

The Mars Exploration Rovers: Spirit and Opportunity

The Mars Exploration Rover Mission

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During their journeys of exploration, Spirit and Opportunity outperformed even the most optimistic expectations of their builders. For scientists studying Mars, the robotic rovers proved to be the next best thing to actually being there with geology tools in hand. The ten-year record of discoveries compiled during the mission has helped scientists reconstruct a past when Mars was awash in water, which may have created environments favorable for microbial life.

Scientific Findings

The mission took one of the first steps in understanding the possibilities for life on Mars: whether the Martian environment ever could have supported life. Analysis of rocks and soil in several of the locales explored by the rovers shows changes in the rock record that could only occur from persistent soaking in water.

Spirit found soils and rocks with extremely high concentrations of materials that typically form in either hot springs or volcanic steam vents. These conditions may have been favorable for supporting microbial life. On Earth, microbes known as “extremophiles” thrive in similar environments.

Opportunity found that more chemically neutral, “drinkable” water once persisted on Mars before an acidic period in the ancient past, thus creating more favorable conditions for microbial life. The rovers’ discoveries made a huge leap forward in expanding the possibility that Mars once provided habitable conditions.

Following the trail of past water on Mars, the rovers successfully allowed scientists to characterize much of what the red planet was like when liquid water flowed there.

Science Tools

Each rover carries a science payload consisting of a Miniature Thermal Emission Spectrometer and Panoramic Camera at the top of a rotatable mast (the rover’s “neck”) to survey the surrounding terrain. A robotic arm helps scientists examine rocks and soils, by using contact instruments (Alpha Particle X-Ray Spectrometer, Mössbauer Spectrometer, and a Microscopic Imager) and a Rock Abrasion Tool. Engineering sensors and other components are also useful for science investigations and for navigation and mobility. These include stereo navigation cameras, front and rear stereo hazard avoidance cameras, wheel motors, wheel motor current and voltage data for measuring ground properties, the wheels themselves for digging, gyros, accelerometers for describing terrain contours, and solar cell readings for measuring how much dust is in the atmosphere or deposited on the rover.

Spacecraft Design

Each spacecraft contained a rover tucked inside a lander. For the trip from Earth to Mars, engineers

packed the lander inside a heat shield and back shell attached to a cruise stage. Upon arrival, with the spacecraft’s velocity still increasing from the pull of Mars’ gravity, the entry capsule jettisoned the cruise stage. A large supersonic parachute inflated in the thin Martian atmosphere to slow the lander. Near the ground, solid rocket motors fired to reduce landing speed further. Airbags inflated around the lander to cushion the impact, and the lander bounced and rolled to a stop on Mars. Once the airbags deflated, the lander’s “petals” opened, revealing the rover ready to raise its “head,” stand up, and roll off for its adventures on Mars.

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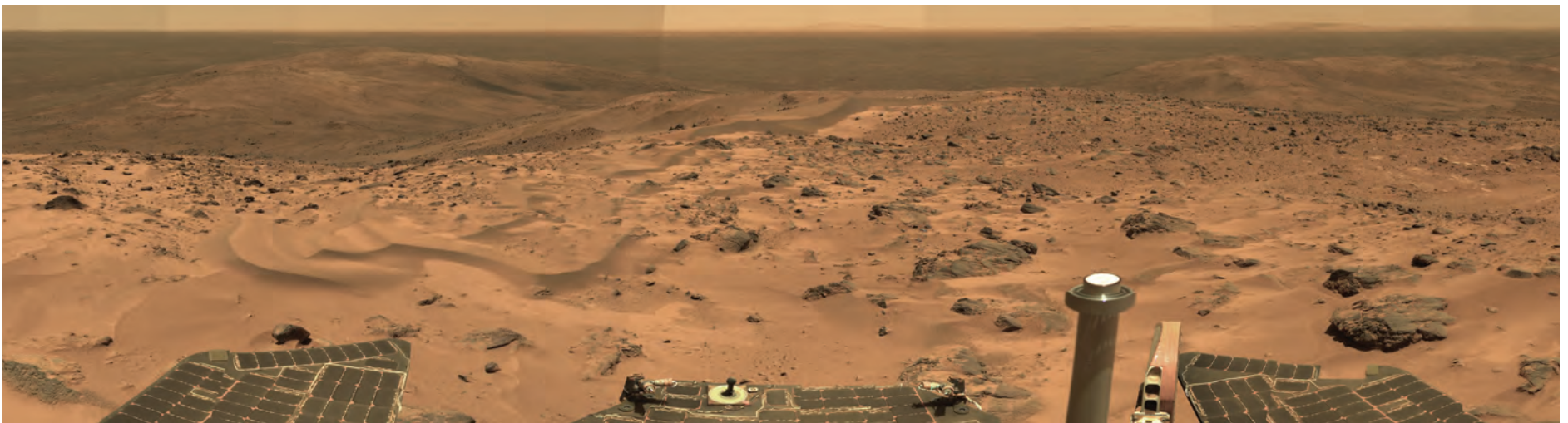
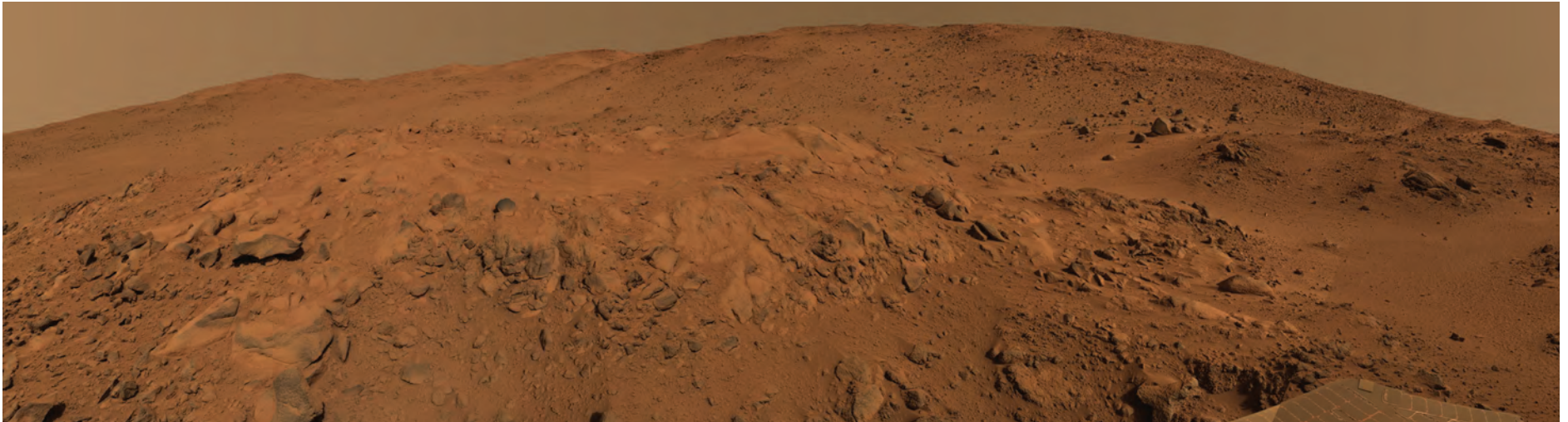
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An artist's concept of one of the Mars Exploration Rovers on the surface of Mars.

Credit: NASA/JPL-Caltech/Cornell



Spirit: Ascent of Husband Hill

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Columbia Hills or Bust

When Spirit landed on a rock-strewn plain, faraway hills beckoned from about 1.6 miles (2.6 kilometers) away. Impossible to reach in the originally planned 90 sols (Martian days), Spirit trekked for six months to reach them, becoming the first mountain-climbing robot on another planet. Spirit scaled the nearest of the seven Columbia Hills, named for each member of the lost crew of Space Shuttle Columbia. Husband Hill, honoring Commander Rick Husband, stands 348 feet (106 meters) higher than the site where Spirit landed 20 months prior. The rover’s months-long trek through different layers of hilly terrain richly rewarded us with new discoveries, as each layer contained clues to past environmental conditions on Mars.

