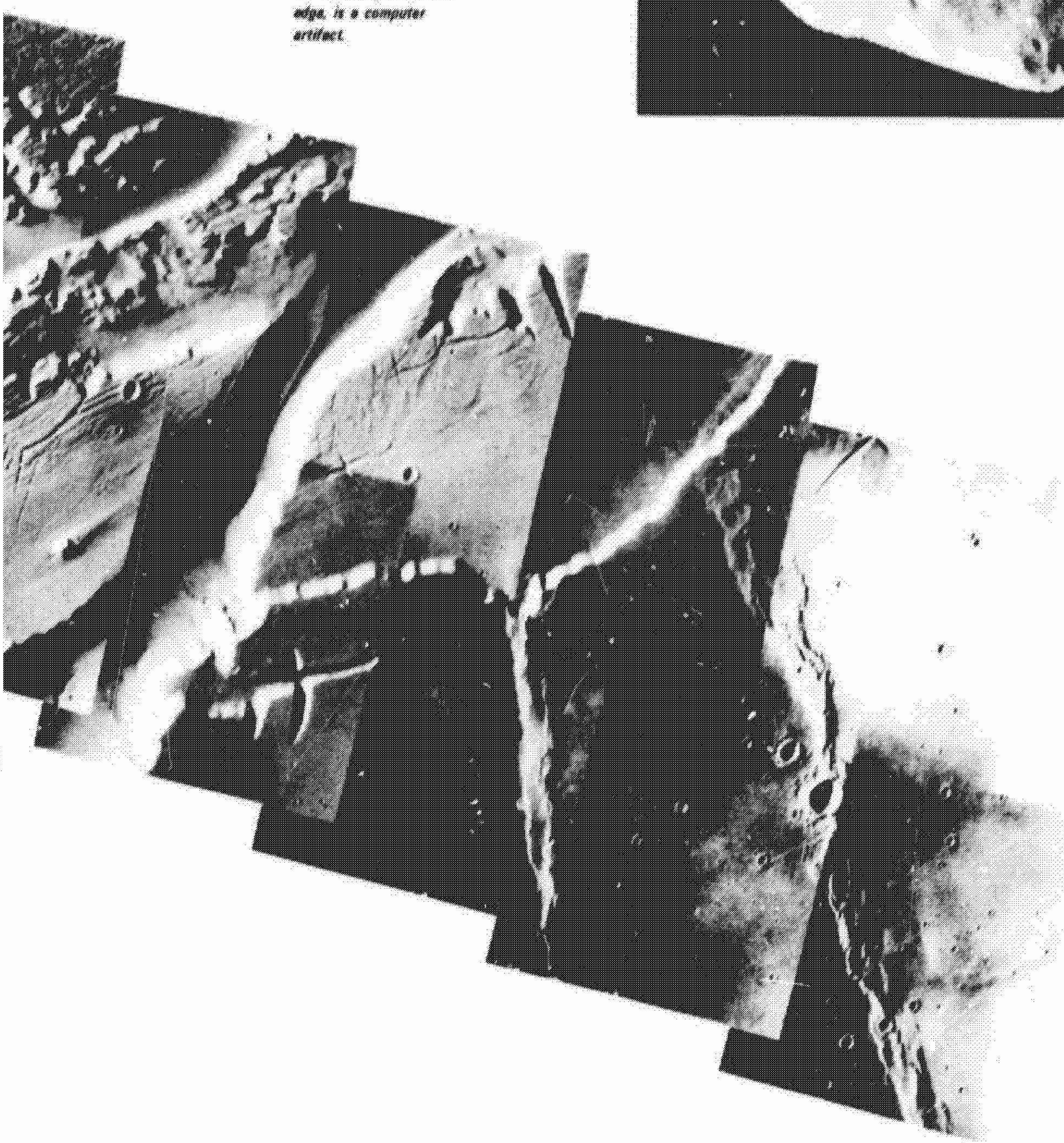
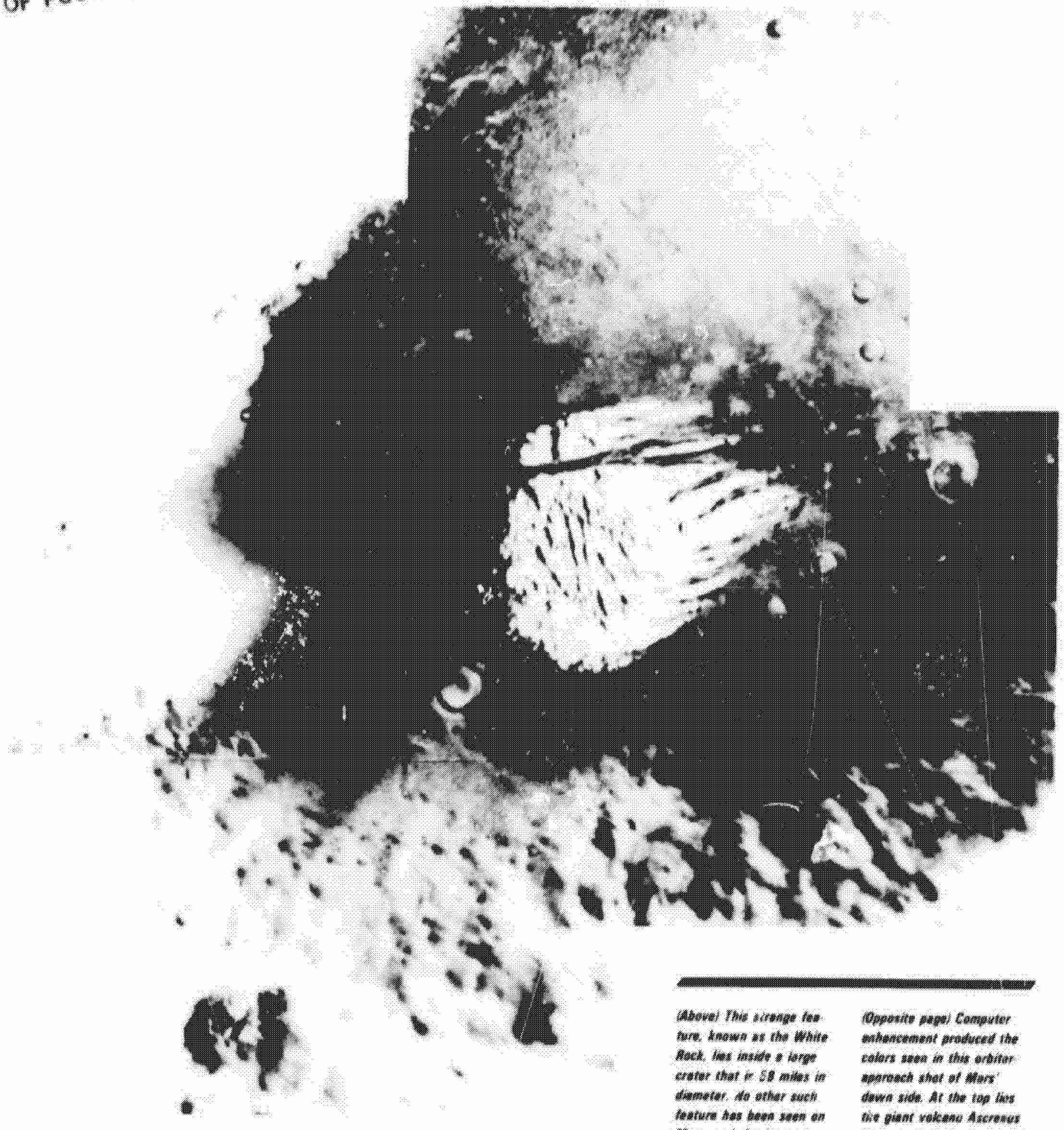
(Below) The many impact craters indicate that this plateau region is ancient, but that it has been heavily modified by later events. Fault valleys cut the plateau, and delicate ridges and grooves, probably created by wind erosion, parallel the fault traces. Rocky knobs stand above the flat terrain; their long tails are also the result of wind erosion. Similar features are found in the Sahara Desert. The valleys were almost certainly cut by water. Their heads are of two types: sharp heads produced by water flowing on the surface, and round heads formed by springs of upwelling underground water.