Hot Springs and Violent Volcanoes

While volcanic rocks covered the plain Spirit crossed on its way to the hill, the ascent of Husband Hill

brought a fascinating new landscape into view and completely different geologic conditions to explore. For the first time in its mission, Spirit found evidence of past water. As the rover gained altitude, more and more signs of a wet past became apparent. From the composition and texture of more than six different types of rock inspected, scientists determined that this area was once a hot, violent place with volcanic explosions and impacts. Extensive water in the form of hot springs or other water features left its mark on debris throughout the area. One of the rock types contained the mineral goethite, which only forms in the presence of water. Thus, finding it represented the first direct evidence of past water in the Columbia Hills.



Investigations of the rock dubbed “Clovis” revealed the mineral goethite, pointing to a watery past in Gusev Crater.

Weary Traveler Seeks Water

Long after completing its primary 90-day mission, NASA’s Spirit rover began showing slight twinges of wear in its mobility system from its roving and hill-climbing experience. As Spirit dug in its wheels as it

struggled up toward a ridgeline on Husband Hill, they churned up bright material. This unexpected discovery was good fortune for Spirit: the rover determined that the salty material had water molecules bound to the minerals. That provided clear signs of its formation or alteration in past water.

A View to the Future

Carrying on after its rewarding climb to the hilltop, Spirit returned images of the southern vista from the top of Husband Hill. The team used these views to plot Spirit’s next leg of travel. Mission planners and scientists selected an alluring feature in the distance that would bring a scientific bonanza, and come to be known as Home Plate.

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1. Spirit looks past Cumberland Ridge toward the summit of Husband Hill.

2. Spirit’s view from the top of Husband Hill.

Credit: NASA/JPL-Caltech/Cornell



Spirit: Comanche Outcrop

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Comanche Points to Past Water

In 2005, Spirit traveled from the highest peak of the Columbia Hills to a flat spot below called Home Plate. On the way, it passed an interesting outcrop of rocks called Comanche. The rover recorded data and images of Comanche, but dust partially blinded one instrument, causing it to return obscured views. Five years later, however, with the data corrected for the effects of the dust, Spirit provided the first evidence that neutral, potentially life-sustaining water had once flowed on Mars.

Scientists found that the rocks at Comanche contained abundant carbonate minerals, ten times higher than previously identified in any Martian rock. Magnesium and iron carbonate-rich rocks seen there likely resulted from a hot springs system in near-neutral pH conditions. Carbonates originate in wet conditions, but dis-

solve in acid, so their continued presence indicates that the neutral environment persisted. The long-ago wet environment that left this mineral evidence would have been more favorable for microbial life than harshly acidic conditions seen elsewhere on Mars by Spirit and Opportunity.

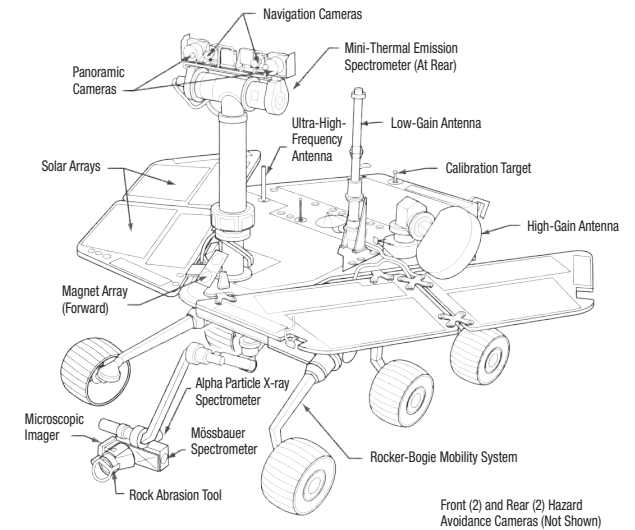
Hints of a Warmer World

The Comanche rocks speak not just to past conditions on and beneath the surface, but also help describe how the ancient martian climate differed from today’s. The carbonates found at Comanche hint that a thicker carbon dioxide atmosphere may have blanketed Mars in the distant past. Carbonate rocks often form when volcanic minerals and water interact with carbon dioxide in an atmosphere. For example, when the volcanic mineral olivine reacts with water and carbon dioxide, the original rock becomes a carbonate. This process “captures” carbon dioxide found in an atmosphere and “locks” it in rocks.

The abundance of carbonate rocks at Comanche indicates a time when carbon dioxide saturated the martian atmosphere and interacted with volcanic minerals. Due to the familiar greenhouse effect, a thicker past atmosphere means that Mars also would have been warmer than today’s cold Martian climes. Warmer temperatures, in combination with water, could have created a more hospitable world for microbial life.

Spirit’s findings at Comanche are considered crucial to understanding the early climate history of Mars and the related question of whether the planet might once have held life.

On the other side of Mars from Spirit’s home at Gusev Crater, Opportunity discovered ample evidence for alteration of rocks by water in Meridiani Planum. However, the water at Meridiani was strongly acidic and less favorable as a potential habitat for microbial life.



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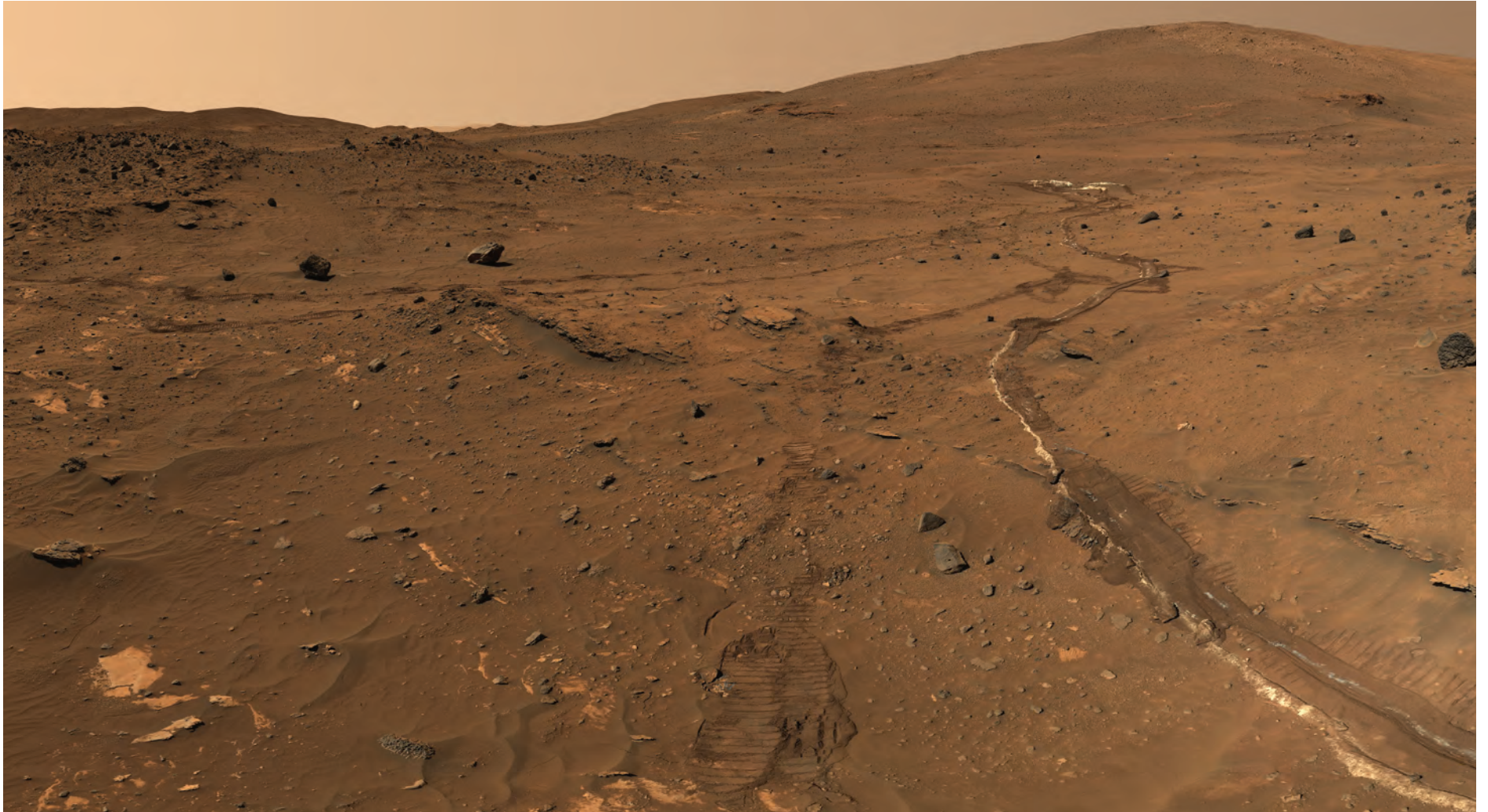
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Spirit’s false-color view of the Comanche outcrop at Gusev Crater.

Credit: NASA/JPL-Caltech/Cornell



Spirit: Home Plate

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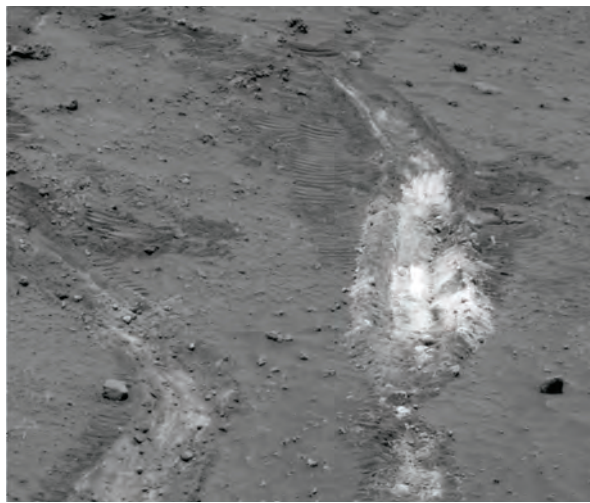
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A Grand Slam at Home Plate

Spirit’s findings at Home Plate painted a picture of a dramatically different world than the cold, dry Mars of today. Home Plate is a plateau of layered bedrock approximately 6 feet (2 meters) high. It lies within the Inner Basin of the Columbia Hills, at the rover’s landing site in Gusev Crater. The bedrock yielded the mission’s first definite identification of deposits from explosive volcanic action. Indications are that hot basalt rock and briny water interacted here to create spectacular, landscape-changing explosions.

One of the strongest pieces of evidence for an explosive origin for Home Plate is a “bomb sag” preserved in layered rocks on the lower slopes of the plateau. On Earth, bomb sags form in volcanic explosions when rocks ejected skyward by the explosion fall into soft deposits, deforming them as they land.

Spirit arrived at Home Plate in February 2006 and spent several months exploring it in detail before driving to Low Ridge to pass the Martian winter. The rover returned to Home Plate in the spring to continue exploring this scientifically rich location.



Plowing New Ground

For the rover’s science team, a broken right-front wheel plowed new furrows of discovery. Near Home Plate, engineers directed Spirit to drive backward, dragging its frozen right front wheel. This ailment made for slower progress, but turned out to be worth the delay. The wheel unearthed white deposits of nearly pure silica (pictured above) of a type that almost always forms near hot, acidic steam vents or in hot springs. On Earth, both of these types of settings teem with microbial life. The discovery suggests that ancient conditions on Mars could have been habitable as well.

A Permanent Home

Spirit spent most of the rest of its operational life in and near the scientifically rich area of Home Plate.

In its fifth year of operation, Spirit was driving south beside the western edge of the Home Plate plateau

when its wheels broke through a crusty surface and churned into soft sand hidden underneath. The rover became stuck. In late 2009, after months of trying to free the sand-trapped rover, a second wheel quit working.

With Spirit’s roving days at end, NASA declared it a stationary vehicle in January, 2010. Tools on Spirit’s robotic arm began studying variations in the composition of nearby soil affected by water. The rover monitored how wind moves soil particles and measured changes in the Martian atmosphere. Spirit transmitted its last communications to Earth on March 22, 2010. Its mission ended, but Spirit lives on in the historic discoveries it contributed to finding both direct and indirect evidence of water and chemically neutral conditions that may have been suitable for microbial life.

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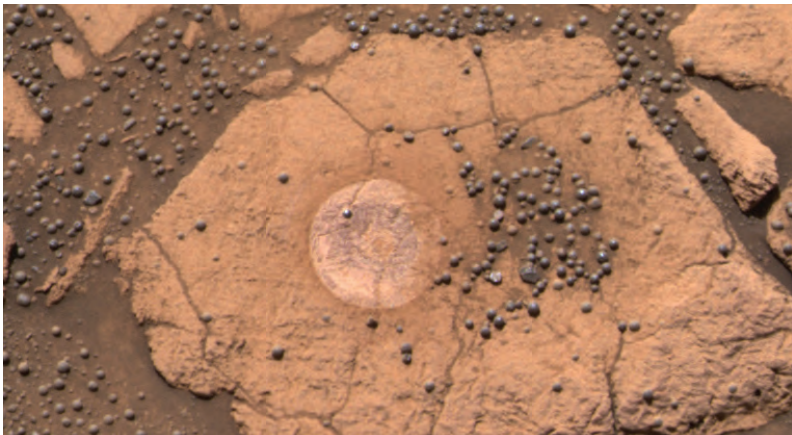
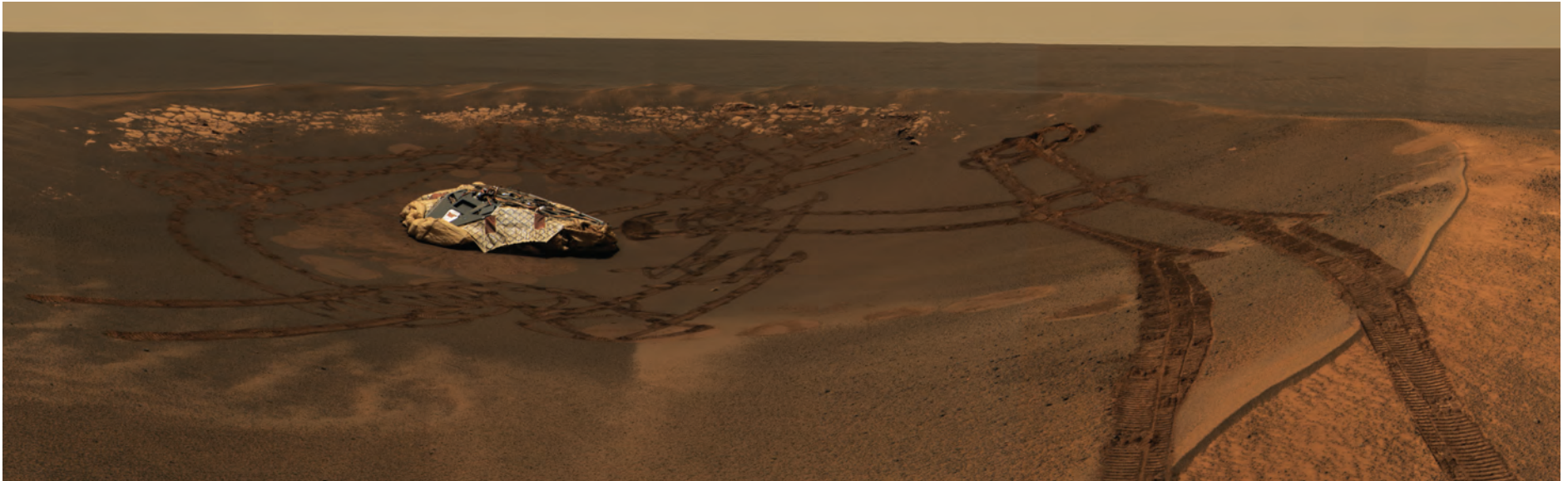
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Spirit’s wheel tracks expose bright underlying material at Home Plate.