(Right) Craters of varying age dot the surface of the Martian moon Deimos, which is somewhat smoother than its counterpart, Phobos. A series of grooves can be seen cutting across the surface; these are interpreted to be faults. Deimos is 7.5 miles in diameter and circles Mars every 1.3 days at an altitude of 15,000 miles. The sawtooth effect along the moon's limb, including the sharp jog at the left edge, is a computer artifact.







(Above) This strange feature, known as the White Rock, lies inside a large crater that is 58 miles in diameter. No other such feature has been seen on Mars, and the feature's composition is unknown. Although the White Rock is highly reflective, it cannot be made of ice or snow because of its equatorial location.

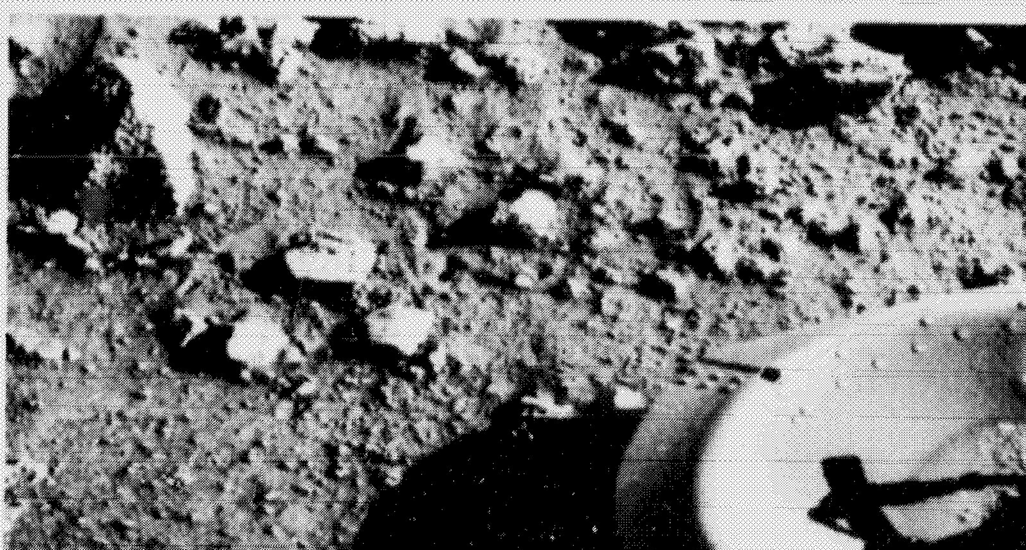
(Opposite page) Computer enhancement produced the colors seen in this orbiter approach shot of Mars' dawn side. At the top lies the giant volcano Ascraeus Mons, with water-ice cloud plumes on its western flank. Other distinct features include Valles Marineris and Argyre Planitia.

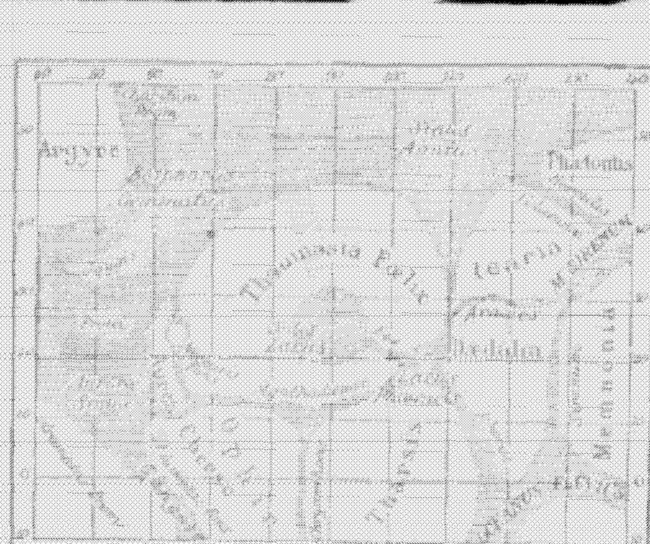
ON THE SURFACE OF MARS

Viking Lander 1 touched down in a moderately cratered, low-lying volcanic plain called Chryse Planitia, the drainage region of a large outflow channel. The landing site is at 22.27 degrees north latitude and 47.97 degrees longitude in a barren desert where rocks are strewn between the sand dunes.

Viking Lander 2 sits in Utopia Planitia at 47.67 degrees north latitude and 225.74 degrees longitude, 4,014 miles from Lander 1. The Lander 2 site is also a barren, rock-strewn desert that, superficially, resembles Lander 1's home.

Viking scientists had expected to see significant changes in the two landing sites as time passed, had even been concerned for the safety of the two landers in Mars' violent wind and dust storms. But the cameras recorded only the most minor changes: slight variations in the brightness and color of a few places on the surface where the winds lay down and blew away extremely thin layers of dust; and two small slumps in the soil at the Lander 1 site that are not readily explainable. The final, and most significant, change was a thin layer each winter of what appeared to be water frost on the ground near Lander 2. But in winter on Mars, the atmosphere is so cold and dry that it cannot hold enough water vapor to produce visible frost. The scientists concluded that water vapor had adhered to dust grains in the southern hemisphere (where it was summer and, therefore, warmer and more moist) and had been carried north across the equator by the wind. Finally, in the north, it became cold





(Above left) This is the first photograph ever taken on the surface of Mars. Just minutes after landing on July 20, 1976, Viking Lander 1's camera photographed its own footpad resting on rocky Martian soil.

(Right) This is the first color photograph taken by Viking Lander 2 and shows a rocky and reddish surface very much like that photographed by Lander 1 more than 4000 miles away. The camera is facing approximately northeast. The photograph was taken in the late afternoon, and the Sun is behind the camera. Because the spacecraft is tilted about 8 degrees toward the west, the horizon appears tilted. In fact, the horizon is nearly level.