Credit: NASA/JPL-Caltech/Cornell



Opportunity: Eagle Crater

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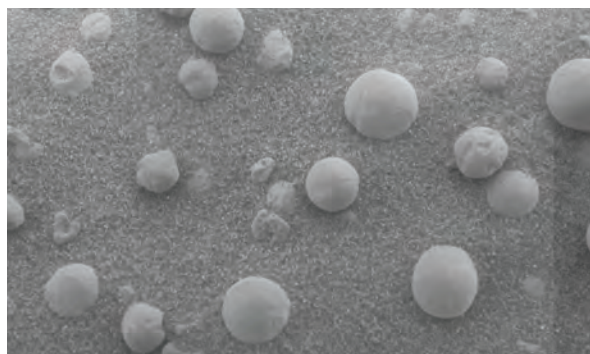
Answers About Water

Before Spirit and Opportunity launched and landed on Mars, the Mars Global Surveyor orbiter identified concentrations of hematite in the Plains of Meridiani (Meridiani Planum). The mineral hematite often forms in a watery environment. Based on this and other geologically intriguing features, NASA chose Meridiani Planum as Opportunity’s landing site. Scientists hoped that following the trail of hematite in this area would lead to evidence of past water on Mars, and it did. Past, persistent water is necessary for life as we know it.

Opportunity’s landing is often referred to as a “hole-in-one” because the spacecraft unexpectedly came to rest inside a small indentation called Eagle Crater, which would quickly reveal secrets of a wet past. Discoveries about water dominated the whole period of Opportunity’s three-month-long original mission.

A Blueberry Banquet

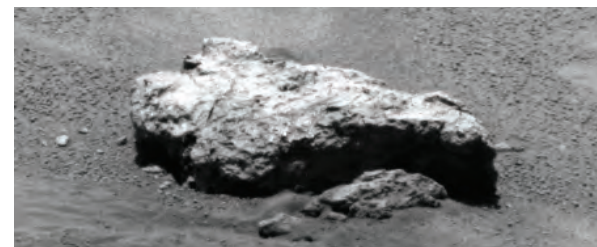
The rover thoroughly investigated a rock outcrop in the crater and found that liquid water soaked the area long ago. The outcrop was high in minerals likely formed in water. Opportunity found blueberry-shaped concretions of hematite (pictured below), which are also blue-hued in false color. The rock outcrop contained jarosite, a mineral that can only result from rock exposed to acidic water. The “blueberries,” jarosite, and other abundant chemical and geological clues in the area pointed scientists to the conclusion that Eagle Crater once held a salty and acidic near-surface and subsurface body of water.



Departing Eagle Crater, Opportunity found similar water signs in other rocks, at a linear fracture informally called Anatolia and in a crater called Fram. The rover found hematite blueberries not just inside Eagle Crater, but covering the landscape and the plains all around. These discoveries enlarged the minimum area covered by the body of water that deposited these rocks long ago.

Stumbling Across a Meteorite

An unexpected opportunity not directly related to the search for water presented itself to the aptly named rover. Coincidentally, Opportunity bounced on an odd, football-size volcanic rock (pictured above, right) dur-



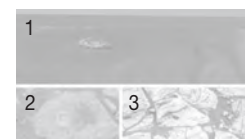
ing its airbag-cushioned landing. Bounce Rock, as the team called it, was lofted to its present location after an impact somewhere else on Mars. Bounce Rock’s composition matches that of a distinctive group of Martian meteorites that periodically land on Earth. The discovery provided new context about one potential region on Mars from which the Martian meteorites could have originated.

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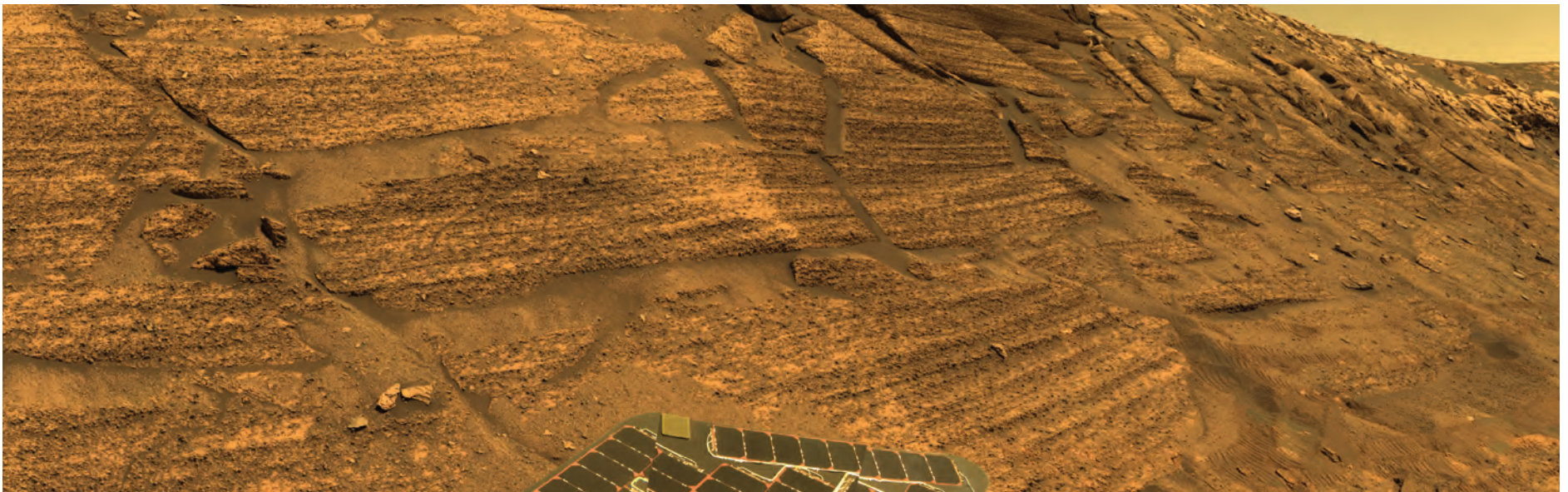
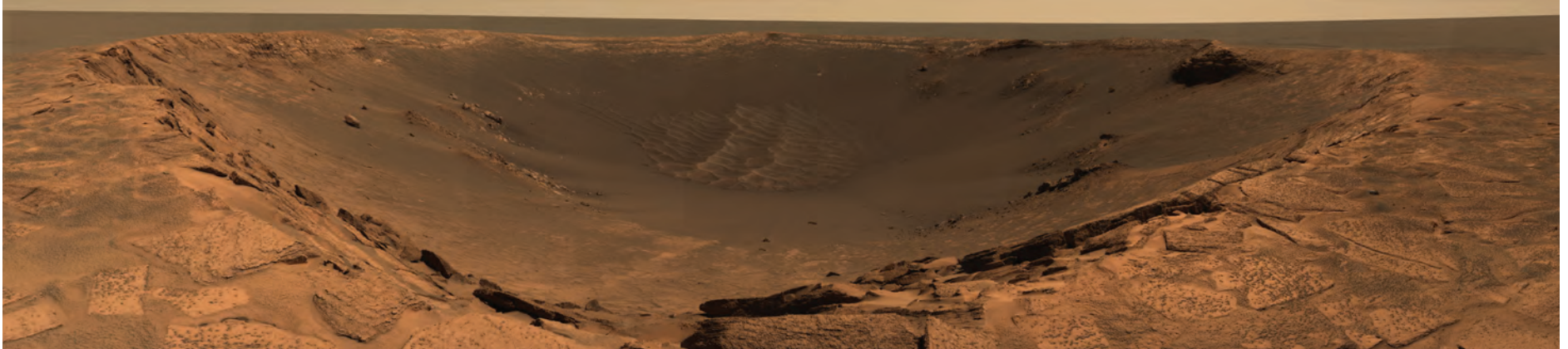
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1. Opportunity departs Eagle Crater.
2. Investigating “blueberries” in rock outcrop near landing site.
3. “Blueberries” in false color.

Credit: NASA/JPL-Caltech/Cornell



Opportunity: Endurance Crater

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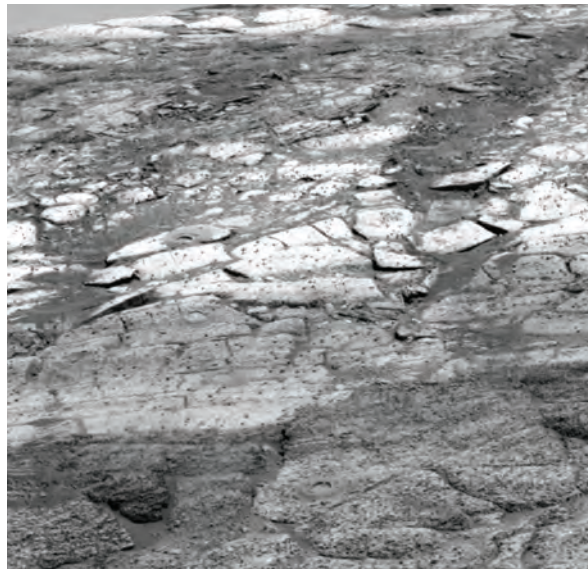
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Endurance

In June of 2004, working overtime after its three-month-long primary mission ended, Opportunity began carefully inching into a stadium-size impact crater called Endurance.

The mission team did not make the decision to send Opportunity into Endurance lightly. The crater had steep slopes and clearly posed a potential sand trap from which the rover might never emerge. However, the team decided that ancient, exposed layers of rock inside the crater held great potential for scientific discovery. The chance to study Mars’ buried past far outweighed the risk of the rover remaining inside Endurance Crater forever. Each rock layer in the crater wall held a record of the environmental conditions in which it formed. The farther down in the crater the layer occurred, the earlier the time period in which it formed.

The six months that Opportunity spent studying rock layers in Endurance rewrote our understanding of the history of water at Meridiani Planum. As Opportunity carefully crept some 30 feet (10 meters) into the crater, the distinct rock layers it studied (pictured below) showed subtle variations in chemistry, texture, and color that suggested the past presence of water.



Opportunity studied rocks whose weathered surfaces had been ground away by the rover’s rock abrasion tool (RAT). The deeper the rover went, the richer the crater’s rocks were in the elements chlorine, sulfur and bromine. Analysis showed these and other minerals settled to the bottom of a salty body of water to form “rock salt” deposits similar to those seen in salt flats in desert regions on Earth.

A portion of the crater wall measuring 33 feet (10 meters) high contained many rock layers, some deposited by water and some by wind. The rover science team named this area Burns Cliff in honor of a geologist who predicted the discovery of jarosite on Mars. Findings here indicate that a salty sea was sometimes present and sometimes not when the rocks formed.

Near the bottom of Endurance Crater, Opportunity investigated the textures of broken rock spheres with different surface characteristics than “blueberries” found elsewhere on Meridiani Planum. These showed signs of having sat in water that ponded in the crater.

While exploring Endurance Crater, even the outer surfaces of the rover helped provide new information on the Martian atmospheric environment. The science and engineering teams documented the presence of morning frost on the rover deck. Scientists gleaned characteristics of local winds from the effects they had in cleaning dust off the rover. The rover’s cameras also observed water-ice clouds in the mid-winter sky.

Understanding how water contributed to the environment on Mars is the first step in determining whether the red planet could ever have supported life.

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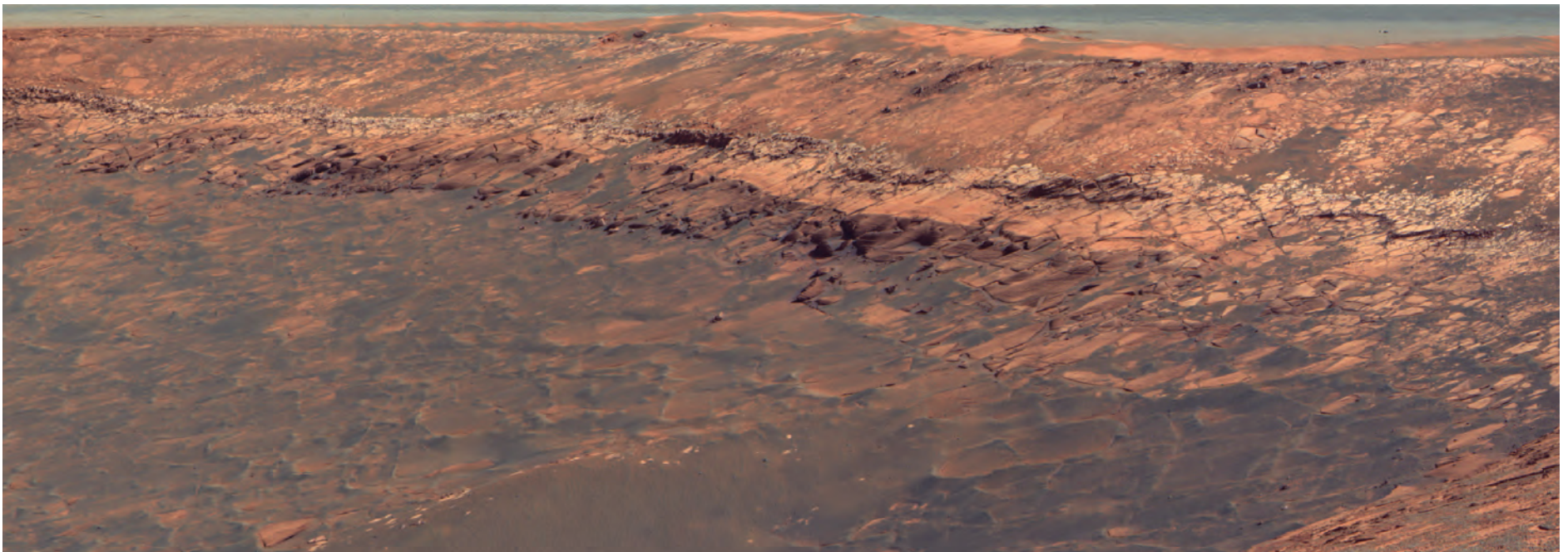
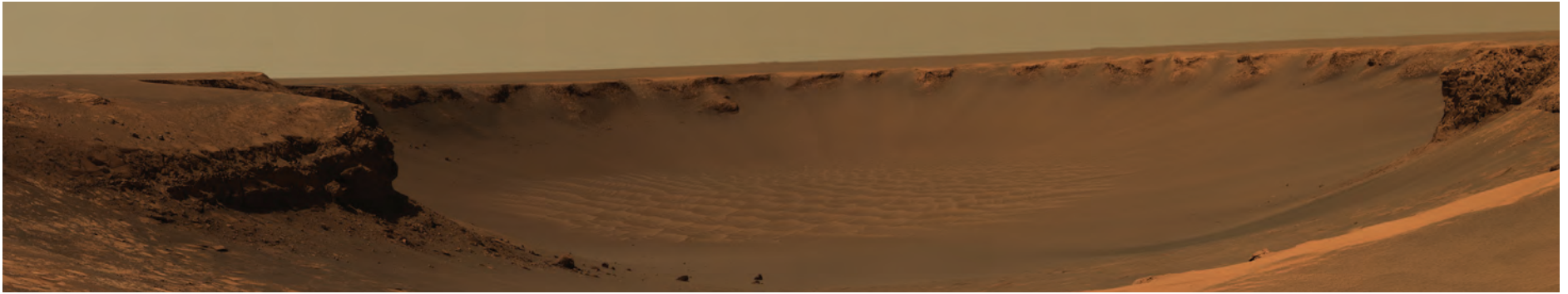
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1. Opportunity views Endurance Crater.