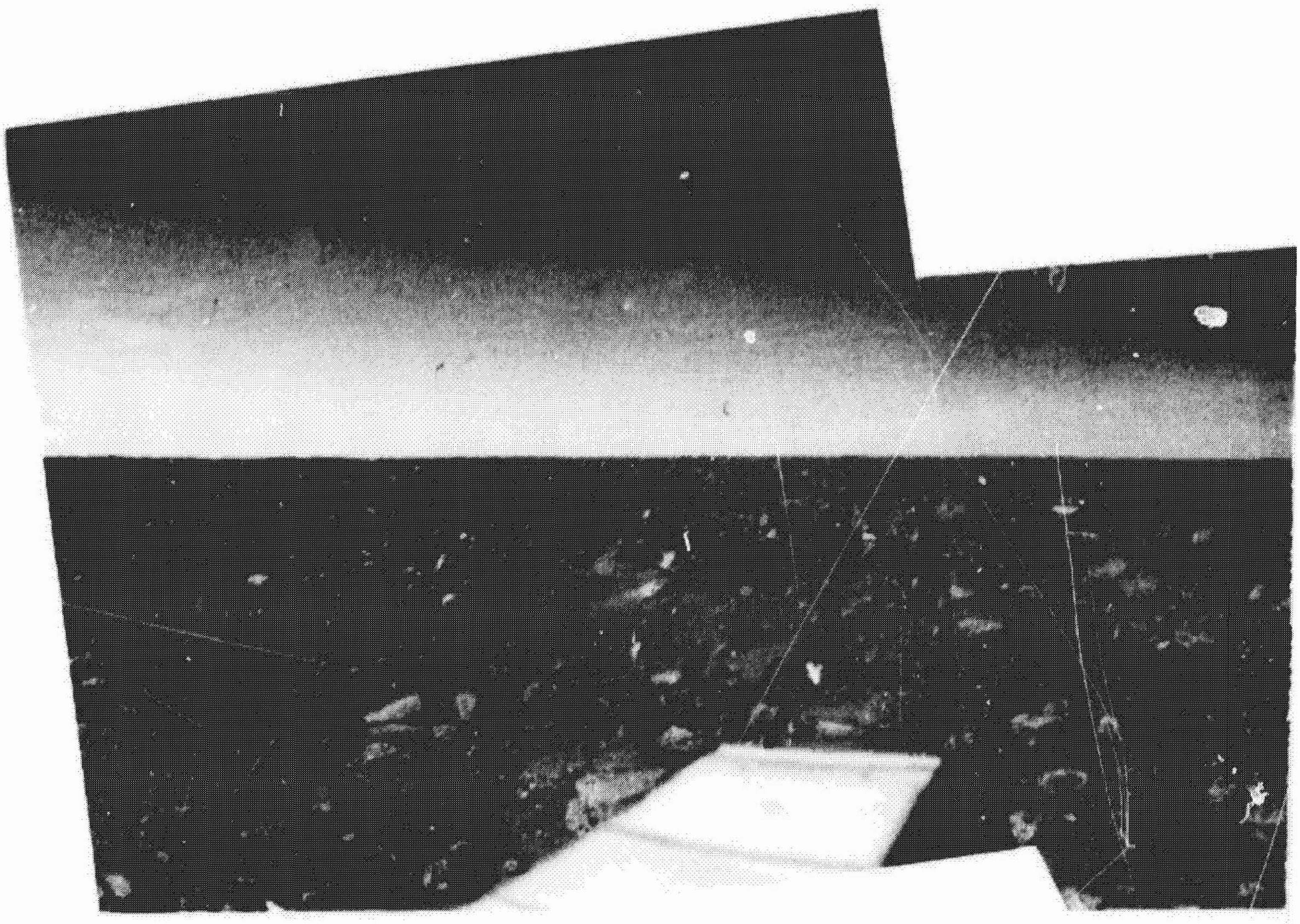
ORIGINAL PAGE
COLOR PHOTOGRAPH

enough for carbon dioxide to condense onto the water-and-dust particles, and they fell to the ground around Lander 2. The scientists first noticed a change in the color of the surface, and then watched the frost accumulate for 80 Mars days. New frost appeared at the identical season each year.

The weather on Mars is cold. The temperature drops to about −92 degrees Fahrenheit just before dawn, and rises in mid-afternoon to about −13 degrees Fahrenheit. Throughout the Martian summer, weather is repetitive to the point of boredom. In winter it becomes variable. Cyclones and anticyclones (low- and high-pressure systems) passed both landers fairly frequently. In a region called Memnonia Fossae, less than 2.4 miles above the mean surface, the orbiters watched frost form every

(Below) The Martian horizon stretches across nearly 200 degrees in this composite of three color photographs taken by Viking Lander 2. The rusty red color of the surface is caused by thin coatings of limonite (hydrated iron oxide).

(Left) Pitted rocks produced by volcanism or marred by meteorite impacts surround Viking Lander 2. The Lander cameras scanned nearby terrain for the best spots for sampling Martian soil.



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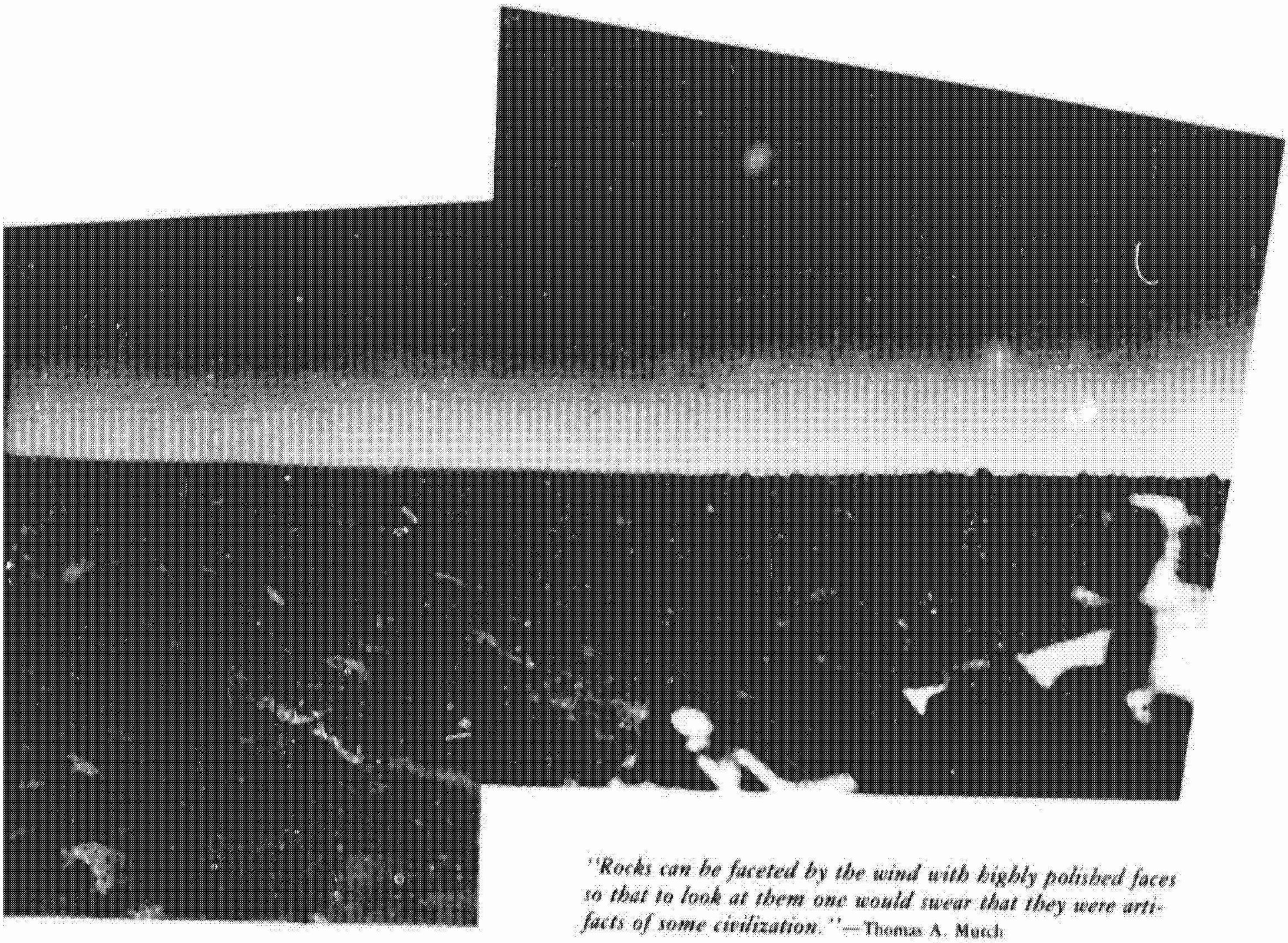

"Rocks can be faceted by the wind with highly polished faces so that to look at them one would swear that they were artifacts of some civilization."—Thomas A. Mutch