2. Opportunity explores Burns Cliff in Endurance Crater.

Credit: NASA/JPL-Caltech/Cornell



Opportunity: Victoria Crater

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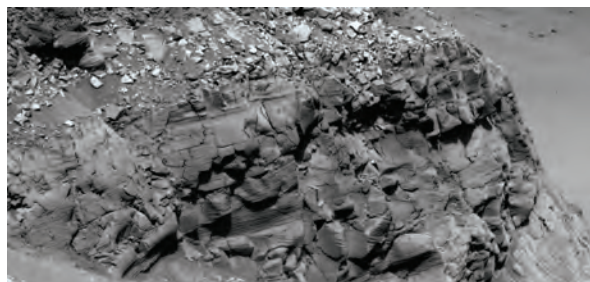
Aging Hardware

With joints in its arm and wheels showing signs of age, Opportunity gamely pressed on in its fourth year of operation on Mars to deliver fresh and intriguing scientific results inside Victoria Crater, about 4.5 miles (7 kilometers) from the landing site. Opportunity explored the half-mile-wide (800-meter-wide) crater for two Earth years, the length of one Martian year, from September 2007 through August 2008.

After a year of scouting from the rim, engineers identified a drivable path down the slope. Opportunity descended into Victoria Crater on September 11, 2007. The rover felt its way down, using contact instruments on its robotic arm to inspect the composition and textures of accessible rock layers.

Around the rim of Victoria Crater, the rover found large and abundant numbers of hematite spherules most likely formed in water. Scientists believe that

the impact that created the crater blasted them to the surface from underground layers. Based on that finding, researchers hypothesize that water once soaked a layer buried beneath the surface long enough to form the spherule concretions subsequently blasted out by the impact. The rover also discovered that a group of small rocks in the Victoria Crater rim turned out to be meteorites, possibly related to the impact that formed the crater. The base of a cliff on the crater rim informally called Cape Verde also laid bare a stack of rock layers 20 feet (6 meters) tall. Opportunity’s studies there suggest that wind deposited the sediments and that groundwater altered them later.

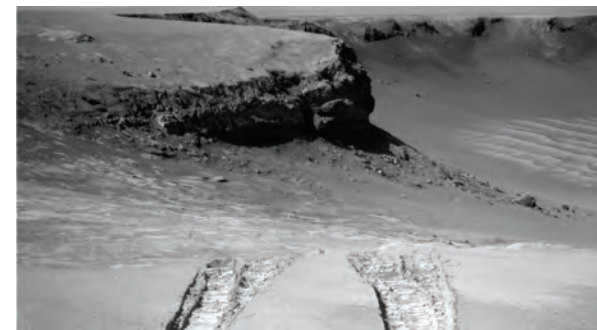


Opportunity’s studies as it rolled into the crater established a rough history of Victoria’s past. A jumble of ejected blocks 3 feet (one meter) or more in size dominates the crater’s top layer (pictured above). The impact excavated and fractured a zone of bedrock. Below that, intact bedrock is exposed, with its surface shaped by eons of wind. Scientists even deduced the northward-blowing direction of ancient prevailing winds from sand-blasted variations in the rock bedding structures of the cliffs.

The rover also found subtle signs of past water in the crater layers. Opportunity studied a continuous set of rock layers that are exposed all the way around Victoria Crater like a bathtub ring.

To climb out of Victoria Crater, concerned rover engineers directed Opportunity to leave via the same, known path by which it had entered (pictured above,

right) to help conserve the rover’s mobility. Concern also mounted over a degraded shoulder motor, so rover engineers stopped folding and stowing the robotic arm after use. This conservative strategy means that the rover now travels with its arm extended, usable for close-up studies of martian rocks for years to come.

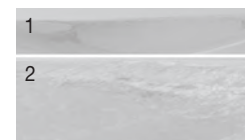


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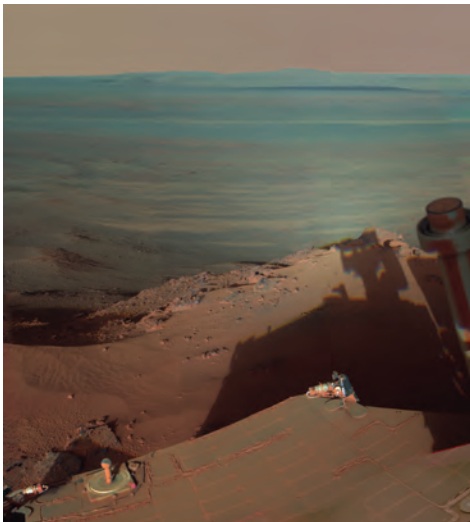
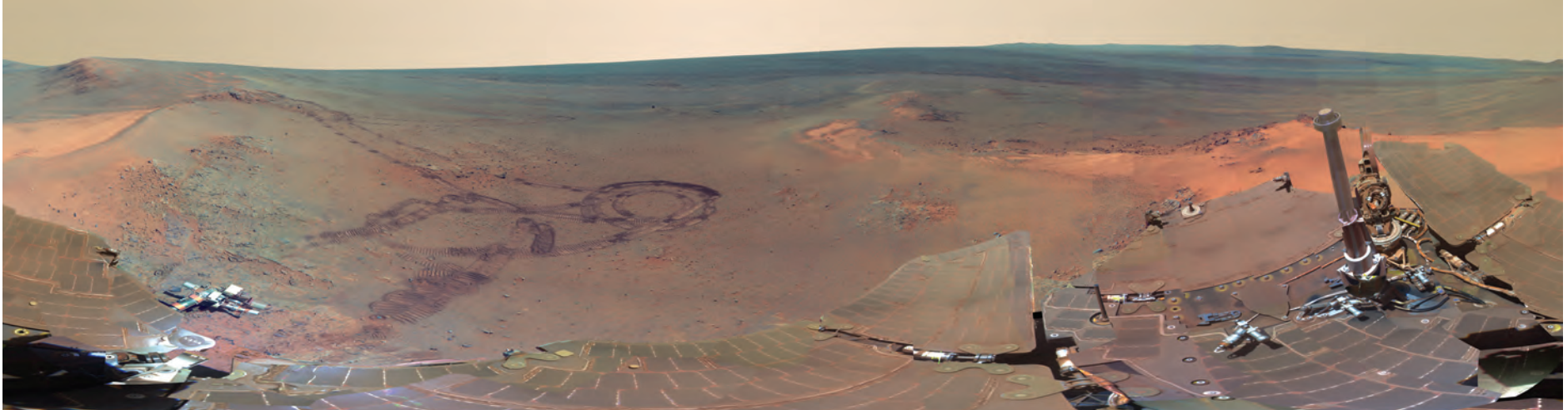
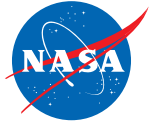
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1. Opportunity views Victoria Crater.
2. False-color image of Duck Bay in Victoria Crater, showing a bright band of bedrock surrounding the crater.