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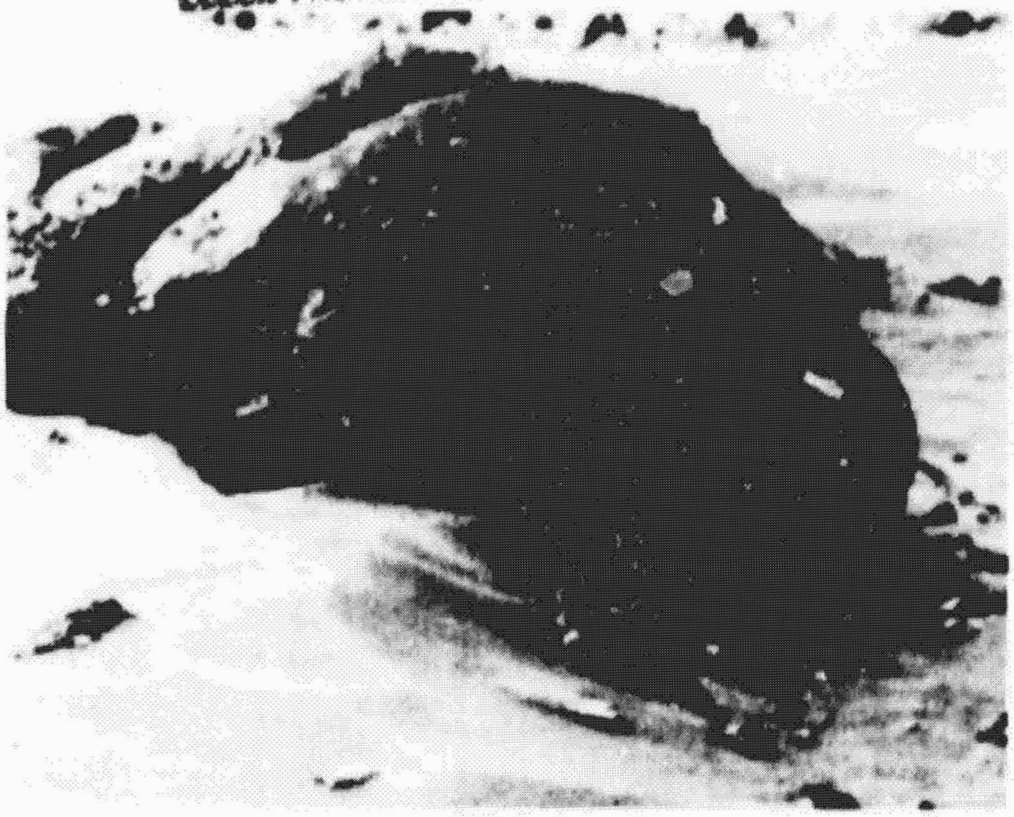
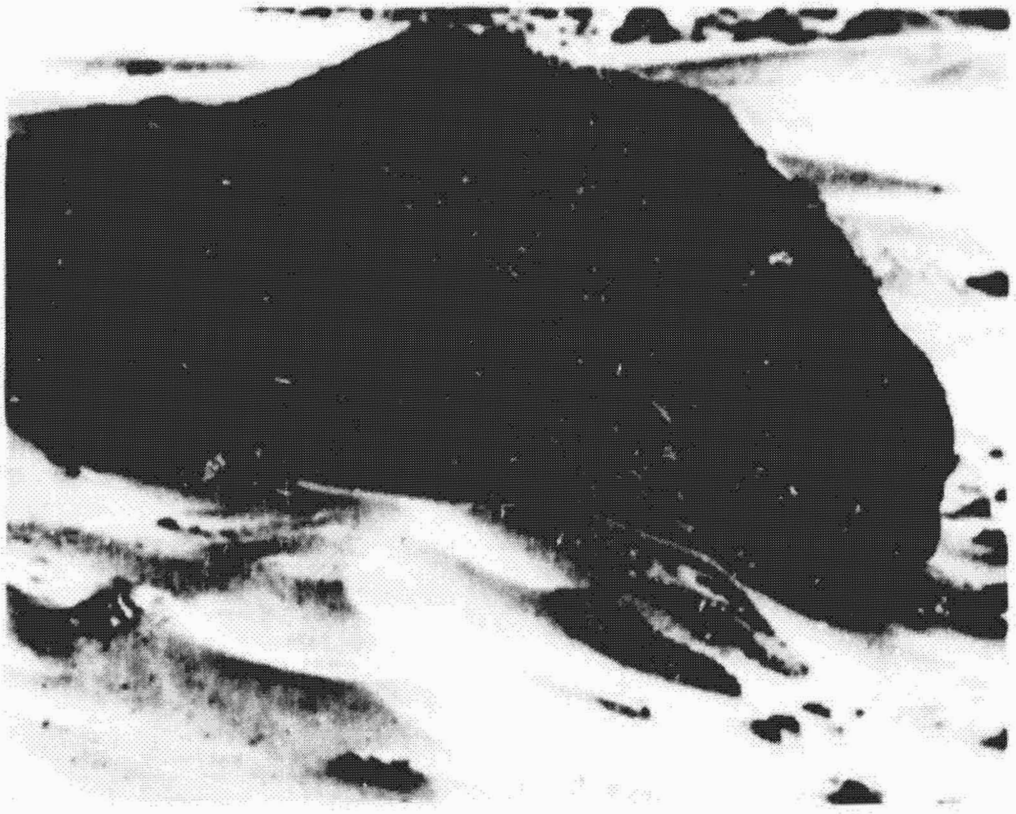
COLOR PHOTOGRAPH

(Opposite page) The clouds seen in storm fronts such as this are made up of water or water-ice, much like those on Earth. This cyclonic storm measures about 155 miles across. False colors have been used to enhance storm features.

(Right) This pair of photographs taken by Viking Lander 1 shows the only unequivocal change in the Martian surface seen by either lander. The upper photograph shows a smooth, dust-covered slope just to the lower right of the 3-foot-high boulder (nicknamed "Big Joe"). In the lower photograph, additional underlying dark material has been exposed. Apparently the surface layer, which is between 1/5 and 1/3 of an inch thick, is less cohesive than the underlying material and slipped downslope, creating a small-scale slump feature. Photographs taken before October 4, 1976, do not show the slump. The first photograph in which it appears was taken January 24, 1977. What triggered the slippage of material is not known, but it could have been temperature variations, wind gusts, a seismic event, or, allowing for a time delay, perhaps even the lander's touchdown on July 20, 1976.





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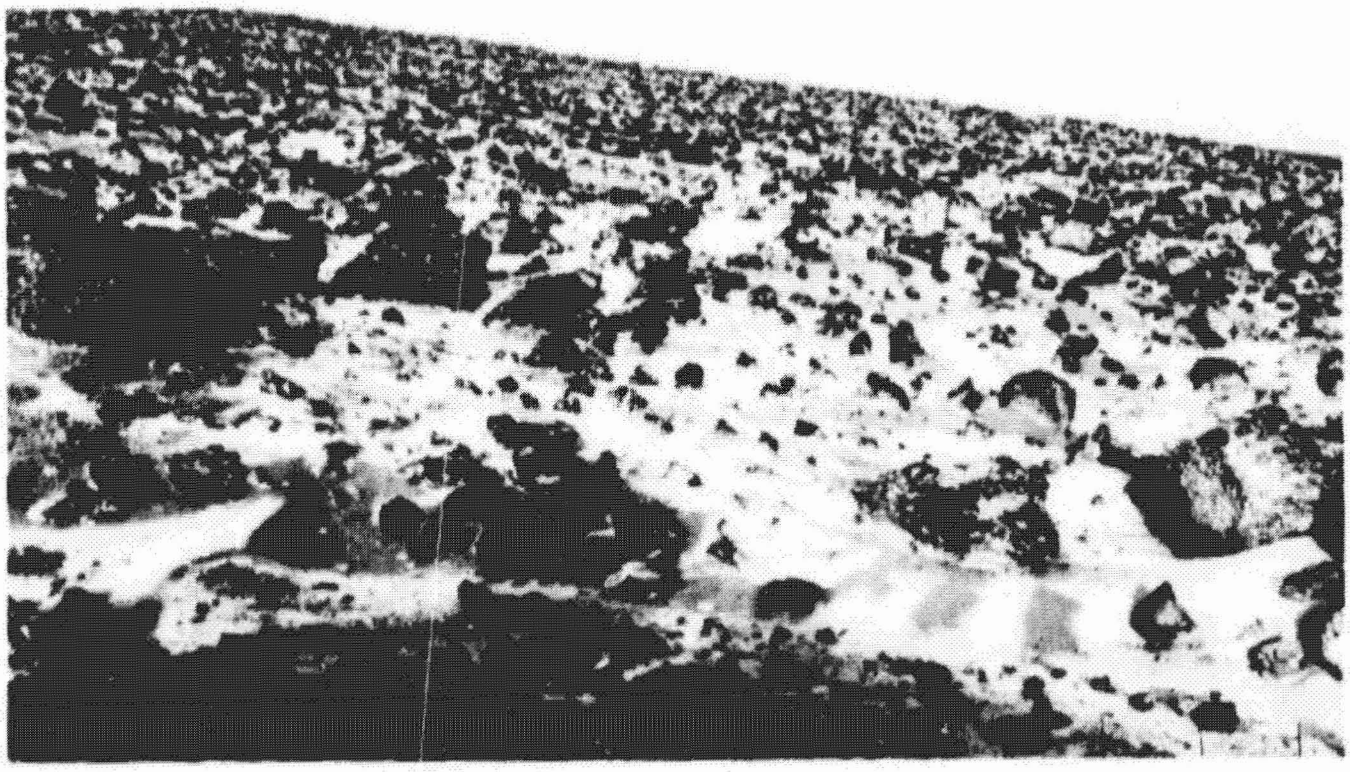
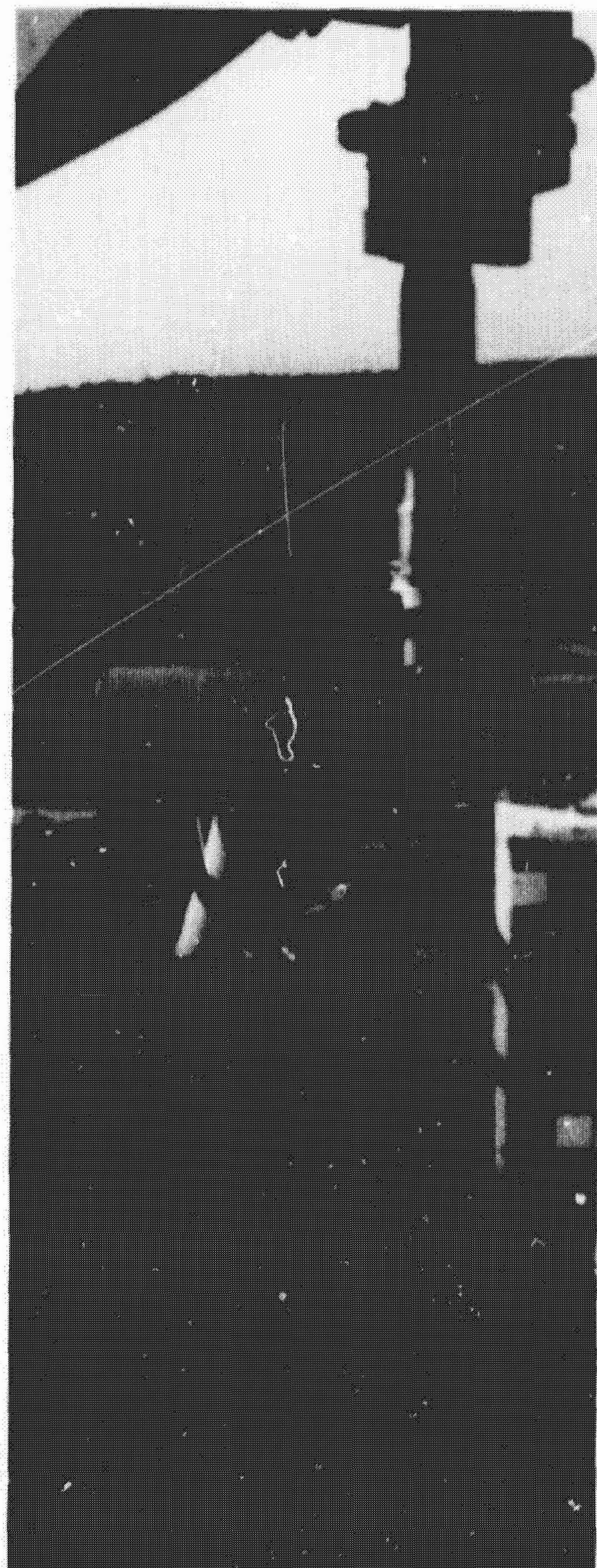


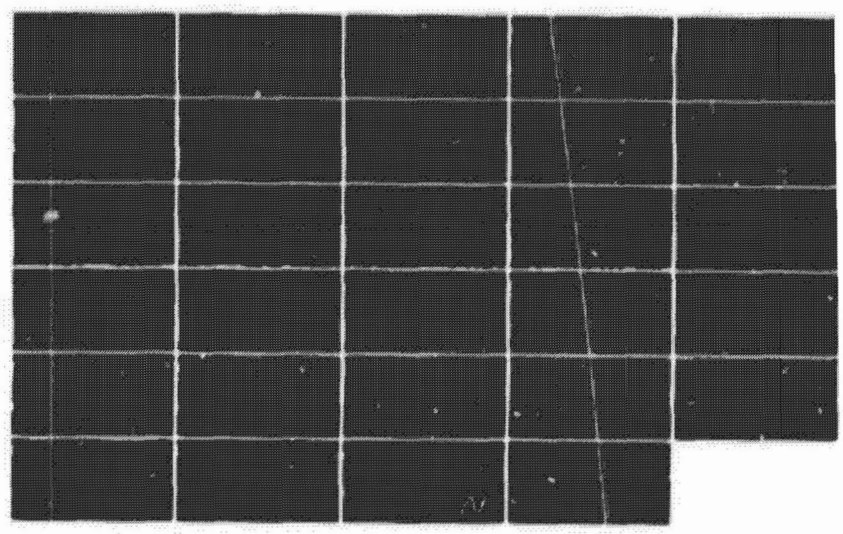
night — even in midsummer — and disappear soon after sunrise.

The Viking landers studied the chemistry of the atmosphere and found that it is 95 percent carbon dioxide. To the surprise of almost everyone, they found nitrogen, at about 2.7 percent. (No earlier spacecraft had detected nitrogen, one of the most important constituents of life, in Mars' atmosphere.) The third most plentiful gas is argon, about 1.6 percent. That leaves less than one percent total for all the other gases. They are, in order of abundance: oxygen, carbon monoxide, neon, krypton, xenon, and ozone. There is some water vapor in the atmosphere, but the amount is highly variable. In summer it reaches 2 to 3 percent of the total; in winter, because most of the water is frozen out and falls to the surface, the percentage is negligible.

The atmosphere must have been denser sometime in the past. Scientists have determined that Mars has lost about 10 times as much nitrogen as is present today, and about 20 times as much carbon dioxide. The scientists also deduced that, throughout its history, Mars produced enough water to cover the entire surface about 33 feet deep. The questions remaining about Martian water are fundamental.

"Light winds from the East in the late afternoon, changing to light winds from the Southeast after midnight. Maximum winds were 15 miles per hour. Temperature ranged from minus 122 degrees Fahrenheit just after dawn to minus 22 degrees Fahrenheit. . . . Pressure steady at 7.70 millibars."
— First weather report from Mars, as given by Seymour L. Hess





(Opposite page) Dark rocks are highlighted by patches of late-winter water frost in this view from Lander 2. The color differences between the white frost and the reddish soil were what initially confirmed that the patches are indeed frost.