Credit: NASA/JPL-Caltech/Cornell



Opportunity: Endeavour Crater/Cape York

The Mars Exploration Rover Mission

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Each rover far outlasted its design lifetime. Spirit launched June 10, 2003, and landed in Gusev Crater on January 4, 2004. Opportunity launched July 7, 2003, and landed in Meridiani Planum on January 25, 2004. Opportunity continues to operate in its tenth year. Spirit’s final communication to Earth occurred on March 22, 2010, about six years into its mission. The rover lasted 20 times longer than its original design.

Surviving longer and traveling farther than ever imagined, Mars rover Opportunity drove across the Plains of Meridiani to successively larger craters to find the deeper, older layers holding clues to the early environmental history of Mars. In its ninth year, after a miles-long trek, Opportunity arrived at the rim of Endeavour Crater. At 14 miles (22 kilometers) wide, it is the biggest and oldest crater yet explored. Opportunity’s findings within the crater walls of Endeavour drew scientists to a pivotal conclusion with significance far beyond the mission’s original objectives. At a segment of the crater’s rim called Cape York, the rover found evidence that, for a time very early in Mars’ history, an abundance of neutral pH, drinkable water likely flowed here, creating conditions that would have been friendly to life.

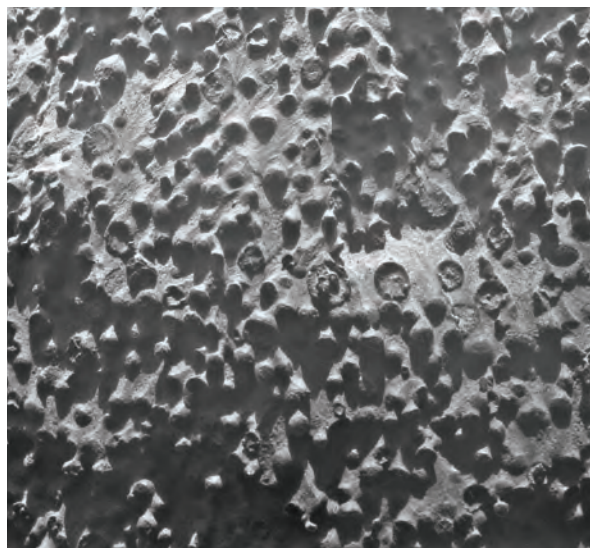
Cape York held geological relics from an era of global flooding called the Noachian Period, the oldest geological era on Mars. Back then, meteorites bombarded

the planet, possibly splashing down violently in bodies of water. Geologists sought rocks that formed in the Noachian to see if water on Mars persisted long enough to sustain life. At Endeavour, they found what they were seeking.

One objective in sending Opportunity to faraway Endeavour Crater was to follow up on the Mars Reconnaissance Orbiter’s detection of smectite, a clay mineral that typically forms in neutral water. Neutral water, plentiful on Earth, is more supportive of life than the ancient, acidic watery environment of which the rovers had found ample evidence elsewhere on Mars.

The exposed rock in the crater walls of Endeavour yielded smectite and other clays that showed an ancient, wet, non-acidic environment once existed.

Opportunity’s exploration of Endeavour turned up other geological treasures that are among the most intriguing of the whole mission. At Cape York’s Matijevic Hill, the rover found a strange, densely packed trove of small spheres similar to, but different from, the iron-rich spherules called “blueberries” at the rover’s landing site. Scientists called the BB-size spheres (pictured



below) “newberries.” Like “blueberries,” they probably formed in water, but have a different composition and internal structure. It is also conceivable they formed in volcanic, impact, or other processes. Scientists continue to study the elusive “newberries” to deduce the part of the story they tell about past Martian environments.

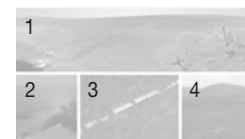
Concluding its historic reconnaissance of Cape York, Opportunity neared its tenth anniversary on Mars and headed to a north-facing slope called Solander Point on Endeavour’s western rim. The mission team chose the spot as a way station where the solar-powered rover could tilt its panels toward the sun, gathering enough sunlight to continue its work during the Martian southern hemisphere winter.

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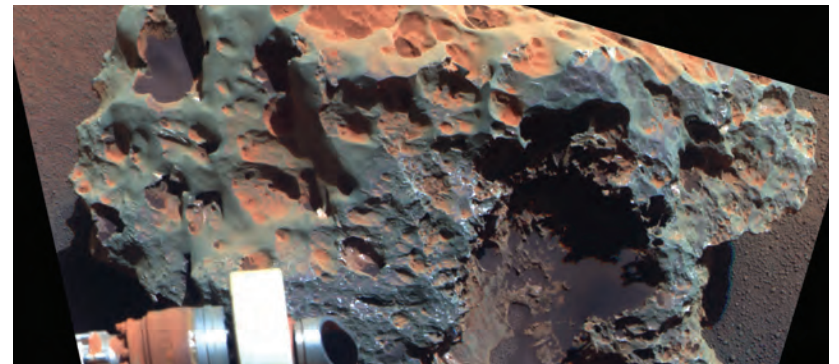
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1. False-color view of Greeley Haven.
2. False-color view of afternoon shadows at Endeavour Crater.
3. False-color view of Homestake, a mineral vein near Cape York.
4. False-color view of Solander Point.

Credit: NASA/JPL-Caltech/Cornell



Spirit and Opportunity: Meteorites

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Space Rocks

Overachieving rock hounds, Spirit and Opportunity surprised their science team with the gift of meteorites they discovered on the surface of Mars. Meteorites are the leftover bits of the original material that drew together to make the planets. Their primitive characteristics are windows to the conditions and events that took place when the planets formed about 4.5 billion years ago.

Previously, scientists had examples of impactors on Earth and two found on the Moon. Spirit’s and Opportunity’s finds are the first space rocks ever found on another planet.

Compared to Earth, Mars is kinder to meteorites. The thin atmosphere of Mars produces less friction and heating. Greater numbers of older meteorites sit in plain view on Mars. They are unaffected in comparison

to meteorites found on Earth, which become worn down by oxygen and moisture.

Heat Shield Rock — Opportunity found the first meteorite ever identified on another planet. This pitted, mostly iron and nickel rock is about the size of a basketball. Only a small fraction of the meteorites found on Earth are similarly metal-rich.

Zhong Shan and Allan Hills — Spirit found two potential iron meteorites amid hilly, sandy terrain in Gusev Crater. Their informal names are in keeping with the science team’s campaign to nickname rocks and soils in the area after locations in Antarctica. Zhong Shang is an Antarctic base honoring the 20th-century Chinese leader Dr. Sun Yat-sen. Allan Hills is an Antarctic locale where scientists have found many Martian meteorites. Among them is the controversial ALH84001, which achieved fame in 1996 when NASA scientists suggested that it might contain evidence for microbial life.

Barberton — The second meteorite Opportunity found is a raisin-size pebble at the rim of Endurance Crater. This little specimen is olivine-rich and contains iron in the form of kamacite, commonly found in metallic meteorites.

Santa Catarina — This fist-size cobble is the third possible meteorite found by the rover team. Opportunity found the fractured rock in the rim of Victoria Crater. It has a high nickel content like many metal meteorites. It may be part of the impactor that blasted out Victoria Crater.

Oileán Ruaidh — Pronounced “ay-lan ruah” in Gaelic, Opportunity’s fourth meteorite is informally named for an island off the coast of northwestern Ireland. It is a dark, toaster-size iron specimen with rounded edges.

Block Island — The largest metallic meteorite found by either rover is about the maximum size that could be slowed in the present atmosphere. The blue-tinted, half-ton meteorite (pictured, above right) is the size of a large watermelon.