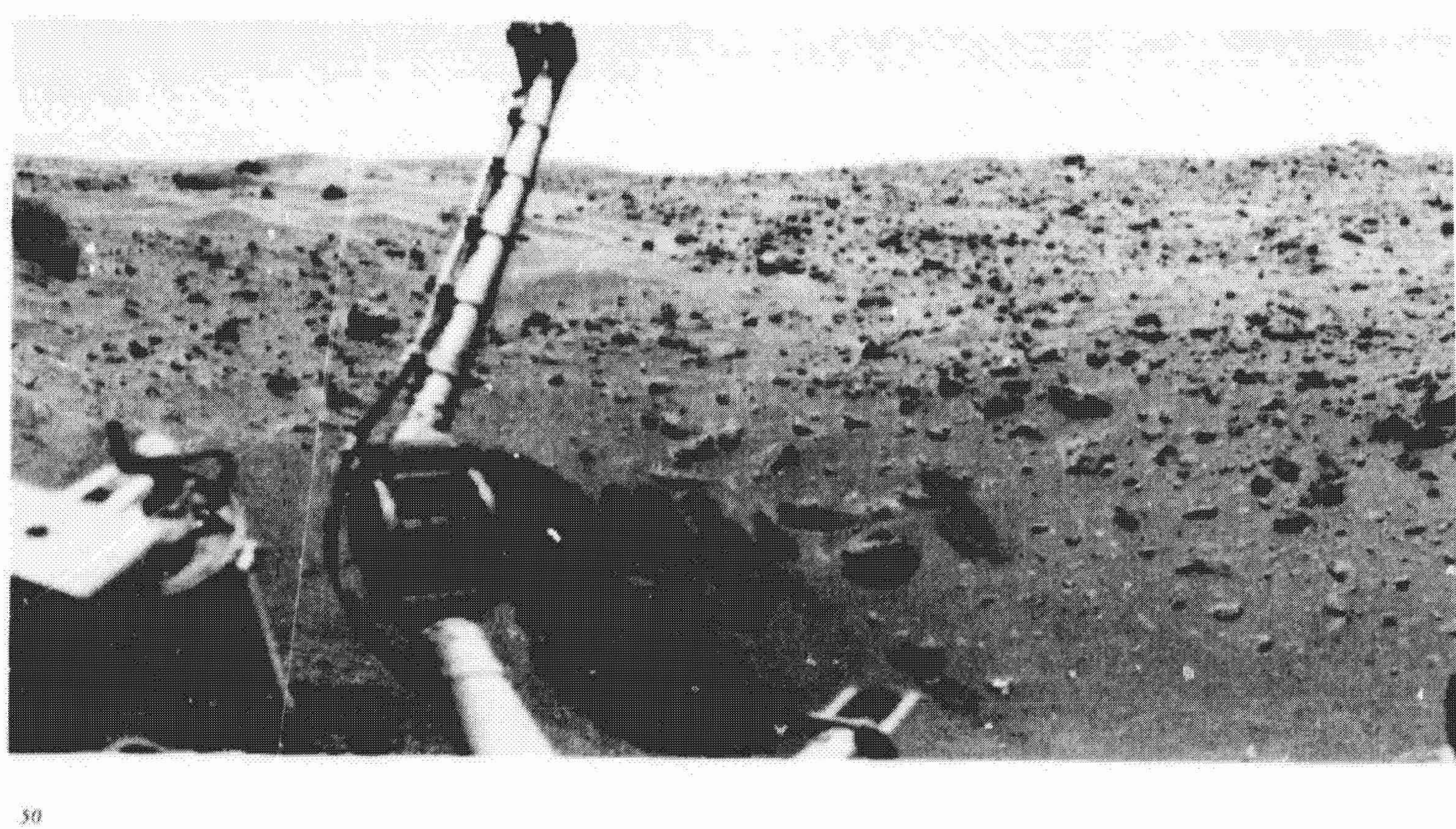
(Left) This photograph also shows late-winter frost on the ground around Viking Lander 2. The lowest predawn temperature measured at the northern landing site was −184 degrees Fahrenheit.

(Above) The dynamic evolution of water vapor in the Martian atmosphere is seen in this series of Mercator projections. Going from left to right, one can track changes over time, as the frames change every 1/24 of a Martian year (about one month on Earth). Red represents the highest levels of water; blue, the lowest; black, regions where no data were obtained by the Mars vapor mapper aboard each orbiter.

Viking's soil scoop was unable to chip or scratch the rocks at the two landing sites, but the landers subjected the fine soil to intense analysis. Silicon and iron are the most abundant elements; about 45 percent silicon dioxide and about 19 percent iron oxide (rust). Magnesium, calcium, sulfur, aluminum, chlorine, and titanium are also present. Sulfur is about 100 times as abundant in the Martian soil as on Earth but potassium is at least five times less abundant. The iron seems to be mixed throughout the soil, which is an iron-rich clay. Some Earth soils are similar to the Martian soil, but none is exactly like it. The soil at the two landing sites probably comes from decomposition of a volcanic material such as basalt. The high iron and low potassium content suggests that differentiation, the separation of material over geologic time by internal heating, has not occurred on Mars as thoroughly as it has on Earth.

(Below) Shallow trenches dug by Lander 1's soil sampler arm are visible in the foreground. Soil samples were delivered to the Lander's organic chemistry instrument for analysis. No evidence of life was found in the samples collected.

(Opposite page) This is the last photograph taken by Viking Lander 1. The photograph was taken 30 minutes after local noon (lander time) on November 5, 1982, when the Martian northern hemisphere was about halfway through its autumn. The photograph shows rocks, smooth drift material, and a trench dug by the lander's soil-sampler arm. The dark appearance of the ground and the diffuse edges of shadows in front of the rocks suggest that a dust storm, detected in photographs taken a few weeks earlier, was continuing.



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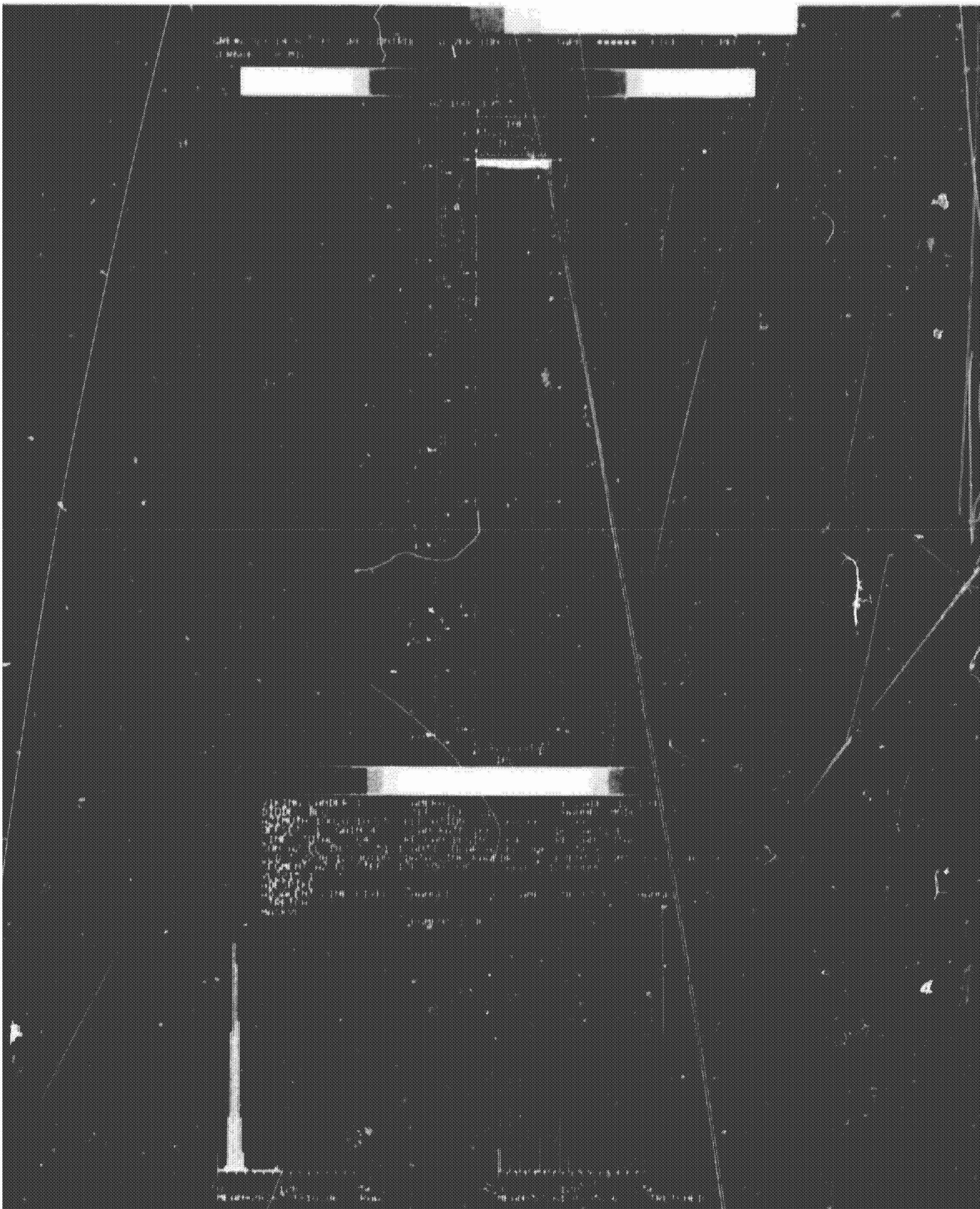