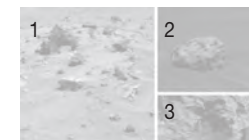


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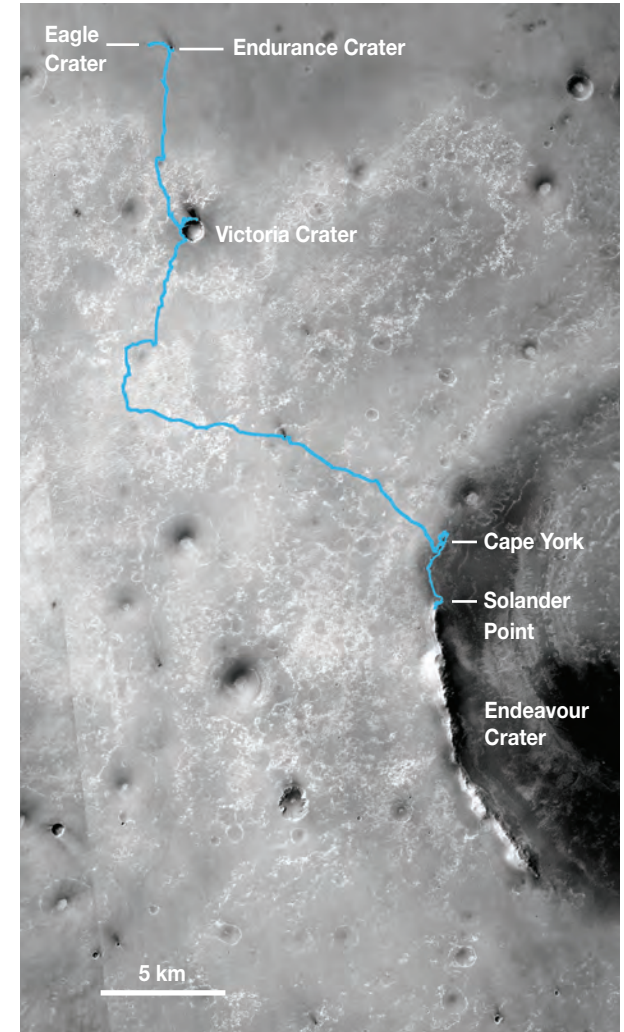
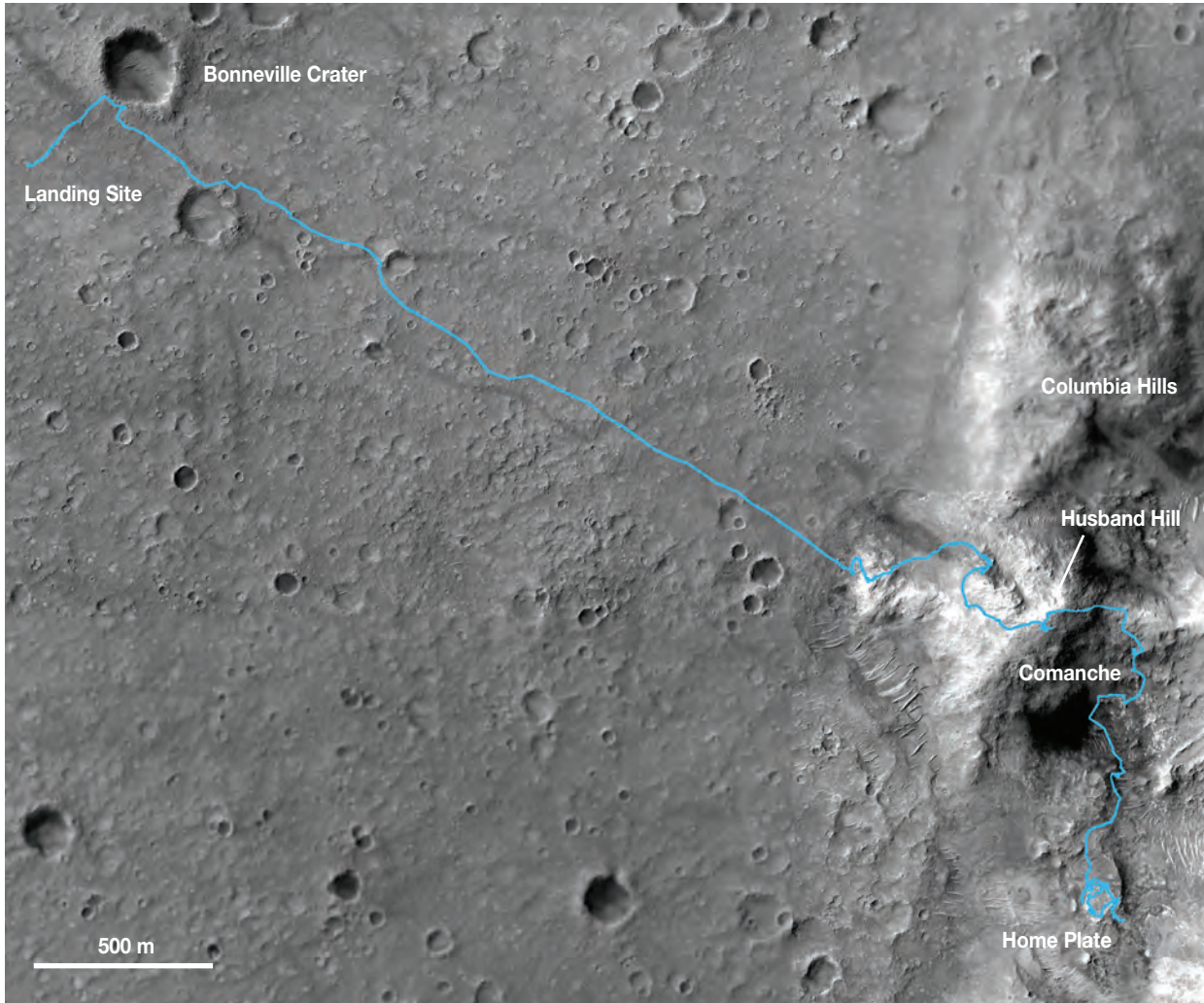
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1. False-color view of Allan Hills.
2. False-color view of Heat Shield Rock.
3. False-color close-up of Block Island.

Credit: NASA/JPL-Caltech/Cornell



Spirit and Opportunity: Traverse Maps

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Wheels In Motion

With the gift of the rovers’ longevity, the mission team determined to use them to explore as much of Mars as possible until the machines wore out from use. What began as a fairly simple geologic experiment on Mars ultimately turned into humanity’s first real overland expedition across another planet.

Faraway bumps on the horizon became realistic destinations. The search for clues toward new discoveries is what drove the direction of Spirit’s and Opportunity’s journeys. The rovers moved from one interesting site to the next, creating the large and small zigzags evident in the overhead view of their paths.

Spirit’s Traverse

Spirit’s Gusev Crater landing spot was named Columbia Memorial Station. From there, the rover made its way to Bonneville Crater, then made a near-beeline,

with many stops along the way, across flat plains to reach the Columbia Hills. The map of the rover’s traverse through those hills resembles that of a hiking trail, testament to Spirit’s challenging trek as it blazed short, steep paths to the top of Husband Hill. At the end of its travels, Spirit had put 4.8 miles (7.73 kilometers) on its odometer, more than 12 times farther than the original goal.

Opportunity’s Journey

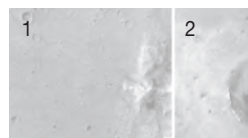
Opportunity’s path on Mars began upon landing at Eagle Crater. The rover’s landing site was formally named the Challenger Memorial Station. Over the course of 10 years, it traveled to Endurance Crater, Victoria Crater, Cape York and Solander Point at Endeavour Crater. By mid-November 2013, Opportunity had traveled more than 24 miles (38.6 kilometers) and continued on.

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1. Spirit’s final traverse map.

2. Opportunity’s traverse map as of mid-November 2013.

Credit: NASA/JPL-Caltech/Cornell



Above: Opportunity’s wheel tracks stretch for miles across the Martian surface.