VIKING INSTRUMENTS

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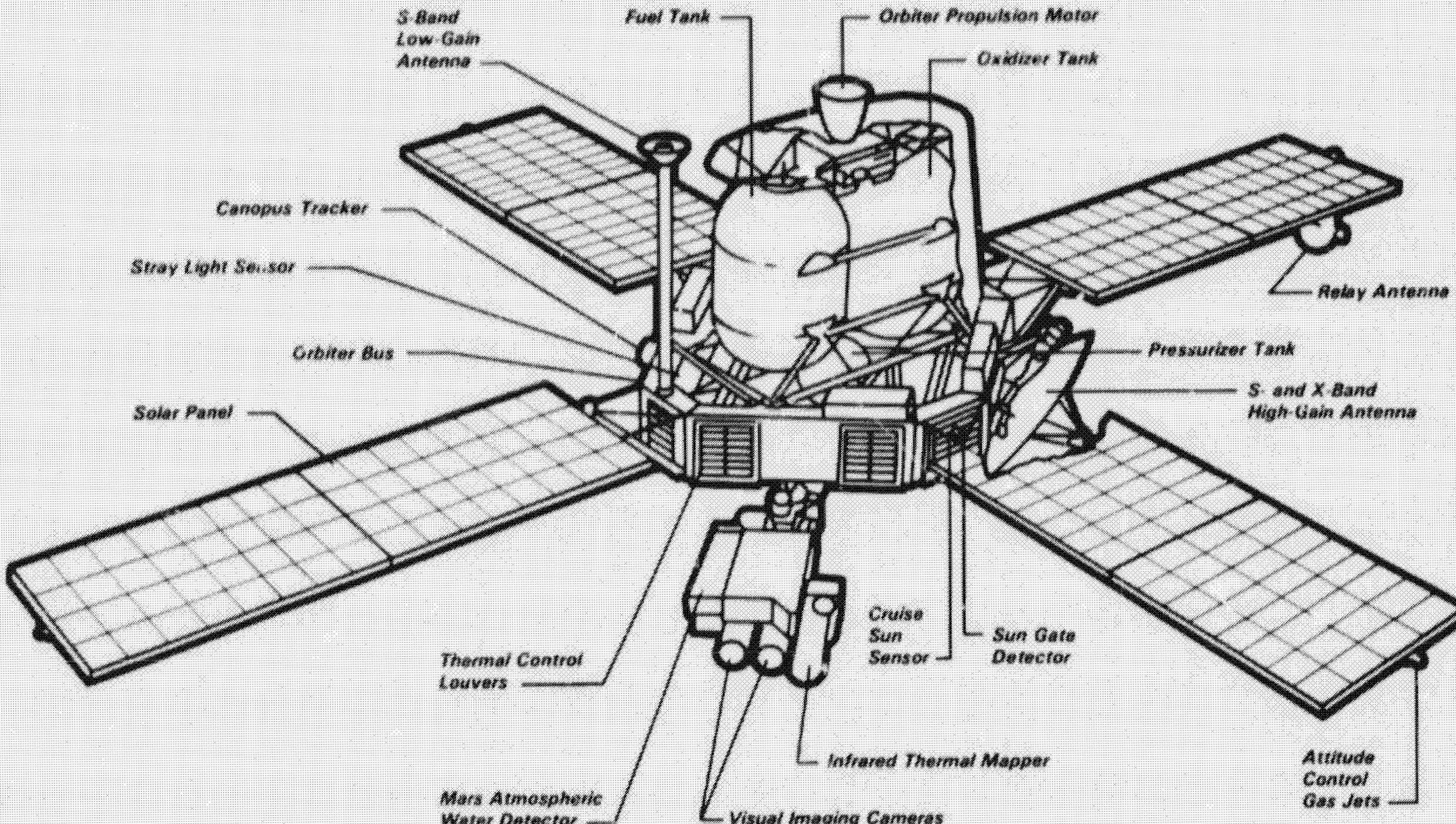


The Viking orbiters carried three scientific instruments:

★ A pair of cameras with 1,500-millimeter focal-length lenses performed systematic searches for landing sites, then looked at and mapped almost 100 percent of the Martian surface. Cameras on the two orbiters took more than 51,000 photographs of Mars.

★ A Mars Atmospheric Water Detector mapped the Martian atmosphere for water vapor and tracked seasonal changes in the amount of vapor.

★ An Infrared Thermal Mapper measured the temperatures of the surface, polar caps, and clouds and mapped seasonal changes.

★ Although the orbiter radios were not science instruments, they were used as such. By measuring the distortion of radio signals from the orbiters to Earth, as the signals passed through the Martian atmosphere, scientists measured its density.

The Viking landers carried 11 instruments:

★ The Biology Instrument consisted of three separate experiments designed to detect evidence of microbial life in the Martian soil. There was always a chance that larger life forms could be present on Mars. But the biologists thought the life forms most likely to be widespread on Mars (as they are on Earth) would be microbes.

★ A Gas Chromatograph/Mass Spectrometer (GCMS) searched the Martian soil for complex organic molecules that might be precursors or the remains of living organisms.

★ An X-ray Fluorescence Spectrometer analyzed samples of the Martian soil to determine its elemental composition.

★ A Meteorology Instrument measured air temperature and wind speed and direction at the landing sites, and returned the first extraterrestrial weather reports in the history of meteorology.

ORIGINAL PAGE
COLOR PHOTOGRAPH

★ *A pair of slow-scan cameras mounted about one meter apart on the top of each lander provided black-and-white, color, and stereo photographs of Mars.*

★ *A seismometer had been designed to listen for "Marsquakes," to help determine the planet's internal structure. The seismometer on Lander 1 did not function after landing and the instrument on Lander 2 found no clear signs of internal activity.*

★ *An Upper-Atmosphere Mass Spectrometer made its primary measurements as each lander flashed through the atmosphere. Viking's first important scientific discovery—nitrogen in the Martian atmosphere—came from this instrument.*

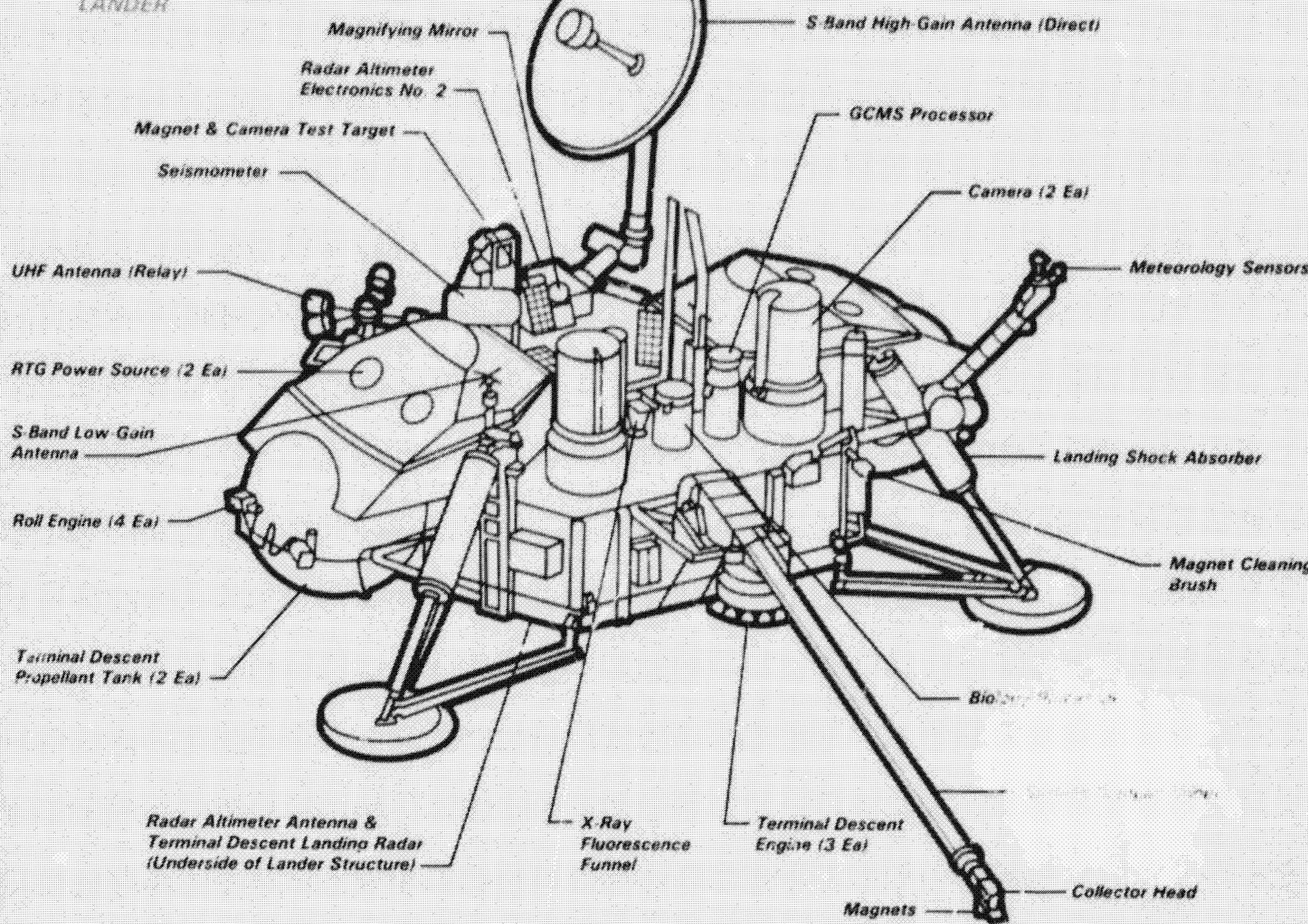
★ *A Retarding Potential Analyzer measured Mars' ionosphere—the region directly above the atmosphere that contains charged particles—during entry.*

★ *Accelerometers, a Stagnation Pressure Instrument, and a Recovery Temperature Instrument helped determine the structure of Mars' lower atmosphere as the landers settled toward the surface.*

★ *A Surface Sampler Boom used its collector head to scoop up bits of soil to feed the biology, organic-chemistry, and inorganic-chemistry instruments. It also offered clues to the soil's physical properties. Magnets attached to the sampler arm provided information on iron in the soil.*

★ *The lander radios also were used to conduct science experiments. Physicists refined their calculations of Mars' orbit by measuring the round-trip time for radio signals between Mars and Earth. The measurements' accuracy allowed physicists to confirm parts of Einstein's Theory of General Relativity.*

LANDER



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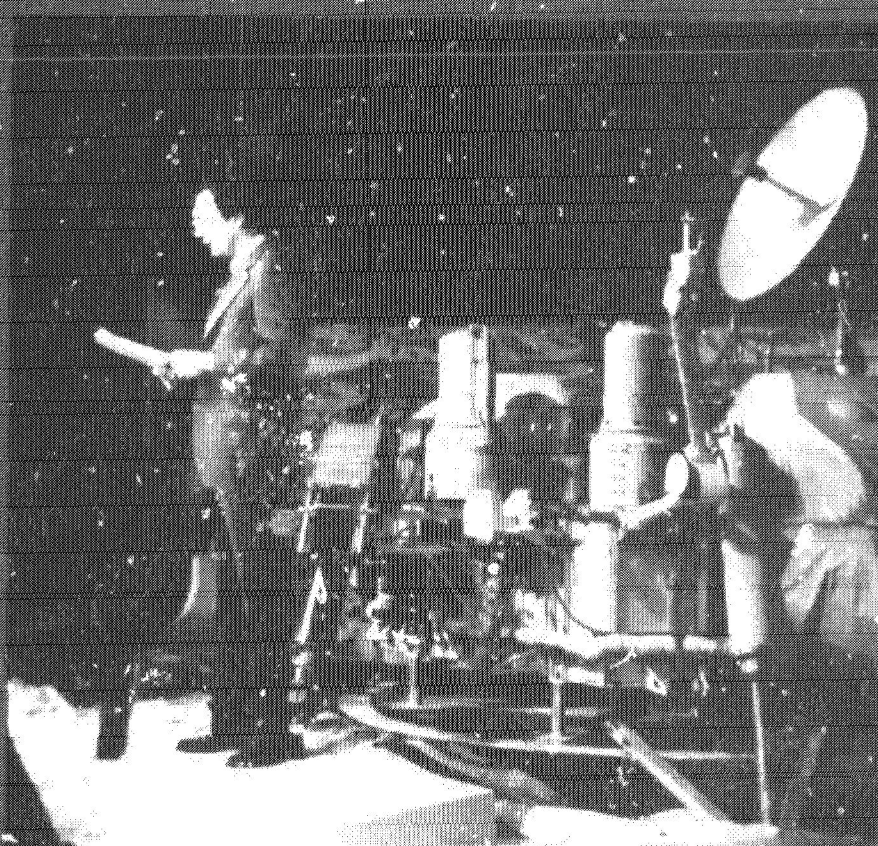
Orbiter 2 was the first Viking probe to [illegible] was shut off on July 25, 1978. [illegible] Lander 2 sent its last message to Earth on April 11, 1980. In the late summer of 1980 Viking Orbiter 1 ran out of fuel and was turned off. The only survivor of the mission was Viking Lander 1. A special computer program allowed the lander to collect weather data and pictures, then transmit them to Earth once a week. Project officials hoped they could keep the lander alive through 1994.

But Viking Lander 1 had already lived far beyond its expected lifetime. Age was reaping its grim toll as it does with all old machines. Viking's last transmission reached Earth in November 1982, and then the lander fell silent. Engineers and scientists worked hard to find out what had gone wrong and to find a way to reestablish contact. But Viking remained stonily silent. In May 1983 the mission was declared at an end.

"—Eight years of planning, moments of frustration, friendships forged by common problems, and now everything happening just as we had disbelievingly promised each other it would." —Thomas A. Mutch



"If you're a scientist, you have to be willing to murder your own favorite ideas in the face of the data. If you are passionate about your beliefs, you can run into trouble."
—Norman H. Horowitz

"Understanding Mars is understanding its history, which gives you some idea of the Earth's history."
—Hugh H. Kieffer

"Even if the immediate future is uncertain, I have no doubts about the distant years. Some day man will roam the surface of Mars. Those wonderful Viking machines will be crated up, returned to Earth, and placed in a museum. Children in generations to come will stand before them and struggle to imagine the way it was on that first journey to Mars."
—Thomas A. Mutch